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Outcomes of cemented and hybrid primary total hip arthroplasty in osteoarthritis: A New Zealand regional study

A thesis
submitted in fulfilment
of the requirements for the degree
of
Doctor of Philosophy in Health, Sport and Human Performance
at
The University of Waikato
by
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THE UNIVERSITY OF
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Abstract

Introduction: Primary total hip arthroplasty (THA) for osteoarthritis (OA) success is typically assessed using implant survival as the primary outcome; however, revision surgery alone underestimates the true burden of suboptimal outcomes (e.g., pain or poor function). Secondary outcomes, or patient-reported outcomes (PROMs), therefore provide a complementary assessment of THA success. During the last two decades, fully cemented THAs have been progressively replaced by uncemented ones, despite limited long-term comparative evidence. Although national registry data allow analysis of broad implant category types, they may lack implant and PROM detail compared to regional registries. This Thesis evaluates whether changes in implant design and fixation strategy have translated into significant and meaningful improvements in implant survival and patient outcomes in the Bay of Plenty region of Aotearoa New Zealand (NZ).

Aims: This Thesis aimed to evaluate long-term survival and PROMs of an early generation cemented, modern cemented, and modern hybrid primary THA for OA, and identify patient factors or funding source associated with these outcomes. The work first synthesised existing evidence comparing cemented and hybrid fixation. It then compared survival between the earlier generation THA and its modern cemented successor of the same lineage. Thereafter, the work identified long-term PROMs in earlier generation cemented THA and then compared 10-year PROMs between the two cemented THA generations. Finally, survival and PROM outcomes of the hybrid THA were compared with the modern cemented. Influential patient and funding factors of primary and secondary outcomes were identified across all studies.

Methods: This Thesis comprised a systematic literature review and linked retrospective cohort studies using prospectively collected arthroplasty survival and PROM data from the NZ joint registry (NZJR) and Tauranga Orthopaedic Research Inc. registry for the Bay of Plenty region. Patients undergoing primary THA for OA between 2003 to 2023 with earlier generation cemented, modern cemented, or modern hybrid THAs were included. PROMs included the Oxford Hip Score (OHS), McMaster University Osteoarthritis index (WOMAC), and Veterans Rand 12-item health survey (VR-12). Baseline differences were addressed using propensity score weighting. Implant survival was analysed using Cox regression, and PROMs were analysed longitudinally including changes from baseline. Multivariable models examined the influence of sex, ethnicity, age at surgery, body mass index (BMI), American Anesthesiologist Society (ASA) rating, and funding source (public versus private) on outcomes.

Results: In the literature, five studies compared survival and three compared PROMs between cemented and hybrid primary THA for OA. Survival outcomes were no different between THAs in three studies, but cemented survival was superior in two studies. PROMs were no different in the three available studies.

Across all registry analyses, a total of 3,186 THAs (early generation cemented $n = 363$; modern cemented $n = 1,267$; modern hybrid $n = 1,556$) were included. The 10-year survival estimates [95% confidence interval] were not significantly different between the modern cemented THA (95.6% [93.4, 97.9]) and its early generation predecessor (97% [95.9, 98.2], $p = 0.334$). Fifteen-year PROMs for the early generation demonstrated sustained long-term improvements in pain and function. No significant differences in physical postoperative PROMs (OHS, WOMAC, VR-12 physical) were observed between early generation and modern cemented THA. Mental health scores were significantly better in the modern cemented THA preoperatively ($p = 0.005$) and at 1 ($p = 0.042$) and 5 years ($p = 0.004$).

Crude 10-year survival in the modern cemented THA (97.0% [95.9, 98.2]) was superior to the hybrid (95.9% [94.7, 97.0], $p = 0.04$). However, after propensity weighting, implants showed no significant difference in revision (hazard ratio 1.40 [0.85, 2.31], $p = 0.188$). Hybrid THA demonstrated larger PROM change scores from baseline, attributable to poorer baseline status. There were no significant differences in postoperative PROMs at 1, 5, and 10-years for OHS and WOMAC. However, VR-12 physical ($p = 0.031$) and mental ($p = 0.047$) PROMs in the modern cemented were better across timepoints.

Regression analyses did not identify patient factors as significant predictors of survival. Preoperative PROMs were consistent predictors of poorer postoperative PROMs in all THAs. Factors such as BMI, ASA, sex, and funding source were significant independent predictors of poorer preoperative PROMs in all THAs. Ethnicity influenced modern cemented and hybrid preoperative mental health, and all modern cemented postoperative PROMs. Age at surgery was also a significant predictor of poorer postoperative PROMs. Analyses indicated poorer outcomes when patients were female, Māori, had a higher BMI, greater ASA, public funding source, and older age at surgery. Although these factors were identified as significant PROM predictors, R^2 values between 0.08 and 0.31 indicate only a modest proportion of the variance was explained.

Discussion: This Thesis demonstrates that iterative changes within cemented implant lineage resulted in no significant changes in survival and physical PROMS up to 10 years. Hybrid THA delivers similar long-term survival and PROM performance in the Bay of Plenty region to cemented. These findings challenge the assumption that newer fixation strategies represent meaningful clinical advancements. In this cohort, PROMs were influenced more strongly by patient and funding characteristics than by fixation type. There are subgroups which are at risk for poorer outcomes that require further investigation.

Conclusion: Modern cemented successor implants provide survival and PROMs that are comparable to their predecessors and to modern hybrid constructs. The widespread shift away from fully cemented THA in this region is not supported by evidence of significantly superior survival or long-term PROMs in hybrid THA.

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My thanks also extend to Wintec for their financial support to publish and present this work, allowing me to undertake additional training, and for allowing flexibility in my workload during my studies. I am equally grateful to my colleagues for their patience and understanding during periods when I was less present than usual, often quite literally locked away in my office.

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Abbreviations

AL	Aseptic loosening
ANOVA	Analysis of variance
ANCOVA	Analysis of covariance
ASA	American Society of Anesthesiologists rating
BCIS	Bone cement implantation syndrome
BMI	Body mass index
BP	Bodily pain
CeCoP	Cemented ceramic on polyethylene
CoCr	Cobalt Chromium
CI	Confidence interval
Coeff	Coefficient
CoP	Ceramic on polyethylene
CR	Competing risk
DF	Degrees of freedom
ECF	Exeter Contemporary Flanged cup
EtO	Ethylene oxide
EQ-5D	EuroQol
F-stat	F-statistic
FJS -12	Forgotten joint score
FU	Follow-up
Hemi	Hemispheric
HHS	Harris hip Score
HOOS	Harris hip outcome score
HR	Hazard ratio
HREC	Human Research Ethics Committee
HRQOL	Health related quality of life
HXLPE	Highly cross-linked polyethylene
GDP	Gross domestic profit
GH	General health
GRADE	Grading of Recommendations Assessment, Development and Evaluation
kGy	Kilorads
MCID	Minimal clinically important difference
MH	Mental health
NZ	New Zealand
NZEU	New Zealand European
NZJR	New Zealand Joint Registry

NZOA	New Zealand Orthopaedics Association
OECD	Organisation for Economic Co-operation and Development
OA	Osteoarthritis
OHS	Oxford hip score
PE	Polyethylene
PF	Physical function
PMMA	Polymethylmethacrylate
Preop	Preoperative
Postop	Postoperative
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analyses
PROM	Patient-reported outcome measure
PROSPERO	Prospective registration
QALY	Quality adjusted life year
Q-Q	Quantile-Quantile
QUIPS	Quality in Prognostic Studies
RCT	Randomized controlled trial
Rimfit	Exeter X3 Rimfit cup
RE	Role emotional
RoB	Risk of Bias
RP	Role physical
SD	Standard deviation
SF	Social function
SF-36	Short form-36 item health survey
SOCRATES	Standardised Orthopaedic Cartilage Repair and Treatment Evaluation Software
STD	Standard
STROBE	Strengthening the Reporting of Observational Studies
THA	Total Hip Arthroplasty
TOR	Tauranga Orthopaedic Research Incorporated
UHMWPE	Ultra-high molecular weight polyethylene
UK	United Kingdom
µm	Micrometer
USA	United States of America
VR-12	Veterans Rand - 12 item health score
VT	Vitality
WOMAC	Western Ontario and McMaster University Osteoarthritis Index
XLPE	Cross-linked polyethylene
YLD	Years lived with disability
3D	Three-dimensional

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Research outputs arising from this Thesis

Publications

Published

Pearce, A., Butcher, A., & Hebert-Losier, K. (2025). Outcomes of cemented and hybrid primary total hip arthroplasty for osteoarthritis: A systematic review with narrative synthesis. *Archives of Orthopaedic and Trauma Surgery*, 145(1), 388. <https://doi.org/10.1007/s00402-025-06007-3> (Chapter 2)

Pearce, A., Joshi, C., Chan, G., Lamberton, T., MacLean, S., Vane, A., & Hebert-Losier, K. (2025). Fifteen-year patient-reported outcomes of a cemented flanged cup and stem combination in primary total hip arthroplasty: A New Zealand study. *HIP International*. <https://doi.org/10.1177/11207000251371132> (Chapter 3)

Pearce A., Joshi C., Chan G., Lamberton T., MacLean S., Vane A., & Hebert-Losier, K. (2025). 10-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis: A New Zealand regional study. *Archives of Orthopaedic and Trauma Surgery*. <https://doi.org/10.1007/s00402-025-06092-4> (Chapter 4)

Pearce A., Joshi C., Chan G., Lamberton T., MacLean S., Vane A., & Hebert-Losier, K. (2026). Patient-reported outcome measure comparison of two cemented primary total hip arthroplasty implant combinations for osteoarthritis: A regional New Zealand study. *European Journal of Orthopaedic Surgery and Traumatology*, 36, 154. <https://doi.org/10.1007/s00590-026-04734-w> (Chapter 5)

For submission

Pearce A., Joshi C., Chan G., Lamberton T., MacLean S., Vane A., & Hebert-Losier, K. (2025). No difference in 10-year survival between a hybrid and cemented implant in primary total hip arthroplasty for osteoarthritis: A New Zealand regional study. (Chapter 6)

Pearce A., Joshi C., Chan G., Lamberton T., MacLean S., Vane A., & Hebert-Losier, K. (2026). Ten-year PROMs comparison of a cemented and hybrid implant combination in primary total hip arthroplasty for osteoarthritis: A New Zealand regional registry study. (Chapter 7)

Presentations

Pearce, A., (2023) *How hip are you?* Tauranga public lecture series, Tauranga, Bay of Plenty, NZ

Pearce, A., (2025) *Comparing cemented and hybrid outcomes in primary total hip arthroplasty surgery for osteoarthritis: A PhD overview* Tauranga Orthopaedic Research, Grace Hospital, Bay of Plenty, NZ

Pearce, A., Joshi, C., Chan, G., Lamberton, T., MacLean, S., Vane, A., & Hébert-Losier, K. (2026, May 30–June 1). *10-year outcomes of cemented and hybrid constructs in primary total hip arthroplasty for osteoarthritis: A NZ regional registry population study* [Oral presentation]. 15th International Congress of Arthroplasty Registries, Lund, Sweden.

Chapter 1. Introduction and background

1.1. Osteoarthritis

Osteoarthritis (OA) is a degenerative joint condition where the protective cartilage cushioning the ends of bones wears down over time, leading to pain, stiffness, swelling, and reduced movement in affected joints, commonly the hands, knees, hips, and spine. OA of the hip is a leading cause of pain, disability, and loss of independence worldwide (Xie et al., 2025) (Figure 1). As populations age and obesity and sedentary behaviour increase, the prevalence of symptomatic hip OA continues to rise (Wang et al., 2024). Consequences of untreated or inadequately treated OA include chronic pain, decreased mobility, loss of workforce participation and productivity, increased reliance on health and social care services, and deterioration in mental health and quality of life (Xie et al., 2025).

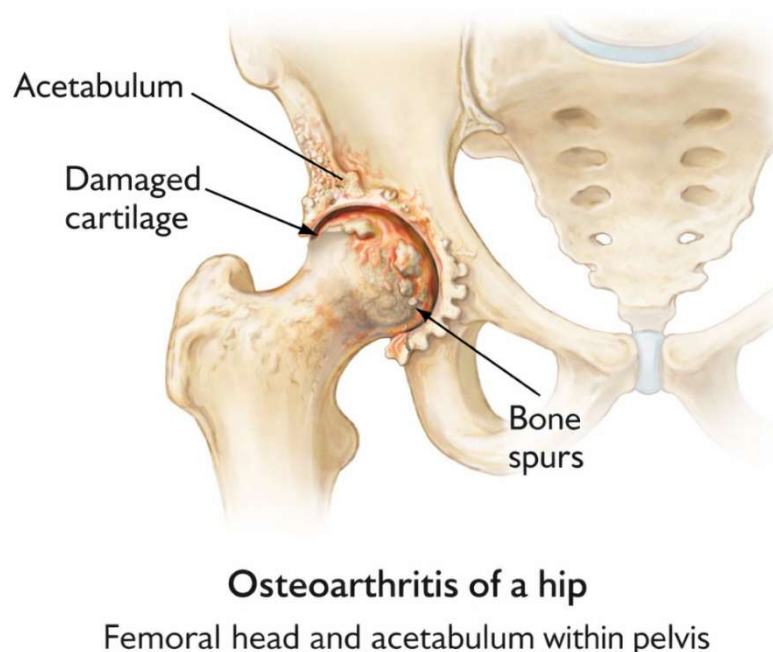


Figure 1. Osteoarthritis of the hip showing the femoral head and acetabulum within the pelvis.

Note. Image generated and checked by the author using ChatGPT (OpenAI), January 2026.

From a public perspective, OA is a major contributor to years lived with disability (YLD) (Hunter et al., 2014) and health system expenditure (Leifer et al., 2022). Wang et al. (2024) reported 606.5 million global osteoarthritis cases by 2021, highlighting it as a major public health challenge due to its disability burden. In 2021 OA was ranked 14 out of 25 of the leading level 3 global causes of YLDs (2.3% of all causes at 21.3 million YDLs), with an increase of 36.9% between 2010 and 2021, greater than 23 of the other 25 causes (including lower back pain, anxiety, depression, vision loss, falls, stroke, and Chronic Obstructive Pulmonary Disease) (Ferrari et al., 2024). Over 450,000 total joint replacements were recorded in New Zealand (NZ) over 23 years up to and including 2021. Of these, 202,460 were primary (first) total hip replacements and 178,165 were due

to osteoarthritis (McKie et al., 2024). In New Zealand (NZ), hip OA accounted for 22,864 disability adjusted life years in 2023 at a cost of over \$1 billion, and 1,967 YDLs. There were over 62,000 people living with OA of the hip and 2684 new cases in 2023 (Institute for Health Metrics and Evaluation, 2024) with a mean age of ~65 years for men and ~68 years for women (McKie et al., 2024). It is estimated the NZ population aged over 65 will grow by 74% from 2018 to 2038 (Hogan, 2022), placing significant demand on clinical services for osteoarthritis and increasing costs exponentially.

1.2. Total hip arthroplasty

Total hip arthroplasty (THA) is widely regarded as one of the most successful surgical procedures for pain relief and functional improvement (Yamate et al., 2023) of hip OA where the affected hip joint is replaced with a prosthetic implant. THA is effective across a broad range of ages and disease severity and capable of restoring independence and quality of life when conservative management fails (Knight et al., 2011). When evaluated using health economic metrics, such as cost per quality-adjusted life year, THA consistently ranks among the most cost-effective medical interventions, even in older patients (Agarwal et al., 2021). Therefore, the necessity of THA for end-stage OA is strongly supported by decades of clinical and economic evidence (Agarwal et al., 2021; Brauer et al., 2005; Lavernia et al., 2015; Nwachukwu et al., 2015; Shichman et al., 2023).

Outcomes following THA are conventionally evaluated on implant survival, but there is increasing recognition that patient-reported outcome measures (PROMs) are important in the assessment of THA success. For the purpose of this Thesis, survival and PROMs are viewed as complementary domains and reported as primary and secondary outcomes respectively. Implant survival reflects the mechanical and biological durability of the prosthesis used in THA and is expressed as time to revision for any cause or for specific reasons for revision, such as aseptic (i.e., without infection) loosening and periprosthetic fracture (i.e., fracture after insertion of a prosthesis) (Khan, 2017). Survival analysis provides an objective indicator of implant performance and is sensitive to differences in fixation method of the implant; implant design, such as material and shape; and patient factors, like sex or age (Clar et al., 2024). In contrast, PROMs capture the patient's perspective of treatment success, encompassing pain, function, quality of life, and satisfaction, and may detect clinically important differences that are not apparent from revision rates alone (Simon et al., 2025). Importantly, high implant survival does not necessarily equate to optimal patient experience (Varacallo et al., 2018). Although two implants may present similar survival rates, one can outperform the other in terms of PROMs. Comprehensive evaluation of THA therefore requires concurrent assessment of both survival and PROMs to fully characterise the effectiveness of competing implant methods.

Three to four components are required for a THA: a femoral stem; a femoral head, also known as a bearing; an acetabular cup; and a liner, which is used with an uncemented acetabular cup. The acetabular cup and the femoral stem are fixed directly to the bone. These components can be attached with or without cement. In an uncemented cup, a liner (usually polyethylene or ceramic) is placed inside the cup, and the femoral head is attached to the stem (Figure 2). Furthermore, there are four implant fixation options: fully cemented, where

the femoral stem and acetabular cup are both cemented to the bone; cementless, both components are cementless and pressed into the bone; hybrid, a cemented stem and cementless cup; and reverse hybrid, a cementless stem and a cemented cup (Pennington, Grieve, Black, et al., 2013). Early generation cemented acetabular cups were usually manufactured from ultra-high molecular weight polyethylene (UHMWPE), whereas modern cemented acetabular cups are typically made of cross-linked polyethylene (XLPE), developed to reduce wear (Kawata et al., 2017; van Loon et al., 2020).

1.2.1. Evolution of polyethylene bearing surfaces

The history of bearing surface development in THA is a history of failure and material refinement, with each generation of implant exposing a previously unrecognised mechanism of biological harm. The earliest attempts at THA were pioneered by Sir John Charnley, who in 1958 introduced the concept of low friction arthroplasty. Central to this design was the use of polytetrafluoroethylene, commercially known as Teflon, as the acetabular bearing surface. Charnley was attracted to polytetrafluoroethylene because of its low coefficient of friction, which he believed replicated the properties of articular cartilage. However, *in vivo* performance was poor (Charnley, 1961).

Following implantation in approximately 300 patients, two critical failure modes emerged: first, polytetrafluoroethylene exhibited wear rates as high as 0.5 mm per month; and second, the resultant wear debris caused a foreign body tissue reaction characterised by periprosthetic inflammation (Gomez & Morcuende, 2005). By 1962, Charnley had abandoned polytetrafluoroethylene acknowledging the biological reactivity of the wear debris had underpinned its clinical failure (Charnley, 1972). This shift in understanding, that implant debris biocompatibility was as critical as bulk material compatibility, would define the trajectory of bearing surface research for the next six decades. In response to the polytetrafluoroethylene failures, Charnley transitioned to UHMWPE as the acetabular cup material, which established the dominant bearing in THA for the remainder of the twentieth century. The Charnley low friction arthroplasty, which paired a 22.25 mm cobalt chromium femoral head with a cemented UHMWPE acetabular cup, demonstrated superior wear performance compared to the polytetrafluoroethylene cup and became widely regarded as the gold standard for THA design (Older, 2002).

Although UHMWPE represented a substantial clinical improvement over polytetrafluoroethylene, it was not without its own failure mechanisms. Long-term data through the 1970s and 1980s identified wear debris as the principal mediator of periprosthetic osteolysis, a destructive biological cascade. Researchers have estimated that approximately 100 million microscopic UHMWPE particles are released into the periprosthetic tissues for each day of patient activity (Kurtz et al., 1999). These particles initiate an inflammatory cascade including macrophage activation, cytokine release, and progressive bone resorption. This process leads to aseptic loosening and implant failure, initially incorrectly attributed to the bone cement used for fixation and described as “cement disease” (Harris, 2001). The identification of these particles represented an important diagnostic advance. Schmalzried et al. (1993) described the use of Oil Red O stain as a technique for identifying UHMWPE

particles within periprosthetic tissues, overcoming the limitations of conventional light microscopy for submicron particles (Perino et al., 2018). The majority of UHMWPE particles are submicron in size with particles in the 0.1-1.0 μm range demonstrating the greatest potential for macrophage activation and osteolytic signalling (Besong et al., 1998). Campbell et al. (1995) confirmed that the majority of UHMWPE were submicron in size and these findings established a clear link between bearing surface wear and the osteolytic response that continues to inform implant design and material selection.

1.2.2. Issues with sterilisation, in-air oxidation, and the shelf-ageing problem

A second distinct mechanism of material degradation arose from sterilisation methods employed during the manufacture of UHMWPE constructs. From the early 1960s to the late 1990s, UHMWPE implants were almost always sterilised by gamma radiation at doses of 25 to 40 kilorads (kGy), administered in ambient air. While effective as a sterilisation technique, gamma irradiation in air initiates a complex chain of molecular degeneration (Premnath et al., 1996). The clinically underappreciated factor of this process was the continuation of degeneration after sterilisation, through the shelf life of the implant prior to use. The consequence was that an implant that appeared mechanically intact at the time of packaging could become significantly brittle and predisposed to accelerated wear by the time of implantation (Besong et al., 1998). Besong et al. (1998) provided quantitative evidence that UHMWPE components aged for 10 years following gamma radiation in air exhibited significantly increased wear and an altered submicron size compared to non-irradiated controls. A landmark review summarised that gamma sterilisation was effective, but not in air (Bracco & Oral, 2011). This prompted a change in sterilisation practice in the 1990s where gamma radiation was performed in an inert atmosphere, but this process still did not fully eliminate reactive oxidation.

The introduction of HXLPE in 2005 represented the most significant advance in bearing material surface science since the adoption of UHMWPE and was triggered by the recognition of wear debris-mediated osteolysis and gamma-in-air oxidation as dominant mechanisms of conventional polyethylene failure (Gomez-Barrena et al., 2008; Oral & Muratoglu, 2007). The central principle of HXLPE is the creation of covalent cross-links between polymer chains, which is achieved by exposing UHMWPE to high dose ionising radiation (50 to 100 kGy) in an inert atmosphere. The result is a three-dimensional polymer network with increased resistance to plastic deformation under force and reduced articulating surface wear rates (McKellop et al., 2000).

A critical additional step in first generation HXLPE manufacture was post-irradiation thermal treatment, which was designed to reduce residual free radicals that remained following irradiation. Two principal thermal approaches were developed: remelting, where the irradiated material is heated above its melting point ($\sim 155^{\circ}\text{C}$) removing all free radicals but reducing its hardness; and annealing, where the material is heated below its melting point, which increases its hardness and mechanical strength, but does not remove all the free radicals (Muratoglu et al., 2001). Hip simulator studies demonstrated that first-generation HXLPE bearing surfaces dramatically reduced wear compared to conventional gamma-sterilised UHMWPE, with reductions in wear of 70 to 90% reported across laboratories and protocols (D'Antonio et al., 2016; Kurtz, 2016).

Despite the clinical success of the first-generation HXLPE, residual concerns remained regarding oxidative stability, particularly for annealed formulations where a small, but measurable free radical population persisted after manufacture. Even though the free radicals were vastly reduced, oxidation might still contribute to late mechanical degeneration, especially under high stress demands such as in knee arthroplasty. This limitation provided the rationale for the development of second-generation HXLPE formulations (Brach Del Prever et al., 2009).

Stryker orthopaedics introduced X3™ bearing technology in 2005. The X3™ process employs a patented sequential irradiation and annealing protocol, where gamma irradiation and sub-melt annealing are performed in three consecutive cycles rather than as a single high dose (D'Antonio et al., 2014; D'Antonio et al., 2012). The rationale is that by introducing an annealing step in between each irradiation dose, the free radicals are reduced before the next cycle introduces new radicals. Because sub-melt annealing maintains the hardness and structure of the material, the properties are preserved avoiding the strength reduction associated with remelted HXLPE formulations. Following the three cycles, the material is moulded and sterilised using non-irradiating gas plasma, thus ensuring no free radicals are introduced during final sterilisation (D'Antonio et al., 2012). Laboratory hip-simulator testing demonstrated up to a 70% reduction in wear for X3™ compared with Crossfire®, Stryker's first-generation highly crosslinked polyethylene (Campbell et al., 2010; Dumbleton et al., 2009). Campbell and Callary (2022) reported 10-year radio isometric analysis wear data from patients with a Stryker Trident system and X3 liners, demonstrating a median three-dimensional wear rate of less than 0.01 mm/year and no acceleration of wear in between 5 and 10 years. National joint registry data from England and Wales, encompassing 45,877 hips with this shell and liner combination, demonstrated improved bearing-related revision surgery at six years for X3 compared to both conventional polyethylene and ceramic-on-ceramic bearings (Campbell & Callary, 2022; Epinette & Jolles-Haeberli, 2016). A recent study by Ozdemir et al. (2026) confirmed that Stryker X3 Rimfit HXLPE cemented acetabular cups demonstrate significantly reduced polyethylene linear wear rates (0.037 mm/year) compared to the conventional UHMWPE Contemporary Flanged cemented cups (0.109 mm/year) in young patients undergoing THA after 10 years of follow-up.¹

1.2.3. Effect of the introduction of highly cross-linked polyethylene in New Zealand

The NZJR 2019 report directly compared UHMWPE and XLPE revision rates. Using ceramic femoral heads, the revision rate per 100 component years was lower for XLPE than conventional polyethylene, being 0.54 and 0.77, respectively. For those cases using a metal femoral head, the corresponding figures were 0.56 and 0.76, roughly a 30% reduction in revision rates at the registry population level (McKie, 2019). A 2024 study by

¹ The term highly cross-linked polyethylene (HXLPE) is used throughout this thesis to refer to ultra-high molecular weight polyethylene subjected to deliberate high-dose irradiation (≥ 50 kGy) followed by post-irradiation thermal treatment, as distinct from conventionally gamma-sterilised UHMWPE. Where registry literature uses the term 'cross-linked polyethylene' (XLPE), this reflects the registry classification system and encompasses all formulations marketed as cross-linked, including both first- and second-generation HXLPE products. The X3 bearing material used in the Exeter RimFit cup examined in this study is a second-generation sequentially irradiated and annealed HXLPE.

Williams et al. (2024) directly analysed NZJR revision data over 21 years and found a pattern consistent with the XLPE transition. There was a statistically significant increase in both femoral fracture (4.1% to 14.9%) and pain (8.1% to 14.9%) as reasons for hip revision rather than at the acetabular level, while dislocation decreased significantly from 57.6% to 17.1%. Both femoral and acetabular loosening increased over the first 12 years, but subsequently decreased over the last 9 years (Williams et al., 2024). The reduction in revision for dislocation, aseptic femoral, and acetabular loosening can be linked to the changing patterns of the use of larger femoral heads and improved bearing surfaces.

The NZJR annual reports show the use of XLPE remained the dominant choice by 2020, accounting for more than 96.9% of all polyethylene used (McKie et al., 2024). The ceramic on polyethylene bearing surface continued to increase in popularity, rising from 42% in 2017 to 54% in 2020. There has also been an increasing use of 36 mm heads since 2017, reflecting increased confidence with XLPE when used to manufacture thinner liners (McKie et al., 2024). By 2020-2021, conventional UHMWPE had been essentially eliminated from New Zealand practice, with XLPE comprising virtually all polyethylene used. A summary of the evolution of various polyethylene categories is provided in Table 1.

Table 1. The polyethylene crosslinking spectrum and evolution: categories, manufacturing characteristics, and clinical examples.

Category	Time period	Radiation dose	Post-irradiation treatment	Clinical examples
Conventional UHMWPE	Early 1960s - late 1990s	25-40 kGy (sterilisation only)	None (or air-packaged - oxidative degradation)	Exeter ECF
Moderately cross-linked PE	Mid - late 1990s	25-40 kGy (deliberate)	Gamma-in-nitrogen or EtO sterilisation; mild annealing	Duration (DePuy); Enduron; some 1990s-era 'enhanced' products
First-generation HXLPE	1998 - 2005	50-100 kGy (single high dose)	Remelting (>155°C) or single annealing (<130°C); EtO/gas plasma sterilisation	Crossfire (Stryker, 75 kGy annealed); Marathon (DePuy, remelted); Longevity (Zimmer, remelted)
Second-generation HXLPE	2005 - present	3 × 30 kGy = 90 kGy (sequential)	Sequential annealing after each dose; gas plasma sterilisation; or vitamin E stabilisation	X3 (Stryker, sequential irradiation/annealing); E1 (Biomet, vitamin E)

Abbreviations: ECF, Exeter Contemporary Flanged cup; EtO, ethylene oxide; HXLPE, highly cross-linked polyethylene; kGy, kilorads; PE, polyethylene; UHMWPE, ultra-high molecular weight.

1.2.4. Cementing of polyethylene acetabular cups

Modern cemented acetabular cups are made with HXLPE and may have spacer beads that can be filled with antibiotics, seal dead space, and create an even cement layer, allowing more uniform pressure (Kulkarni et al., 2021). Polymethylmethacrylate (PMMA) is used as a cement grout. The PMMA is not adhesive, but rather, it is used to fill the space between the surfaces of the component and the irregular acetabular bone to create a mechanical interlock that evenly spreads the load. This design reduces the risk of the cup loosening (Maggs &

Wilson, 2017; Vaishya et al., 2013). Cement can also contain antibiotics, which can limit infection rate. Bone cement implantation syndrome (BCIS) is one of the reasons cited for using hybrid and cementless THA over cemented ones, with BCIS associated with low oxygen levels and blood pressure, and/or cardiac arrhythmia during surgery with PMMA. However, there is insufficient evidence to firmly establish a causal link between PMMA cement and BCIS (Barakat & Browne, 2025; Brokke et al., 2025; Donaldson et al., 2009). Recent systematic evaluation indicates incidence varies widely and episodes are transient and mild in most cases (Barakat & Browne, 2025; Brokke et al., 2025). Although clinical vigilance remains important, BCIS alone is generally not considered a strong argument against the use of cement in patient-centred models of care.

1.2.5. Introduction of uncemented cups

Concerns with aseptic loosening of cemented acetabular components, which became apparent through the 1970s and 1980s, provided the primary reason for the development and widespread adoption of cementless acetabular fixation (Ries, 2008). Although cemented femoral fixation has retained strong evidence and clinical longevity (Ries, 2008), the acetabular side proved more susceptible to loosening, and biological fixation became the dominant paradigm for acetabular reconstruction from the 1980s onward.

The transition from cemented to cementless acetabular fixation was driven primarily by aseptic loosening of acetabular cups (Schmalzried et al., 1992) and three other concerns: biological osseointegration, lower revision rates, and potential for bone stock preservation. Biological osseointegration was hypothesised to offer a more durable, self-renewing fixation method for younger patients, a rationale supported by the Nordic arthroplasty register (Pedersen et al., 2014). Furthermore, population-level registry data consistently confirmed lower revision rates for cementless fixation in patients under 75 years (Zhang, 2017). Thirdly, cementless fixation is anecdotally believed to better preserves acetabular bone stock for future revision, but this speculation lacks direct acetabular-specific comparative evidence and should be regarded as an unsubstantiated assumption rather than a proven outcome advantage.

The longevity of uncemented THA depends fundamentally on the achievement and maintenance of a stable biological fixation at the bone-implant interface, a process termed osseointegration. Unlike cemented fixation, cementless fixation relies on an ordered biological sequence: initial mechanical stability at surgery, progressive bone thickening and widening, and growth into or onto the implant surface.

Osseointegration of cementless acetabular implants can be achieved through two distinct, but related mechanisms, each dependent on the design and surface of the implant (Kim & Yoo, 2016). Bone ingrowth refers to the direct proliferation of osteogenic cells into the porous spaces of a macro structured implant surface (Small et al., 2013). Bone on growth is the growth of bone directly onto a roughened or textured implant surface, forming direct bone-to-implant contact without requiring a macro porous scaffold. The contribution of each of the two mechanisms depends on the surface preparation of the implant (Kim et al., 2008). Porous coatings in acetabular implants have historically included titanium beads, titanium fibre mesh,

and recently three dimensionally (3D) printed trabecular titanium structures (Tigani et al., 2025), such as Stryker's Tritanium™ technology. The addition of hydroxyapatite to plasma-sprayed titanium surfaces provides a scaffold for osteoblast attachment and accelerated increase in bone width and thickness. Current observational studies and recent systematic reviews suggest that 3D-printed porous titanium acetabular cups achieve promising early and mid-term clinical outcomes, high survivorship, and reliable radiographic osseointegration (Castagnini et al., 2024; St John et al., 2024; Tigani et al., 2025); however, high-quality comparative studies and long-term follow-up data remain limited (Almeida et al., 2025; St John et al., 2024). Higher manufacturing costs also requires consideration.

Uncemented or “press-fit” acetabular cups are slightly larger than the opening of the cancellous or trabecular bone prepared for them. The cups have a metal casing and either a HXLPE or ceramic liner. The cup generates pressure around the circumference of the acetabulum, termed hoop stress (McTighe, 1999), to promote socket fixation. These cups may also have pegs or spikes and a porous coating on the surface for stability (Maggs & Wilson, 2017). The acetabulum must have decent bone stock for osseointegration into the metal casing of the cup (Schulze et al., 2020). Osseointegration leads to durable biological fixation of press-fit acetabular cups (Overmann et al., 2020), with evidence of long-term stability in younger and more active patients (Gwynne-Jones et al., 2017).

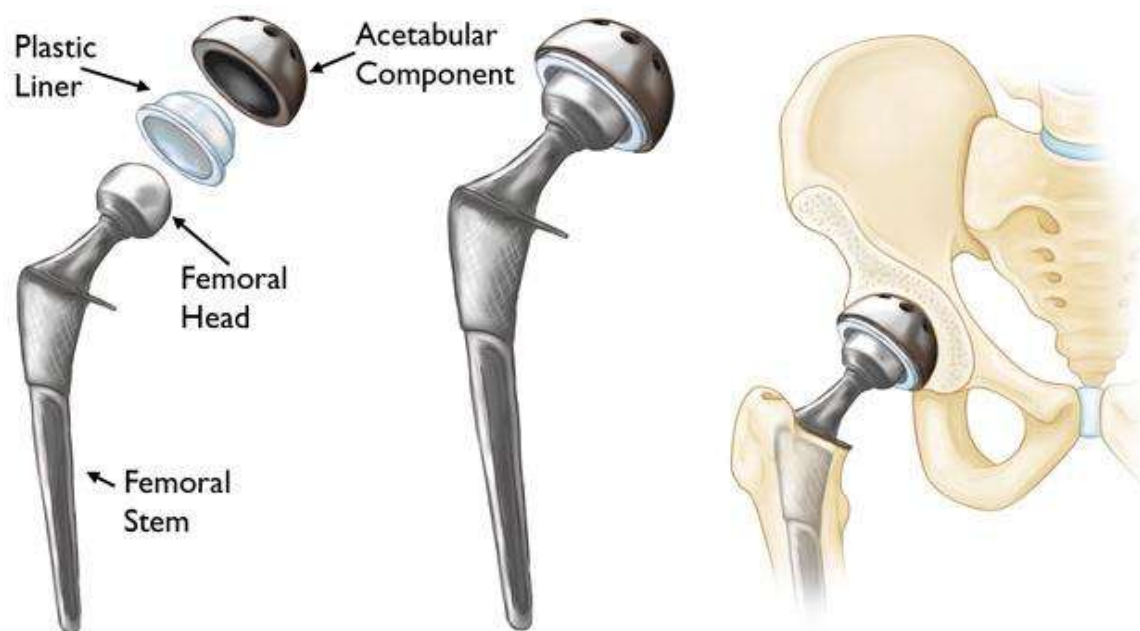


Figure 2. Components of an uncemented total hip replacement prosthesis combination.

Note. From Hip replacement – prosthesis components. By Blausen Medical Communications, Inc., 2014, Wikimedia Commons (CC BY 3.0).

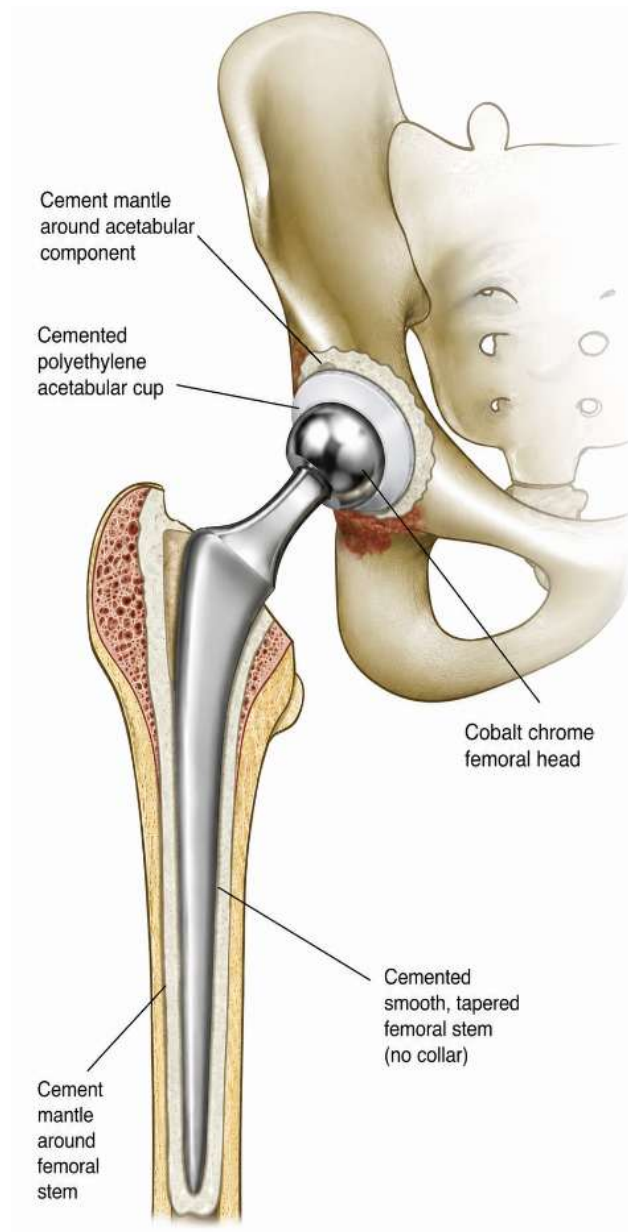


Figure 3. Components of a fully cemented total hip replacement prosthesis combination.

Note. Image generated and checked by the author using ChatGPT (OpenAI), June 2026.

1.2.6. Femoral head size and material selection

The selection of femoral head size and material has evolved in parallel with advances in polyethylene bearing technology, and the two variables are closely interrelated in determining long-term implant wear and longevity. In the era of UHMWPE, a 22 mm and subsequently a 28 mm cobalt chromium head were standard, principally because heads larger than these diameters generate proportionally greater polyethylene wear, and the wear resistance of UHMWPE was insufficient to tolerate larger articulation diameters without clinically meaningful debris (Kurtz, 2016). With the introduction of HXLPE, the dramatically reduced wear rate of bearing surface

rendered larger femoral heads clinically acceptable, enabling the adoption of 32 mm and 36 mm heads from the early 2000s onward, with the anticipated benefits of improved dislocation reduction without an increase in osteolysis risk (Shah, 2019). The choice of femoral head material, cobalt-chromium (CoCr) versus ceramic is clinically relevant to perceived implant longevity, as the surface hardness and smoothness of the articulating head directly influences polyethylene wear rates. A metaanalysis of 36 studies demonstrated a statistically lower linear wear rate for ceramic heads compared to CoCr heads on HXLPE liners (Mertz et al., 2023). However, a systematic review and metaanalysis comparing ceramic-on-XLPE with metal-on-XLPE found no significant difference in wear rates when stratified for head size (22 mm, 28 mm, 32mm), and no difference was noted between ceramic and CoCr heads on XLPE (Spir et al., 2022). A multicentre RCT comparing oxidised zirconium (a patented, "ceramicised" metal alloy) similarly found reduced wear with the ceramic material but did not reach clinical significance and did not translate to differences in osteolysis, functional outcomes, or revision at 10 years (Kayani et al., 2022). Although ceramic heads may provide modest wear rate advantage over CoCr, this difference is unlikely to translate into a clinically meaningful survival benefit within typical follow-up periods with modern HXLPE bearing surfaces. The choice of polyethylene generation remains the dominant determinant of long-term wear performance, with head material a secondary consideration.

There is currently no consensus on whether cemented or uncemented acetabular fixation is most optimal, with the controversy ongoing for decades (Abdulkarim et al., 2013; Hossain et al., 2017; Maggs & Wilson, 2017; Nilsson & Lohmander, 2003; Onsten & Carlsson, 1994; Toci et al., 2022). Over the last five years, the fully cemented option accounts for less than 5% of the THA in NZ, with hybrid THA representing 45%, and the remaining 50% represented by fully uncemented THA (McKie et al., 2024). Although cemented THAs report successful survival outcomes worldwide (Maggs & Wilson, 2017; Mishra et al., 2025; Satalich et al., 2022), there is far less PROMs evidence available (Mishra et al., 2025). Hybrid survival (Moskal et al., 2022) and PROMs outcomes (Goldberg et al., 1996; Jonas et al., 2019) are limited and there is a lack of studies comparing cemented and hybrid outcomes, particularly for primary THA with the diagnosis of primary OA independent of other hip pathology (inflammatory arthritis, osteonecrosis, developmental dysplasia, tumours or trauma) (Van Praet & Mulier, 2019). Very few studies also investigate patient and health system related factors relevant to survival and patient outcomes (Van Praet & Mulier, 2019).

1.3. Cost effectiveness

Although THA is cost effective overall, it is a high-volume and resource-intensive intervention (Mufarrih et al., 2019). A New Zealand cost-effectiveness analysis by Wilson et al. (2021) using data from 713 patients undergoing primary THA at a public hospital, informed by NZJR follow-up data, modelled to 15 years, demonstrated cumulative health gains of 2.8 quality-adjusted life years (QALYs) per patient. Cost-effectiveness improved markedly with follow-up duration, with the incremental cost-effectiveness ratio falling from NZ\$74,400 per QALY at one year to NZ\$6,000 per QALY at 15 years. THA was cost-effective after two years and highly cost-effective after three years, well within the GDP per capita benchmark of approximately NZ\$60,600 used in that analysis as the cost-effectiveness threshold for the NZ healthcare system (Wilson et al., 2021).

Small differences in implant costs, revision rates, and PROMs could, however, translate into substantial cumulative costs at a population level. Implant survival alone is an incomplete marker of success and revision surgery an imperfect definition of failure. Many patients may live for years with persistent pain, functional limitation, and reduced quality of life without undergoing revision, generating real but invisible costs to patients, families, and health systems (Singh et al., 2021). Poorly performing implants may therefore drive excess hospital admissions, rehabilitation and outpatient needs, and long-term disability despite apparently acceptable survival, with inferior pain, function, or mental health outcomes emerging over time (Brauer et al., 2005; Hesselting et al., 2019; Karachalios et al., 2018). Cost effectiveness thus depends on outcomes rather than implant price alone. A lower cost implant is not necessarily more cost effective if associated with worse PROMs, greater downstream healthcare use or increased risk in specific patient subgroups. Conversely, a more expensive implant cannot be justified without demonstrable improvements in survival, PROMs, or system-level costs. These effects are not distributed uniformly across the population. Older, frailer patients and those experiencing socioeconomic disadvantage or prolonged waiting times are disproportionately affected, and poorer survival and PROMs have been consistently associated with higher comorbidity burden, advanced age, female sex, and socioeconomic factors (Boyle et al., 2023; Karachalios et al., 2018; Lizcano et al., 2025; Singh, 2024; Stafinski et al., 2022). Failure to account for such predictors increases the risk of incorrectly attributing poorer outcomes to implant performance, thereby masking underlying inequities in care. A multivariable approach allows separation of implant effects from patient characteristics.

Equity considerations should be an integral part of research into THA outcomes. Publicly funded patients and those with greater comorbidity generally present later, have worse baseline PROMs, and experience poorer postoperative outcomes (Lizcano et al., 2025; Mannion et al., 2020; Singh, 2024). If certain implants perform less well in these groups, continued use without supporting evidence presents an equity and ethical issue, not just a clinical one. Generating evidence on which implants perform best, in which patients, under which health system conditions is essential to delivering fair, evidence-based arthroplasty care. Cost effectiveness therefore depends on comparative efficacy, which requires implant level data, adjustment for patient and health system factors, and measurement of outcomes that matter to patients.

1.4. Arthroplasty registries

Given the scale of hip OA and the volume of THAs performed globally, randomised controlled trials alone are neither feasible nor sufficient to evaluate long-term outcomes, rare events, or implant performance in real-world populations (Schnell-Inderst et al., 2017). National arthroplasty registries therefore play a crucial role in monitoring survival and PROM outcomes at scale for primary and revision THA. These registries provide large, population-based, observational cohorts with longitudinal follow-up across the implant lifespan and real-world data reflecting clinical practice rather than idealised trial conditions (Baker et al., 2023). Analyses of these registries enables assessment of survival, revision patterns, and PROM data in a way that aligns with health system realities and cost pressures. The NZ national joint registry (NZJR) is a national database established in 1999 by the NZ Orthopaedics Association (NZOA) to collect data on joint replacements, track implant

performance, surgeon outcomes, and patient results to improve arthroplasty care in NZ. It provides valuable insights for quality assurance, benchmarking, and research, with comprehensive capture across all NZ hospitals. The NZJR uses the Oxford Hip Score (OHS) PROM tool (Murray et al., 2007) postoperatively for registered THAs at six months and then every five years following surgery. National registries are often restricted by capacity in the number of questionnaires collected and seek the minimum sample size needed to satisfy statistical power calculations rather than using an entire population (Lazem & Sheikhtaheri, 2022). This limitation may introduce regional biases, whereby PROMs for certain regions or demographic groups are not equally represented or absent. For example, the NZJR uses the OHS from a minimum sample size of 20% of the total number of THAs performed nationally (McKie et al., 2024), restricting the ability to determine detailed outcomes, particularly in patient subgroups/regions. The distribution of PROMs may also not be truly representative of the population given the voluntary self-reporting of outcomes.

Regional data offer several advantages over national registries. Benefits of regional data are the ability to detect emerging performance issues earlier, inform procurement and clinical guidance more rapidly, and support timely modification of implant use, which has clear implications for patient safety and cost containment. Regional registries are directly relevant to evaluate necessity, effectiveness, and cost efficacy of THA by capturing outcomes in a defined healthcare system, in a relatively homogenous funding and referral structure with consistent thresholds for surgery and revision. This homogeneity improves internal validity and ensures that findings are directly applicable to regional clinical practice and policy decision-making (Slingerland et al., 2024). Regional registries increase sensitivity to health system and equity factors, such as public versus private funding, access to rehabilitation, socioeconomic deprivation, rurality, and ethnicity, which are often poorly captured or diluted in national datasets (Chami et al., 2021; Slingerland et al., 2024; Sorensen, 1997). Regional registries are better positioned to capture outcome disparities, system-level predictors, and equity-related differences in implant survival and PROMs. This positioning is particularly important in interpreting survival, as revision is influenced by access and eligibility (Lizcano et al., 2025). Regional registries benefit from standardised PROMs collection for an entire population, reducing opportunity for heterogeneity which obscures true differences in implant performance or patient outcomes. One limitation of regional registries, however, is their potential for limited generalisation to other regions, countries, healthcare systems, or populations. However, this is a limitation of scope, not validity, and reinforces the need for multiple high-quality regional datasets, rather than the reliance on pooled averages.

Tauranga Orthopaedic Research Inc. (TOR) is an independent non-profit organisation that monitors the surgical outcomes from all orthopaedic patients in the Bay of Plenty region of NZ. In 2003, TOR created an independent registry for all joint replacement surgeries performed in their region, specifically to capture detailed PROMs to evaluate pain, function, and quality of life preoperatively, at 1-year, at 5 years, and every 5 years thereafter. Three PROM tools are sent to every patient on the register: the OHS, McMaster University Osteoarthritis index (WOMAC) (WOMAC, 2021) and Veterans Rand 12-item health survey (Iqbal et al., 2009). Completion of the

questionnaires is optional, but highly recommended. The aim of the registry is to monitor individual patient's long-term and ensure the highest quality care and outcomes in the Bay of Plenty region.

1.5. Patient-reported outcome measure tools

The OHS is a 12-item PROM tool developed in 1996, updated in 2007, and standard in general hip care given it is rapid to complete and achieves high patient completion rates (Putman et al., 2021). The OHS assesses subscales of pain and function (Harris et al., 2016; Murray et al., 2007) over the previous four weeks, with a minimum score of 0 and maximum score of 48. Higher scores indicate superior outcomes. Pain and function are classified as: poor <27, fair 27-33, good 30-41, and excellent >41 (Kalairajah et al., 2005).

For detailed tracking of specific aspects in osteoarthritis research or management, like stiffness and function, the WOMAC PROM tool provides richer data than the OHS (Garbuz et al., 2006), noting it is osteoarthritis rather than joint specific. The WOMAC is a 24-item PROM tool developed in 1982 and updated in 1988. It has three subscales: pain, stiffness, and physical function (WOMAC, 2021). Scores range from a minimum of 0 and a maximum of 96. Lower scores indicate superior outcomes. Severity of symptoms classification is as follows: minimal/no symptoms ≤ 24 , mild 25-41, moderate 42-69, severe 70-86, extreme ≥ 87 (Pojala et al., 2025). Some researchers recommend using both OHS and WOMAC for comprehensive evaluation, yet both PROMs tools are limited in their ability to predict patient satisfaction after THA (Yeo et al., 2020). THA satisfaction has been directly linked to changes in health-related quality of life, is a valid patient-reported outcome, and should be included in the follow-up of patients after THR surgery (Ray et al., 2020). TOR incorporates the VR-12, a brief 12-question survey that assesses physical function, bodily pain, mental health, social functioning, and general health perceptions. Answers are summarised into physical and mental health scores, which evaluates the patient's overall quality of life and disease burden. The VR-12 has been validated by cross-system comparisons (Kazis et al., 2017). This Thesis uses the OHS, WOMAC and VR-12 data from the TOR registry to evaluate of hip-specific function and pain, osteoarthritis-related stiffness and functional limitation, and wider physical and mental health-related quality of life. Considering all three PROM tools provides a comprehensive assessment of patient-reported outcomes.

1.6. Evaluating specific implants versus broad categories

Grouping implants into broad categories for comparison, such as cemented, hybrid, or uncemented, allows for an increased sample size and general appreciation of implant type performance, generalizable principles such as benchmarking (Wyatt et al., 2021), cost-effectiveness, simplified decision making, and population-level safety. However, broad categorisation assumes homogeneity of implants within each category. Implants within the same category may differ in geometry, surface coatings, materials, and metallurgy (Kumar et al., 2025). These differences can meaningfully influence early and late survival results, failure mechanisms, and patient-reported pain and function. Evaluating at the category level risks diluting clinically important effects (Boyle et al., 2023). Comparatively, assessment of individual components allows the identification of underperforming implants that appear acceptable within a broad category, recognition of high-performing implants that

outperform others, and a more accurate estimation of implant-related risk independent of patient factors (Boyle et al., 2023; Boyle et al., 2022; Paxton et al., 2019; Sox & Goodman, 2012). This approach aligns with the principles of comparative effectiveness research (Sox & Goodman, 2012), which encourages head-to-head comparisons of treatments relevant to day-to-day clinical practice to inform patient-centred models of care and support evidence-based implant selection.

Health systems procure implants at scale. Implant-specific data enable value-based purchasing decisions, such as the purchase of higher-cost implants based on outcomes rather than marketing. Without implant-level evidence, procurement decisions risk being driven by cost alone or historical preferences rather than patient benefit. Certain implants may perform differently in older patients, women, patients with higher comorbidity status or greater body mass index (BMI), or publicly funded models of care. Implant-specific analysis allows identification of differential benefit or harm, subgroups at risk of poor outcomes, and opportunities to tailor implant choice to patient characteristics.

1.7. Early generation and modern implants in New Zealand

This Thesis focuses on three acetabular cup implants with the same cemented stem to represent an early generation cemented, a modern cemented, and a first-generation modern hybrid THA. The acetabular components were selected to reflect successive design eras and fixation strategies used in routine clinical practice in the Bay of Plenty region of NZ over the study period. These cups represent clinically relevant acetabular technologies, in high use, implanted during overlapping time periods (

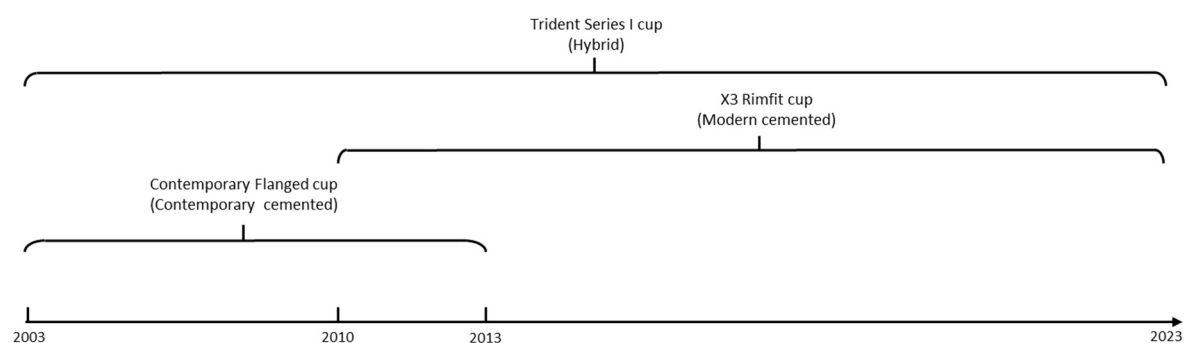


Figure 4). The Thesis first sought to determine whether the modern HXLPE cemented acetabular cup performed at least as well as the early generation UHMWPE cemented predecessor when paired with the same cemented femoral stem. Only after establishing this internal benchmark was the modern cemented THA compared to the uncemented acetabular cup (with HXLPE liner) or hybrid THA with the same cemented stem. This approach was intended to isolate the effect of acetabular fixation and design, and to evaluate whether the more costly hybrid THA delivered equivalent or superior survival and PROMs.

Anonymised survival data of all primary THAs for OA in the Bay of Plenty region of NZ, performed between 1 January 2003 and 30 June 2023 with a cemented Exeter® V40™ stem and either an early generation cemented UHMWPE Exeter® Contemporary Flanged cup (2003-2013)(ECF), modern cemented HXLPE Exeter® X3 Rimfit™

cup (2010-2023) (Rimfit) or modern uncemented Exeter® Trident™ Series 1 cup (2003 – 2023), with HXLPE liner (Trident) (Stryker Orthopaedics, Mahwah, NJ), were retrieved in January 2024 from the NZJR. A cemented V40 stem with the uncemented Trident creates the hybrid THA implant (Figure 5).

Anonymised PROMs data of all cemented primary THAs for OA performed between 1 January 2003 and 30 June 2023 with an Exeter V40 stem and either an earlier generation cemented ECF (2003-2013), modern cemented Rimfit (2010-2023) or modern hybrid Trident (2003 – 2023) implant in the Bay of Plenty region of NZ were retrieved in January 2024 from the TOR regional joint registry.

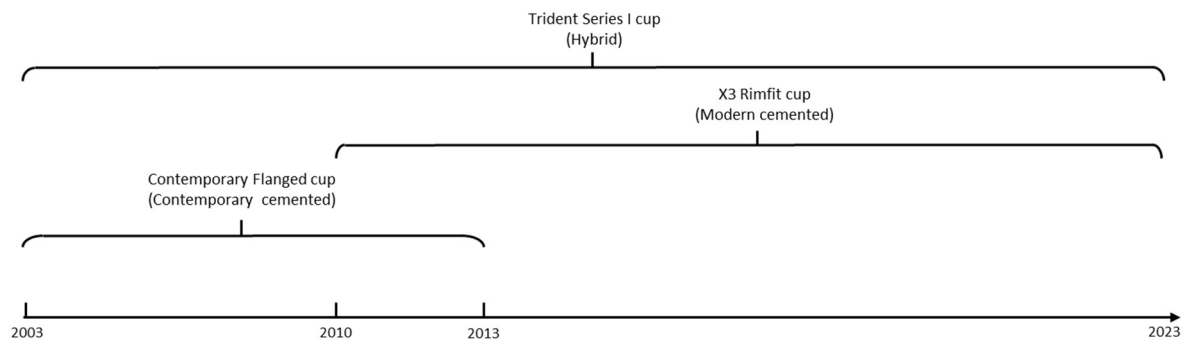


Figure 4. Timeline of acetabular component with Exeter V40 femoral stem use across the study period (2003–2023).

Note: Acetabular components represent overlapping but non-exchangeable design eras, while the V40 cemented femoral stem remained constant throughout. The arrow indicates continued clinical use beyond the study period.

(a)

(b)



(c)



(d)



Figure 5. Implants analysed in this Thesis (a) cemented Exeter V40 femoral stem, (b) early generation cemented ECF cup, (c) modern cemented Rimfit cup, (d) modern uncemented Trident cup .

Note. Permission to use images requested from Stryker.

1.8. Overview and significance of the research

This Thesis was supported by a Doctoral Partnership between the University of Waikato and TOR. The work aimed to determine whether primary (survival) and secondary (PROMs) outcomes of cemented and hybrid THA for OA in the Bay of Plenty region were comparable, given that cemented fixation has dropped to less than 5% of all THAs in NZ in the last 5 years (McKie et al., 2024) despite successful outcomes (Havelin et al., 2000; Maggs & Wilson, 2017; Mishra et al., 2025; Satalich et al., 2022). As hybrid THA maintains a cemented stem, the main difference between cemented and hybrid THA is the fixation method of the acetabular cup, reducing confounding that may occur when comparing uncemented stem and cup combinations. This Thesis progressed from a systematic review (Part 1) to cemented survival and PROMs analyses (Part 2) to cemented versus hybrid survival and PROMs comparative analysis (Part 3), as illustrated in (Figure 6).

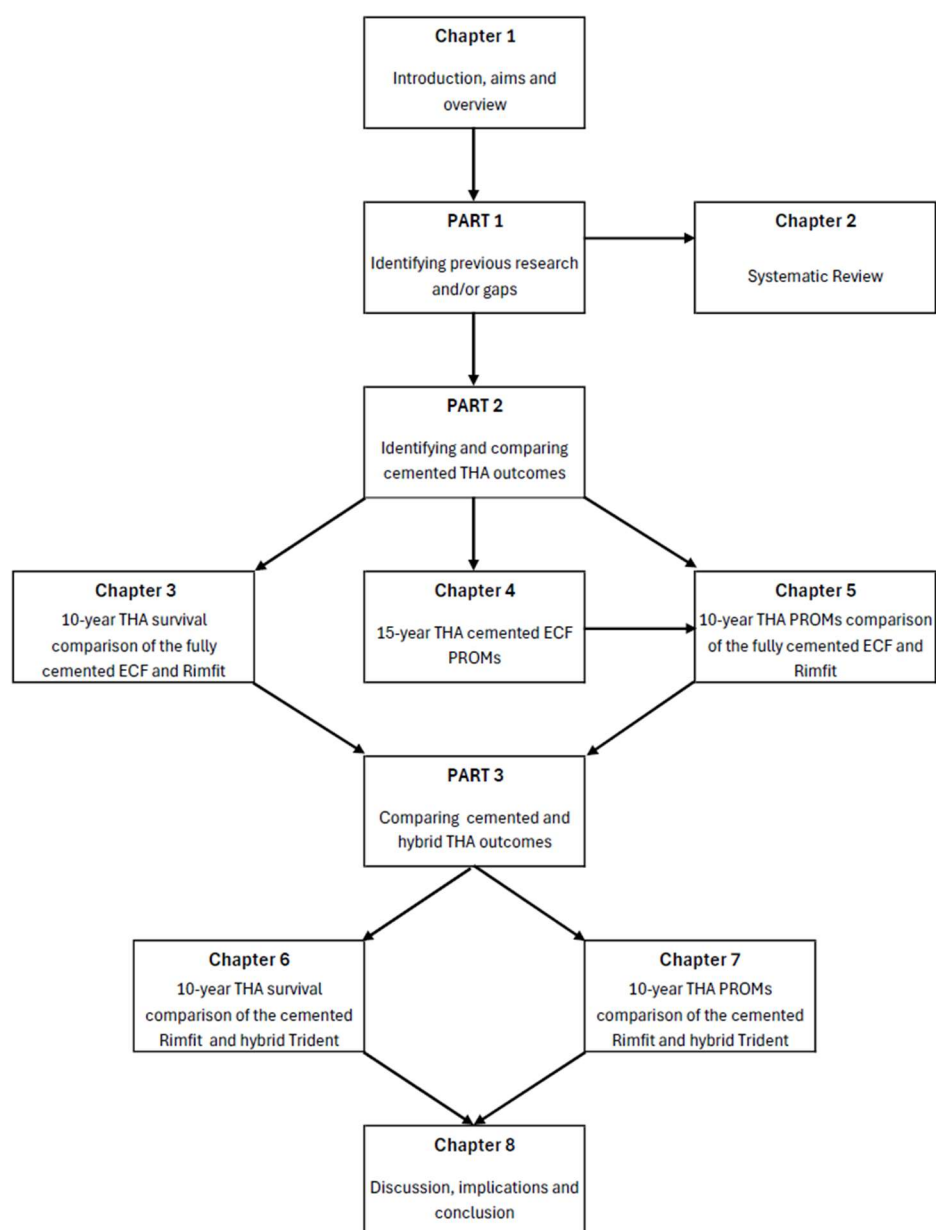


Figure 6. Thesis structure schematic

Abbreviations: ECF, Exeter Contemporary flanged cup; Rimfit, Exter X3 Rimfit cup; PROMs, Patient-reported outcome measure; THA, Total hip arthroplasty; Trident, Exeter Trident Series 1.

Cemented THA represents the longest-established and most extensively evaluated fixation strategy in modern hip replacement. It therefore provides the most methodologically stable and biologically understood reference standard against which newer fixation constructs should be assessed. Given survival analysis remains the most consistently recorded and longest-term outcome available through arthroplasty registries compared to PROMs, establishing survival similarity or difference provides essential context for subsequent PROMs analysis interpretation (Chapter 3). Hybrid THA was introduced to solve a failure of cemented fixation and emerged during a period of rapid expansion of cementless acetabular technology (Satalich et al., 2022). Concerns with aseptic loosening of cemented acetabular components, which became apparent through the 1970s and 1980s, provided the primary reason for the development and widespread adoption of cementless acetabular fixation (Ries, 2008). However, its widespread uptake occurred despite limited long-term comparative PROM data, particularly beyond early survivorship endpoints. Thereafter both survival and PROMs comparison between the modern cemented and hybrid implants were performed (Chapter 6 and 7). Hybrid THA is the intermediate step between fully cemented and fully cementless practice. Understanding whether it delivers any incremental patient-centred benefit is essential to evaluating the rationale for the broader shift away from cemented fixation. By comparing hybrid and cemented constructs that share the same cemented femoral stem, the analysis isolates the acetabular fixation method as the primary exposure. This isolation reduces implant heterogeneity and strengthens causal inference. Given the higher cost and complexity of hybrid systems, absence of patient-centred benefit challenges their cost-effectiveness. Hybrid THA is not studied as a standalone innovation, but as a hypothesis-driven extension of cemented THA; it directly tests whether the shift in fixation philosophy has translated into meaningful improvements in long-term patient outcomes.

Together, the studies follow a deliberate progression by initially establishing the current state of knowledge regarding THA cemented and hybrid implant outcomes (Chapter 2). Establishing survival of two lineage related cemented implants (Chapter 3), secondly evaluating long-term PROMs of the predecessor implant (Chapter 4), thirdly directly comparing PROMs between early generation and modern cemented implants (Chapter 5), fourthly assessing and comparing survival of a popular hybrid construct to the modern cemented implant (Chapter 6) and lastly comparing PROMs between the modern cemented and hybrid THAs (Chapter 7). This structured approach enables evaluation of both incremental design change and strategic shifts in fixation philosophy, using patient-centred and system relevant outcomes derived from both national and regional registry data.

1.9. Thesis aims

The aims of this Thesis were to:

1. Determine if there is empirical universal evidence of superiority in primary and secondary outcomes between broad category cemented and hybrid primary THA for severe endpoint osteoarthritis in a systematic review.

2. Determine at the implant level, if the modern Rimfit cemented implant reports similar survival compared to its predecessor, the early generation cemented ECF implant up to 10-years, considering patient characteristics age, sex, BMI, ethnicity, ASA rating, and funding source, in a primary THA for OA population in the Bay of Plenty region.
3. Determine the long-term PROMs (up to 15 years) of the early generation ECF considering patient characteristics age, sex, BMI, ethnicity, ASA rating, and funding source, in a primary THA for OA population in the Bay of Plenty region.
4. Determine if the modern Rimfit cemented implant reports equivalent PROMs compared to the early generation cemented ECF implant up to 10-years, considering patient characteristics age, sex, BMI, ethnicity, ASA rating, and funding source, in a primary THA for OA population in the Bay of Plenty region.
5. Determine whether the modern cemented Rimfit or first-generation modern hybrid Trident, has superior survival outcomes considering patient characteristics and funding source up to 10 years, in a primary THA for OA population in the Bay of Plenty region.
6. Determine whether the cemented Rimfit or hybrid Trident, has superior PROMs considering patient characteristics and funding source up to 10 years, in a primary THA for OA population in the Bay of Plenty region.
7. Identify subgroups of patient characteristics reporting poorer survival and/or PROMs in a primary THA for OA population in the Bay of Plenty region.

1.10. Thesis hypotheses

The following hypotheses were stated:

1. Universal evidence will indicate superior primary and secondary outcomes for cemented than hybrid primary THA for OA.
2. The modern cemented Rimfit implant has superior survival outcomes to the early generation cemented ECF implant across patient characteristics and funding source up to 10 years, in a primary THA population for osteoarthritis in the Bay of Plenty region.
3. The early generation cemented ECF implant in a primary THA population in the Bay of Plenty region, reports better long-term PROMs than the broad cemented category of implants in NZ up to 15 years.
4. The modern cemented Rimfit implant has superior PROMs to its predecessor, the early generation cemented ECF implant, across patient characteristics and funding source up to 10 years, in a primary THA for osteoarthritis population in the Bay of Plenty region.
5. The modern hybrid Trident implant has superior survival outcomes to the cemented Rimfit implant across patient characteristics and funding source up to 10 years, in a primary THA for OA population in the Bay of Plenty region.
6. The hybrid Trident implant has superior PROMs to the cemented Rimfit implant across patient characteristics and funding source in primary THA for OA up to 10 years.

7. Subgroups of patients (public funded, greater BMI) have poorer primary and secondary outcomes, which influence physical and mental health.

1.11. Thesis structure

This Thesis is developed in three Parts (Figure 6). Chapters are presented as manuscripts for publication. Chapters 2, 3, and 4 have been published in peer-reviewed journals, with Chapter 5 under revision and Chapters 6 and 7 are prepared for publication, to be submitted after submission of this Thesis.

The Thesis begins with an introduction Chapter 1. Part 1 contains Chapter 2, which is a systematic review that evaluates peer-reviewed literature that compared cemented and hybrid THA outcomes for OA (Pearce, Butcher, et al., 2025). The review concludes that the widespread shift away from fully cemented THA towards hybrid fixation is not supported by clear evidence of improved implant survival or superior PROM outcomes. The review determines cemented THA continues to deliver excellent durability and equivalent patient-centred results, particularly in older patients (Pearce, Butcher, et al., 2025). The rationale for hybrid use appears driven more by practice trends than demonstrable patient effect.

Part 2 includes three chapters (Chapters 3, 4, and 5). In Chapter 3, the survival outcomes of two high-use fully cemented primary THAs for OA (an early generation and a modern THA) were compared using the NZJR (Pearce, Joshi, et al., 2025a). Data were used to examine survival and reasons for revision of the two cemented THAs in the Bay of Plenty region. These two cemented implants share common design lineage, with the modern Rimfit implant adapted from the early generation on the bases of incremental design and material modification, rather than outcome evidence (Junnila et al., 2016; Lamberton et al., 2023).

Chapter 4 focuses on 15-year PROMs for the cemented ECF in the Bay of Plenty region (Pearce, Joshi, et al., 2025b). No evaluative evidence of this cemented implant's PROMs beyond 12 years (Maggs et al., 2016) was identified, despite it being one of the most used cemented acetabular implants in the UK, Sweden, Denmark, Norway, Australia, and NZ (Junnila et al., 2016; Maggs et al., 2016; McKie et al., 2024). This implant had sufficiently mature follow up and PROMs completeness to allow the evaluation of outcomes well beyond the early postoperative period. This analysis was necessary because long-term PROMs data following THA are scarce and survivorship alone does not capture persistent pain, functional limitation, or quality of life in patients who never undergo revision. Older or more comorbid patients, who are less likely to be revised, may also still experience substantial outcome burden. The analysis of the early generation implant at 15 years provides insight into the durability of patient benefit, rather than simply implant retention, and establishes a benchmark against which its successor, the modern Rimfit implant can be interpreted. Additionally, the effect of six patient predictors was evaluated to determine those patient factors and/or subgroups which may exhibit poorer PROMs: age, sex, BMI, ethnicity, American anesthesiologist rating (ASA), and funding source.

Chapter 5 directly compares 10-year PROMs between the early generation cemented THA and its successor the Rimfit (Pearce et al., 2026). This timeframe reflects the longest period over which comparable PROMs were available for both implants, allowing fair and methodologically sound comparison. This study addresses a critical evidence gap. The Rimfit has been widely adopted with limited long-term PROMs evaluation (Boyle et al., 2023; Boyle et al., 2022; Junnila et al., 2016) and there is no study evaluating PROMs of the Rimfit in primary THA for OA independent of other hip pathologies. Assumed equivalence based on design and material evolution does not guarantee equivalent patient experience. Differences in pain, function, or mental health outcomes may emerge even when survival may appear similar. By restricting the comparison to shared follow-up periods and adjusting for patient and system factors (age, sex, BMI, ethnicity, ASA rating, and funding source), the study isolates implant specific effects on patient-centred outcomes.

Following the implant-level comparison of the two cemented components, Part 3 (Chapter 6 and 7) further evaluates outcomes associated with a widely used modern hybrid THA implant from the same manufacturer, incorporating the same cemented femoral stem. This implant choice was intentional and addresses the broader and increasingly relevant question in arthroplasty practice whether hybrid or cemented THA offers better outcomes. Over the past two decades, there has been a substantial global shift away from fully cemented THA in favour of hybrid and cementless constructs, despite continued evidence supporting the survival and cost effectiveness of cemented fixation. The drivers include perceived advantages of cementless fixation (Moskal et al., 2022), training and generational changes in surgical practice (Ryan et al., 2022), industry influence, and assumptions of superior long-term outcomes in younger patients (Veldman et al., 2021). However, whether this transition has been accompanied by measurable improvements in survival or PROMs remains uncertain.

Chapter 6 examined survival and reasons for revision of a commonly used, modern hybrid implant compared with the modern cemented implant introduced in Chapter 3 and Chapter 5. By retaining the same cemented stem across both fixation types, the analysis isolated the effect of acetabular fixation rather than stem design. This survival analysis was necessary to determine whether the move towards hybrid fixation (with this implant in particular) is associated with improved implant longevity, whether any observed differences reflect fixation strategy and whether a hybrid implant demonstrates superior performance in real-world registry data. Evaluating survival first ensured that any difference in PROMs is again interpreted in the context of implant durability and revision risk. The addition of patient specific and system factors increased the specificity of the analysis within the region.

In the final comparison, Chapter 7 directly compared 10-year PROMs between the modern cemented and hybrid THA and addressed whether the widespread adoption of hybrid fixation results in better PROMs compared with modern cemented THA, or if this practice has shifted in the absence of clinical benefit. By controlling for patient and system level factors and holding the femoral stem constant, this analysis focuses on whether acetabular fixation strategy confers additional benefit in terms of pain, function or health-related

quality of life. The final comparison study situates the Thesis within the broader context of evolving arthroplasty practice.

The final chapter (Chapter 8) summarises the findings, discusses clinical implications, and makes recommendations to the NZJR and for future research. If modern cemented constructs demonstrate equivalent or superior survival and PROMs compared with hybrid THA, the rationale for the reduction of fully cemented fixation in NZ, particularly in publicly funded and higher risk populations warrants reconsideration. Conversely, if hybrid fixation confers measurable advantages, this result would provide empirical justification for current NZ practice trends. Either outcome has significant implications for implant selection, surgical training, procurement, cost effectiveness, and equity of care. Outside of any measurable differences between the cemented and hybrid components, the identification of patient subgroups that may present with poorer outcomes, either survival and/or PROMs, remains of critical importance. Mean treatment effects may obscure clinically relevant heterogeneity, whereby specific demographics, clinical, or psychosocial characteristics predispose individuals to inferior postoperative recovery despite otherwise successful THA. Recognition of these vulnerable subgroups enables more accurate preoperative counselling, supports shared decision making, and facilitates the development of targeted perioperative and rehabilitative strategies aimed at improving outcomes for those at greatest risk of persistent pain, functional limitation, or dissatisfaction (Stisen et al., 2024).

Chapter 2. Systematic review with narrative synthesis

Prelude:

The aim of this review was to determine whether there is consistent evidence of differences in primary (survival) and secondary outcomes (PROMs) between cemented and hybrid primary THA for OA, across patient characteristics and funding resource settings. Specifically, the review sought to identify, synthesise, and critically appraise the available evidence relating to PROMs, implant survival, periprosthetic fractures, and methodological quality in earlier generation and modern cemented and hybrid THA cohorts.

This review was undertaken to directly inform the rationale, outcome selection, and analytical framework of the present study. By systematically evaluating both reported findings and study quality, the review enabled the identification of clinically relevant outcomes with inconsistent or limited evidence, as well as key sources of heterogeneity related to patient characteristics and healthcare settings. These findings informed the selection of primary and secondary outcomes, justified the comparative focus of the current research, and highlighted specific evidence gaps that the present study was designed to address.

2.1. Introduction

Total hip arthroplasty (THA) is recommended for severe primary osteoarthritis of the hip and is one of the most frequent surgeries worldwide. Wang et al. (2024) reported 606.5 million global osteoarthritis cases by 2021, highlighting it as a major public health challenge due to its disability burden. As joint replacement surgeries increase, identifying the most effective and durable treatment approach is essential to ensuring quality of life. THA for osteoarthritis can be performed with cemented (both femoral stem and acetabular cup cemented), cementless (both stem and cup are cementless), hybrid (cemented femoral stem and cementless cup), or reverse hybrid (cementless femoral stem and cemented cup) implants. Controversy over fixation methods for THA has been ongoing for decades, and there seems to be no consensus on which fixation method provides optimal survival and patient-reported outcomes (PROMs) despite several systematic reviews and meta-analyses on the topic (Abdulkarim et al., 2013; Clement et al., 2012; López-López et al., 2017; Mei et al., 2019; Pakvis et al., 2011; Tsertsvadze et al., 2014; Van Praet & Mulier, 2019). Most of the reviews in this area exclusively focus on survival and revision rates (Bloemhevel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014; Stea et al., 2014), whereas it is recognised that PROMs are an important consideration in establishing THA success and promotion of patient-centred care (Baumhauer & Bozic, 2016; Lavalley et al., 2016). In addition, certain of these reviews present methodological concerns where data from the same registry reported in different studies (Van Praet & Mulier, 2019), systematic reviews or meta-analyses (Clement et al., 2012; Tsertsvadze et al., 2014; Van Praet & Mulier, 2019), and registry reports (Van Praet & Mulier, 2019) alongside original research were included in the analysis, biasing findings by duplicating data analysed. Making inferences on the superiority of fixation methods for THA outcomes specifically for osteoarthritis is further challenged considering how several of these reviews included additional hip pathologies as criteria for surgery (e.g., lupus, systemic sclerosis, rheumatoid arthritis) (Abdulkarim et al., 2013; López-López et al., 2017; Mei et al., 2019); involved hemi-arthroplasty in addition to full THA (López-López et al., 2017); limited their review to restricted age groups (Mei et al., 2019); or failed to specify whether stems were cemented or uncemented, focusing only on acetabular fixation (Abdulkarim et al., 2013; Clement et al., 2012; Pakvis et al., 2011). This study identified four reviews that included PROM comparisons as a secondary outcome to implant survival (Abdulkarim et al., 2013; López-López et al., 2017; Tsertsvadze et al., 2014; Van Praet & Mulier, 2019), but only one of these exclusively targeted osteoarthritis (Van Praet & Mulier, 2019).

The use of cemented THA implants was first described in 1891 and became more common from the 1950s (Bota et al., 2021) with Sir John Charnley the pioneer of the modern THA (Gomez & Morcuende, 2005). Cemented THA has been identified as the most affordable fixation method (Abdulkarim et al., 2013; Van Praet & Mulier, 2019; Veldman et al., 2021) and is often considered the “gold standard” (Van Praet & Mulier, 2019), setting the bar that newer implants need to surpass for widespread adoption. At the other end of the spectrum, cementless THA is considered the most costly fixation method (Jameson, Mason, Baker, Gregg, Porter, et al., 2015) and is typically associated with poorer outcomes (Bloemhevel et al., 2022; Jämsen et al.,

2014; Pedersen et al., 2014) and higher revision and periprosthetic fracture rates (Sassoon et al., 2024) than cemented. Hybrid THA, despite costing more than cemented, may however, offer superior postoperative quality of life (Pennington, Grieve, Sekhon, et al., 2013) and function (Rolfson et al., 2016). Consequently, hybrid THA has been identified as the most cost-effective replacement surgery (Van Praet & Mulier, 2019) in all age groups and both sexes (Veldman et al., 2021), and hybrids with conventional polyethylene show a survival advantage over cemented THA (Fowler et al., 2019). Consideration of both surgical and patient-related measures in quantifying success of THA, regardless of fixation method, is needed to shift the focus from surgeon to patient-centred models of care (Zhang, 2017).

Given the identified gaps in the existing reviews comparing THA outcomes between fixation methods, this systematic review with narrative synthesis aimed to compare both primary (revision and periprosthetic fracture rates) and secondary (PROMs) outcomes between cemented and hybrid primary THA for severe endpoint osteoarthritis. The hypothesis was that cemented THA would demonstrate potentially superior primary and secondary outcomes to hybrid THA for patients with end stage osteoarthritis.

2.2. Methods

This systematic review with narrative synthesis forms part of independent research supported by a PhD scholarship award jointly funded by Tauranga Orthopaedic Research Incorporated and The University of Waikato. This review was designed to meet the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) reporting guidelines (Page et al., 2021) and was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO identifier: CRD42023462884).

Review methods and inclusion criteria were specified in advance. The primary outcomes of interest were survival and/or revision rate and periprosthetic fracture (PPF) rate (acetabular and/or femoral), and secondary outcomes of interest included any physical criteria PROMs, including but not limited to, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford hip score, Harris hip score, Forgotten hip score; as well as any mental health or lifestyle related PROMs (HRQOL), such as Hospital Anxiety and Depression Scale, Short Form-36 item health survey (SF-36), and Veterans Rand 12 item health survey (VR-12). Original, peer-reviewed research articles published in English were included and spanned observational studies (prospective and retrospective) and randomised control trials. The study further limited the inclusion criteria to studies evaluating outcomes over a period of at least 1 year. Where multiple studies reported on the same/similar patient cohort, the study with the longest follow-up was included to avoid duplication of data. Study population included adult patients with end stage hip osteoarthritis who had been assigned a fully cemented (cemented femoral stem and acetabular cup) or hybrid (cemented femoral stem and cementless acetabular cup) THA. Revision risk, hazard, mortality, and economic evaluations; editorials; systematic reviews; meta-analyses; joint registry reports; letters to the editor; and conference abstracts were excluded. Studies including any condition other than end stage osteoarthritis of the hip, revision outcomes, or bilateral THA surgeries only were excluded. Studies that included fully cementless (cementless femoral and cementless

acetabular cup) or reverse hybrid (cementless femoral stem and cemented acetabular cup) procedures were included when comparisons were made between fully cemented and hybrid THA within the study. A strength of the inclusion criteria ensured that the same dataset was not featured multiple times in different studies thereby inflating results.

Four electronic databases (PubMed®, EBSCO, ScienceDirect®, and Scopus®) were initially searched on 1 October 2023, with the search updated on 15 November 2024. The search included articles from journal inception up to and including the date of search. Broad syntax terms included “primary hip replacement”, “primary hip arthroplasty”, “osteoarthritis”, “cement*”, “hybrid” and “outcome”. Detailed descriptions of the syntax used for each database is provided as supplementary material (Appendix J). The database search was complemented by searching reference lists, orthopaedic joint registries, and hip arthroplasty manufacturer websites for relevant articles. All records identified via the database search (AP) were imported to the review software Rayyan (Ouzzani et al., 2016) and duplicates removed. Two reviewers applied eligibility criteria independently (AP, AB) and then met to discuss conflicts. There was one unresolved conflict that required input from a third reviewer (KHL). The initial screening for eligibility was performed on titles/abstracts, and the process repeated for full-text articles by the same two independent reviewers. A customised data collection form was developed for this review (Appendix K) and data collated in Microsoft Excel (v2501, Microsoft Corp., Redmond, WA, USA). Information extracted from each study included study type, fixation method, country of study, sample size, mean follow-up period, primary endpoint, statistical methods for survival calculation, predictors of interest, and results. Missing data were identified, and corresponding authors of these studies were contacted. If there was no response from the authors, data were reported as “missing”. Data were summarised in table format to facilitate narrative synthesis and interpretation (Appendix K). Studies were assessed for risk of bias and critically appraised. Two reviewers assessed each study independently (AP, AB), with a third (KHL) available for conflict resolution, but not required. Observational studies were assessed for risk of bias using the Quality in Prognostic Studies (QUIPS) tool (Hayden et al., 2013) and randomised control trials with the Cochrane ROB version 2.0 (Sterne et al., 2019). The QUIPS is considered a useful and reliable tool for systematically assessing the risk of bias in prognosis research across six key domains (study participation, attrition, factor measurement, confounding, outcome measurement and analysis/reporting). The ROB 2.0 provides a structured framework to evaluate potential bias across five domains relevant to randomised controlled trials (randomisation, deviations from intended intervention, missing outcome, measure of the outcome, selection of the reported result) (Sterne et al., 2019).

Although a meta-analysis was planned to provide a quantitative synthesis of the findings from aggregate data, the decision to perform a narrative synthesis was motivated by six factors: data availability and homogeneity, type of data, study design, purpose of the synthesis, study quality and reporting, and flexibility. As five or more studies using similar statistical methods and reporting the same outcomes from similar populations are needed to achieve reasonable power from a random effect model meta-analysis (Jackson & Turner, 2017), data extracted as part of this review were deemed insufficient for meta-analysis of primary and secondary

outcomes. A narrative synthesis systematically synthesises evidence to generate new insights by analysing and interpreting findings from included studies. The process involves three steps: developing a preliminary synthesis, exploring data relationships, and assessing the robustness of the synthesis (Sukhera, 2022). These steps were followed when undertaking the synthesis. The overall quality of evidence for each gradable outcome was assessed by one reviewer (AP) using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) working group system (Brennan & Johnston, 2023), and verified by a second (KHL). This structured approach has four levels of certainty of evidence ratings (very low, low, moderate, and high) used to assess risk of bias, imprecision, inconsistency, indirectness, and publication bias. Gradable outcomes were survival/revision rate, PPF rate, and PROMs. Study design, risk of bias assessment, and quality of evidence ratings did not constitute study exclusion. Results were organised based on primary and secondary outcomes. Comparison and synthesis of results for each of these categories of outcome were summarised and categorised as conclusive (either “there is difference” or “there is no difference”) or inconclusive (2024) based on heterogeneity, statistical uncertainty, inconsistency in treatment effects, and/or incomplete information.

This review focused specifically on studies reporting survival percentages and revision rates (absolute outcomes), rather than those which modelled the risk of revision over time. The study aimed to determine how many hips had been revised or remained unrevised at a specific timepoint rather than the statistical likelihood of revision. This focus on absolute outcomes allows for clarity and accessibility of easily interpretable data with concrete outcomes (Sashegyi & Ferry, 2017), relevant for decision making, such as benchmarking (national registry reports use survival percentage at 5, 10 or 15 years to compare models) (Kandala et al., 2015) and clinical planning (surgeons want information on likelihood of a revision, not just the relative risk). This approach also aligns with real-world clinical goals, such as identifying implants that consistently exceed revision benchmarks (Kandala et al., 2015).

2.3. Results

The initial search identified 1095 studies, with nine studies identified from citation searches. After duplicate removal, 1027 studies were excluded at title and abstract screening (Figure 7). Ultimately, eight studies met inclusion. Five of these reported on the primary outcome (all observational), and three of these addressed the secondary outcome (two randomised control trials and one observational). The author attempted to contact three authors (Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) for further information, but no replies were received.

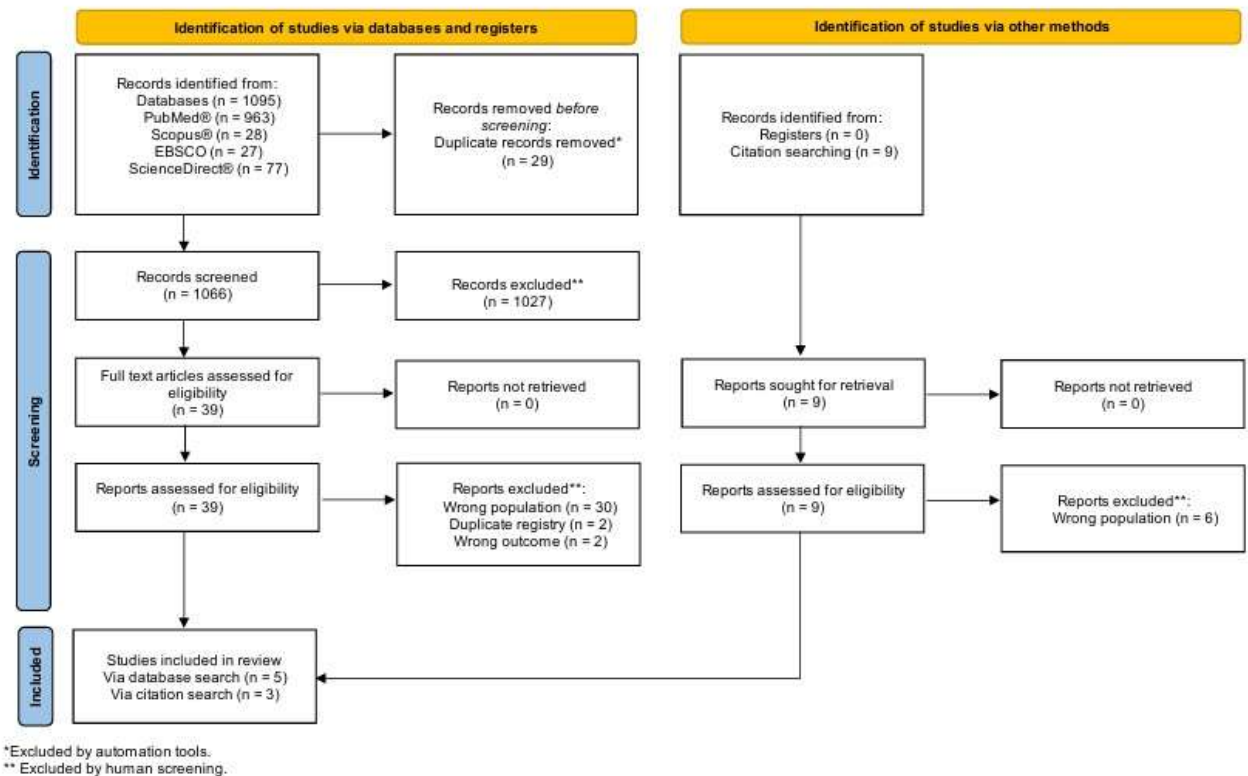


Fig 1. PRISMA flow chart of the search strategy and study selection process

Figure 7. PRISMA flow chart of the search strategy and study selection process

2.3.2. Primary outcome: Survival and periprosthetic fracture rate

2.3.2.1. Risk of bias

The five studies identified were assessed for risk of bias. Direct comparison of sex ratios and mean age were possible in one of five studies, which indicated no difference in proportion of male to female observations ($p = 0.610$) or mean age ($p = 0.464$) (Jämsen et al., 2014). All other studies reported adjusting for age and sex within their statistical models to avoid confounding (Bloemheuvel et al., 2022; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014). Three observational studies had independent low risk of bias (Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008), and one indicated moderate risk in prognostic factor measurement and study confounding (Pedersen et al., 2014). One study displayed a high-risk of bias related to confounding and moderate bias in both study attrition and prognostic factor measurement (Bloemheuvel et al., 2022).

Detailed results of the individual bias assessments can be found in Table 2.

Table 2. Risk of bias assessment for primary and secondary outcomes in the included studies

Primary outcome (survival)						Secondary outcomes (PROMs/HRQOL)			
	Bloemheuvel et al. (2022)	Jämsen et al. (2014)	Kandala et al. (2015)	Mäkelä et al. (2008)	Pedersen et al. (2014)	Nilsdotter and Lohmander (2003)		Norman- Taylor and Villar (1997)	Onsten and Carlsson (1994)
QUIPS*							ROB 2**		
Study participation	+	+	+	+	+	+	Randomisation process	x	+
Study attrition	!	+	+	+	+	!	Deviations from the intended intervention	+	+
Prognostic factor measurement	!	+	+	+	!	!	Missing outcome data	+	+
Outcome measurement	+	+	+	+	+	!	measure of the outcome	+	!
Study confounding	x	+	+	+	!	!	Selection of the reported result	+	+
Statistical analysis and reporting	+	+	+	+	+	+	Overall	!	!

x: High risk; !: moderate or unclear risk; +: Low risk. Abbreviations: HRQOL, health related quality of life; PROMs, patient-reported outcome measures. * The Quality in prognostic study (QUIPS) tool uses the six important domains that should be critically appraised when evaluating validity and bias in studies of prognostic factors (Hayden et al., 2013). ** Cochrane risk-of-bias tool for randomized trials (Higgins et al., 2024)

2.3.2.2. Overall quality of evidence

Due to the heterogenous nature of the observational survival studies, both survival and PPF evidence was determined to be of low quality and certainty. Four studies collected data from participants of different age group categories. Data were collected across multiple timepoints, spanning several years, with studies capturing survival outcomes over 1-5 years, 5-10 years, or 10-16 years, making it difficult to determine a summary of primary outcomes. Only age and fixation type consistently appeared as moderating factors. GRADE quality of evidence for the outcome of survival and PPF rate was low, with moderate-to-high risk of bias, serious indirectness, serious imprecision, and suspected publication bias (Table 3).

2.3.2.3. Study characteristics

The five observational studies included in the analysis (Bloemheuvel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014; Stea et al., 2014) represented 244,032 cemented and 39,068 hybrid THA observations (Table 2). All studies reported on European national joint registry data (four Nordic studies, one England and Wales), and included cemented, hybrid, and cementless survival comparisons, with two studies also examining reverse hybrid THA (Bloemheuvel et al., 2022; Pedersen et al., 2014). There was notable clinical heterogeneity in the age groups studied, with age ranging from 18 to 102 years in the studies that reported age. Two studies focused specifically on patients aged over 80 years (Bloemheuvel et al., 2022; Jämsen et al., 2014), one study included individuals aged 55 years and older (Mäkelä et al., 2008), another targeted patients between 35 and 55 years (Pedersen et al., 2014), and one study did not specify the age or age range of participants (Kandala et al., 2015). Two studies reported overall male and female observations combined for all THA categories within the study (Bloemheuvel et al., 2022; Pedersen et al., 2014), while two others provided separate implant observations by sex (Jämsen et al., 2014; Mäkelä et al., 2008). One study did not specify or report male and female observations (Kandala et al., 2015). Study observation periods spanned from 1980-2019 with follow-up durations ranging from 1 to 16 years. Survival outcomes were reported at different follow-up periods. Two studies reported survival at 1, 3, and 5 years (Bloemheuvel et al., 2022; Jämsen et al., 2014), and one study at 2 years (Pedersen et al., 2014). Four studies reported survival at 10 years (Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014) and one at 16 years (Pedersen et al., 2014). Three studies (Bloemheuvel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015) employed a competing-risk Kaplan-Meier approach, while two used standard unadjusted Kaplan-Meier survival analysis (Mäkelä et al., 2008; Pedersen et al., 2014), reflecting methodological heterogeneity. Two studies reported PPF rates (Bloemheuvel et al., 2022; Jämsen et al., 2014). Detailed characteristics can be found in Table 4.

Table 3. Certainty of evidence GRADE* for primary and secondary outcomes in the included studies

Certainty assessment							Summary of findings		
Outcome	Studies (n)	Study design	Risk of bias	Indirectness	Imprecision	Publication bias	Included in narrative synthesis	Results	Quality of evidence (GRADE)
Survival	5	Observational studies ^a	moderate-high	serious ^f	serious ^{jl}	suspected ^l	Hybrid: 39,068 Cemented: 204,964	No difference in survival rates heterogeneity in population/samples	+ - - -
PROMs	3	2 Randomised Control trials ^{b,c} ; 1 Observational study ^d	moderate- high	serious ^{gh}	serious ^l	suspected ^m	Hybrid: 138 Cemented: 247	No significant difference between hybrid and cemented PROMs. Old studies, poorly conducted with limited results.	+ - - -
PPF	2	Observational studies ^e	moderate-high	serious ^{fe}	serious ^k	suspected ⁿ	Hybrid: 3,745 Cemented: 25,836	Lowest in hybrid compared to cemented. Extremely limited study number	+ - - -

*GRADE, grading of recommendation, assessment, development and evaluation; RCT, randomised controlled trial. ^a 3/5 studies did not justify sample size, study attrition, prognostic factor measurement and study confounding; ^b One study did not identify the randomisation process and deviated from the intended intervention; ^c Studies did not effectively measure the intended outcome; ^d The only observational study did not clearly define study attrition, prognostic factor measurement, statistical analysis and reporting used a mean follow-up; ^e Study designs were not specific to periprosthetic fracture rate, this was an additional outcome; ^f Differences in age categories of all studies; ^g Two studies used the same PROMs instrument but reported the results differently; ^h Different HRQOL instruments; ⁱ Time point collection for each study was different; ^j Studies had differing predictors of interest and varied between short, medium and long-term net and cumulative statistical survival calculation; ^k Periprosthetic fracture rate only recorded if part of revision, not recorded if revision not required; ^l National registries represented, results may not be attributable to other populations; ^m Only two small samples represented in the RCTs, from the same country; ⁿ Only reported in 2/8 studies.

Table 4. Survival study characteristics in cemented and hybrid primary total hip arthroplasty for osteoarthritis

Author and year	Study period and country	Study design	Sample size* (cemented; hybrid)	Age group (years)	Mean follow-up, collection time points (years), collection end	Outcomes	Predictors of interest	Key findings
Bloemheuvel et al. (2022) [†]	2007-2019 Netherlands ¹	Observational. Cemented, hybrid, cementless, reverse hybrid	n = 43,053 (22,025; 3,243)	≥80	Mean: 4.2 (0-13) Times: 1, 3, 5 End: Revision	Competing risk Kaplan-Meier; Revision rate (%)	Age, sex, ASA, fixation, head size, approach	No difference in survival at either 1, 3 or 5 years. PPF rates cemented 6%, and hybrid 3%.
Jämsen et al. (2014) [†]	1998- 2009 Finland ²	Observational. Cemented, hybrid, cementless.	n = 4,777 (3,811; 502)	≥ 80	Mean: 4 (1-13) Times: 1, 3, 5, 10 End: Revision	Competing risk Kaplan-Meier % survival.	Age, sex, facility, year, comorbidity type, popularity of implant	No difference in survival at 1, 3, 5 or 10 years. PPF 11% in cemented, 18% cemented women vs 0% hybrid.
Kandala et al. (2015)	2003-2012 England and Wales ³	Observational. 2 cemented, 2 cementless and 1 hybrid.	n = 239,089 (137,990; 28,471)	Not reported	Mean: not reported Times: 1, 5, 10 End: Revision	Competing risk Kaplan-Meier; Bathtub, Weibull, Loglogistic, Flexible Revision rate (%) ‡	Age, sex, fixation, bearing type	Conclusive. Reported new 5% benchmark for revision. Revision rate of 1.88-2.11% in cemented and 2.42% in hybrid.
Mäkelä et al. (2008)	1980-2004 Finland ²	Observational. 2 cementless, 1 cemented and 1 hybrid.	n = 50,968 (34,296; 3,784)	55-64, 65-74, >75	Mean: 4.5-9.2 Times: 10, 15, 20 End: Revision	Kaplan-Meier standard % Survival	Implant groups, age, sex	No difference. All age groups in both hybrid and cemented groups had a survival of >90% at 10 years.
Pedersen et al. (2014)	1995-2011 Sweden, Denmark, Finland, Norway ⁴	Observational. Cemented, cementless, hybrid and reverse hybrid.	n =29,558 (6,842; 3,068)	35-45 & 46-55	Mean: not reported Times: 2, 10, 16 End: Revision	Unadjusted Kaplan- Meier % survival at 2, 10 and 16 years	Age, sex, fixation technique and calendar year	Conclusive. Cemented indicated higher survival percentage at 2, 10 and 16 years for any revision reason, revision for aseptic loosening and revision for any other cause.

Abbreviations: ASA, American anesthesiologist physical status rating; PPF, periprosthetic fracture rate.

All studies included cementless/uncemented and/or reverse hybrid fixation or more than one cemented/hybrid component for comparison.

* Total sample size includes all hip fixation methods within the study, including cementless and reverse hybrid, where applicable. ** Specified a loaded-taper or composite beam stem. † These studies included periprosthetic fracture rates. ‡ Actual revision rates at 5 years and estimated 10-year rates for 70-year-old males and females only. ¶ No data at 15 or 20 years for hybrid fixation. The fixation technique did not fulfil the proportional hazards assumption for Cox proportional hazards calculation; therefore, the population was split into subgroups (1995-1999, 2000-2003, 2004-2007, 2008-2011). ¹ Dutch arthroplasty register; ² Finnish Arthroplasty Registry; ³ National registry for England and Wales; ⁴ Nordic arthroplasty registry.

2.3.2.4. Narrative synthesis

Three survival studies with the lowest risk of bias (Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008) identified no significant difference in survival between cemented and hybrid THA at 1, 3, 5, and 10 years. All three studies presented mean survival for each fixation method, which ranged between 98.6 to 98.8% at 1 year, 98.1 to 98.3% at 3 years, 97.8 to 98.1% at 5 years, and 83 to 96% at 10 years. Due to heterogeneous methodologies, these survival percentages were not directly comparable. In an England and Wales 10-year follow-up study (Kandala et al., 2015), after completing five different Kaplan-Meier model analyses, the cemented prostheses with metal-on-polyethylene bearing surface had the highest estimated mean survival rate of 98.02% at 10 years, with cemented ceramic-on-polyethylene survival second with 97.5%, and hybrid metal-on-polyethylene third with 97.32%. With similar 10-year estimates between prostheses and a revision percentage below 5%, the authors recommended the 10-year benchmark revision rate for all THA in England and Wales be lowered from 10% to 5% (Kandala et al., 2015). No difference in survival between hybrid and cemented THA was reported, although not assessed for statistical significance. Mäkelä et al. (2008) identified that at 10 years, all age groups in both hybrid and cemented THAs exceeded a survival of 90% with no significant difference between the two fixation categories across age groups ($p = 0.22$ to 0.80). A moderate risk of bias study (Pedersen et al., 2014) reported survival comparison at 10 and 16 years for both cemented and hybrid THA using three endpoints: revision for any reason, revision for aseptic loosening, and revision for other causes. Cemented THA was reported to show superior survival to hybrid THA at 10 years when the endpoint was revision for any reason ($90.2 \pm 0.43\%$ versus $86.6\% \pm 0.69$), for aseptic loosening ($92.8\% \pm 0.38$ versus $91.4\% \pm 0.59$) and for other reasons other than aseptic loosening ($97.3\% \pm 0.23$ versus $94.8\% \pm 0.44$). The same pattern was reported at 16 years, with cemented exhibiting higher survival than hybrid. Statistical significance results were not reported. Synthesis of results seems to indicate that at timepoints up to 10 years, survival tends to be similar and that there is little, if any, difference in survival between cemented and hybrid implants, but that longer time frames may favour cemented THA. Clinical follow up beyond 15-years is required to determine if a difference exists.

Two studies reported PPF rates (Bloemheuvel et al., 2022; Jämsen et al., 2014), with one of these studies only reporting cemented PPF rate and not the hybrid PPF rate. The low risk of bias study (Jämsen et al., 2014) reported a 10-year cemented PPF revision rate of 11%. The high risk of bias study (Bloemheuvel et al., 2022) reported a PPF rate of 6% in cemented and 3% in hybrid THA at 5 years (Jämsen et al., 2014), thus it is not possible to definitively establish whether PPF rates are lower in cemented or hybrid THA. Both studies showed no difference in survival between hybrid and cemented THA (Bloemheuvel et al., 2022; Jämsen et al., 2014). Detailed survival study information can be found in Table 5.

Table 5. Survival and revision rate outcomes for the included studies in hybrid and cemented primary total hip arthroplasty for osteoarthritis

Study (Age group)	Sample size	Periprosthetic fracture rates	1-y survival %	2-y survival %	3-y survival %	5-y survival %	10-y survival %	15-y survival %	16-y survival %
Bloemheuvel et al. (2022) ^{ab}	Cemented: 22,025	26/427 (6%)	Net:98.7 (98.6-98.8) ^{gh}	-	Net: 98.2 (98.1-98.3) ^{gh}	Net: 97.8 (97.7-97.9) ^{gh}	-	-	-
≥ 80 years			CR: 98.7 (98.6-98.9) ^{fh}		CR: 98.3 [98.1-98.4] ^{fh}	CR: 98.0 (97.7-98.2) ^{fh}			
Median age: 83 (80-108) ^e									
M:10,931; F: 32,073 ^e									
Median FU: 4.2y	Hybrid: 3,243	2/61(3%)	Net: 98.6 (98.4-98.8) ^{gh}	-	Net: 98.2 (98.0-98.4) ^{gh}	Net: 98.0 (97.7-98.3) ^{gh}			
			CR: 98.8 (98.3-99.1) ^{fh}		CR: 98.3 [97.8-98.7] ^{fh}	CR: 98.1 [97.5-98.6] ^{fh}			
Jämsen et al. (2014) ^{ab}	Cemented: 3,811	5/46 (11%) 1y	CR:98.8 (98.4-99.2) ^{fh}	-	CR: 98.1 (97.7-98.6) ^{fh}	CR: 97.8 (97.3-98.3) ^{fh}	CR: 97.4 (96.9-98) ^{fh}	-	-
≥80y	M: 1,143; F: 2,668	10/57(18%) in F							
Mean FU: 4y	Hybrid: 502	0/5(0%) in F	CR: 98.6 (97.6-99.7) ^{fh}	-	CR: 98.1 (96.9-99.4) ^{fh}	CR: 98.1 (96.9-99.4) ^{fh}	CR: 98.1 (96.9-99.4) ^{fh}	-	-
	M: 145; F: 357								
	Mean age: 82y (80-95)								
Kandala et al. (2015) ^{abcd}	Cemented: 137,990	-	-	-	-	-	CeCoP: 98.12f (97.89-98.03) ^j	-	-
Age not specified	M: -; F: -						CeMoP: 97.78f (97.17-97.58) ^j		
Median age: 70.4y ^e	Hybrid: 28,471	-	-	-	-	-	HyMoP: 97.58f (96.92-97.50) ^j	-	-
Mean FU: -	M: -; F: -								
							Aseptic loosening ^j	Aseptic loosening ^j	
							55-64y: 85 (84-86) n = 2,138	55-64y: 71(69-73) n = 1,086	
							65-74y: 91 (91-92) n = 5,899	65-74y: 85(84-86) n = 2,049	-
							≥75y: 95 (95-96) n = 2,299	≥75y 93(92-94) n = 441	
							All: 91 (91-91) n = 10,335	All: 83(82-84) n = 3,575	
							All reasons ^j	All reasons ^j	
Mäkelä et al. (2008) ^{ad}	Cemented: 34,296	-	-	-	-	-	55-64y: 83 (82-85) n = 2,140	55-64: 68(66-70) n =1,088	
	M: 12,004; F: 22 292						65-74y: 89 (89-90) n = 5,904	65-74: 82(81-83) n = 2,051	-
	Mean age: 70y (55-95)						≥75y: 93 (93-94) n = 2,300	≥75y: 91(90-92) n = 441	
55- >75y							All: 89 (89-89) n = 10,343	All: 80(80-81) n = 3,579	
							Aseptic loosening ^j		
	Hybrid: 3784	-	-	-	-	-	55-64y: 90 (85-95) n = 77		
	M: 1,551; F: 1,548						65-74y: 93 (91-95) n = 194	-	-
mean FU: 3.6-10.2y	Mean age: 72y (55-96)						≥75y: 96 (93-100) n = 73		
							All: 93 (92-95) n = 343		
							All reasons ^j		

Study (Age group)	Sample size	Periprosthetic fracture rates	1-y survival %	2-y survival %	3-y survival %	5-y survival %	10-y survival %	15-y survival %	16-y survival %	
							55-64y: 83 (76-89) n = 78			
							65-74y: 88 (86-91) n = 194	-	-	
							≥75y: 92 (88-95) n =73			
							All: 88 (86-90) n = 344			
Pedersen et al. (2014) ^a	Cemented: 6,842	-	-	Any: 98.6 ± 0.14 ⁱ	-	-	All: 90.2 ± 0.43 ⁱ	-	All: 77.4 ± 1.13 ⁱ	
				AL: 99.6 ± 0.43 ⁱ			AL: 92.8 ± 0.38 ⁱ		AL: 80.5 ± 1.13 ⁱ	
				Other: 99.0 ± 0.12 ⁱ			Other: 97.3 ± 0.23 ⁱ		Other: 96.1 ± 0.39 ⁱ	
	35-55y									
	Mean age: -									
M: 15,391 ^e				Any: 97.7 ± 0.27 ⁱ			All: 86.6 ± 0.69 ^j	All: 68.5 ± 2.12 ⁱ		
F: 14,167 ^e		-	-	AL: 99.3 ± 0.15 ⁱ	-	-	AL: 91.4 ± 0.59 ^j	-	AL: 75.9 ±2.17 ⁱ	
Mean FU: -				Other: 98.4 ± 0.23 ^j			Other: 94.8 ± 0.44 ⁱ		Other: 90.1 ± 1.08 ⁱ	
		Hybrid: 3,068								

Abbreviations: AL, aseptic loosening; CeCoP, cemented ceramic on polyethylene; CeMoP, cemented metal on polyethylene; CR, competing risk (death); F, female; FU, follow-up; M, male. ^a Included other hip types (cementless and/or reverse hybrid) in the comparison; ^b Only included specific makes of component;

^c Included bearing surface as a predictor of survival; ^d Bilateral THR not mentioned; ^e Of the entire sample only; ^f Crude survival rate - Competing risk survival rate with death as a competing risk; ^g Net survival rate- The estimated survival rate accounting for only those who survived long enough to require revision potentially; ^h Mean survival% [95%CI][low - high]; ⁱ Mean survival% ± standard deviation; ^j Range of survival percentages between Bathtub, Weibull, Loglogistic and flexible Kaplan-Meier models.

2.3.3. Secondary outcome: Patient-reported outcome measures

2.3.3.1. Risk of bias

Three studies (Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) were identified as including PROMs and evaluated for risk of bias. The only observational study (Nilsdotter & Lohmander, 2003) was evaluated using the QUIPS tool (Hayden et al., 2013), and the two remaining RCTs (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) evaluated using the ROB 2 (Sterne et al., 2019). Baseline comparisons showed no age or sex differences between cemented and hybrid groups in the Swedish RCT (Onsten & Carlsson, 1994) (low risk of confounding). In the UK RCT (Norman-Taylor & Villar, 1997), the hybrid group was significantly younger than the cemented group ($p < 0.001$, $d = 0.97$), indicating possible age-related confounding. The Swedish observational study (Nilsdotter & Lohmander, 2003) had more females and older participants in the cemented group, suggesting imbalance in key demographic variables. While both RCTs showed comparable sex ratios ($p > 0.05$) (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994), the observational study did not (Nilsdotter & Lohmander, 2003). These differences lower confidence in the observational findings due to risk of confounding and contribute to downgrading the certainty of evidence. The observational study (Nilsdotter & Lohmander, 2003) indicated a moderate risk of bias in study attrition, prognostic factor and outcome measurement, and study confounding, with all other factors indicating a low risk of bias. Both RCTs scored moderate risk of bias overall (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994). Individual high-risk of bias was identified in the randomisation process in one of the RCTs where randomisation was not described (Norman-Taylor & Villar, 1997). Results can be found in Table 2.

2.3.3.2. Overall quality of evidence

The overall certainty of evidence was very low based on GRADE for secondary outcomes (PROMs) when comparing hybrid and cemented THA, with moderate-to-high risk of bias, serious indirectness, serious imprecision, and suspected publication bias (Table 3). All three studies indicated methodological heterogeneity, using assorted and inconsistently applied tools at varying follow-up points (1, 2, and 3.6 years), and across heterogeneous populations with poorly defined or non-existent subgroups. These factors severely limited the validity, comparability, and applicability of findings to clinical practice.

2.3.3.3. Study characteristics

Characteristics of individual studies can be found in Table 6. The three studies (Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) together compared PROMs scores between 138 hybrid and 247 cemented primary THAs (186 males and 200 females) for osteoarthritis. Two RCTs ($n = 80$ and $n = 60$ respectively) (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994), and one observational study ($n = 196$) (Nilsdotter & Lohmander, 2003) were performed in Europe (two in Sweden (Nilsdotter & Lohmander, 2003; Onsten & Carlsson, 1994) and one in the UK (Norman-Taylor & Villar, 1997) and compared specific hybrid and cemented implants rather than broad category components. Observation periods ranged from 1988 to 1998 and reported short-term (1, 2, and 3.6-year) PROMs, with two studies also reporting preoperative scores

(Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997). Both RCTs (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) used the Harris hip score measurement tool, however one RCT converted the original Harris score to Rosser Index pain and disability values (Norman-Taylor & Villar, 1997), and reported Rosser Index quality of life results rather than Harris hip score.

Table 6. Characteristics of included studies comparing PROMs in cemented and hybrid total hip arthroplasty for osteoarthritis

Author	Study period and country	Study design	Sample size	Age group	Outcomes	Follow-up period	Collection time points	Predictors of interest	Key findings
Nilsdotter and Lohmander (2003)	1995-1998 Sweden	Observational†	n = 196 C-139 H- 57	NR	HRQOL: SF-36 PROM: WOMAC Preop: Yes	3.6 y	1 and 3.6y	Age, sex, fixation, follow-up time, baseline values	No difference in PROMs between cemented and hybrid THR noted. Statistically significant improvement in postoperative scores for both fixation types.
Norman-Taylor and Villar (1997)	1992-1994 United Kingdom	RCT	n = 80 C- 40 H- 40	<70	HRQOL: Rosser Index PROM: Harris Hip Score Preop: Yes	1 y	1 y	Age, sex	Inconclusive. Harris hip score used to determine Rosser index score
Onsten and Carlsson (1994)	1988-1991 Sweden	RCT	n = 60 C- 30 H - 30	40-70 y	HRQOL: No PROM: Harris Hip Score Preop: No	2 y	2 y	Fixation	No difference in PROMs between cemented and hybrid THA noted.

Abbreviations: C, cemented; H, hybrid; HRQOL, health related quality of life; THA, total hip arthroplasty; NR, not reported; Preop, preoperative; PROM, patient-reported outcome measure; RCT, randomised control trial; SF-36, 36-Item Short Form Survey; WOMAC, Western Ontario and McMaster Universities Arthritis Index. † Hospital sample

The results of the Swedish RCT study (Onsten & Carlsson, 1994) indicated a 2-year mean Harris pain score of 42 out of 44 for each THA group, and mean Harris hip score of 91 and 92 for hybrid and cemented respectively, with no reporting of statistical significance. In the UK RCT (Norman-Taylor & Villar, 1997), there was no statistically significant difference between the cemented and hybrid preoperative Rosser Index HRQOL scores ($p = 0.596$); but at 1-year, hybrid THAs performed statistically significantly better than cemented THAs (0.988 ± 0.018 , 0.995 ± 0.006 respectively, $p = 0.015$) with the cemented hip reporting better Rosser Index HRQOL scores. The Swedish study determined a hybrid prosthesis did not impair early quality of life outcomes and although HRQOL scores increased in all 80 patients, the study identified that 60% of hybrid THA patients achieved maximal HRQOL scores after 1 year. This HRQOL study however, suggested improvement in quality of life was not dependent on prosthesis type.

The observational study (Nilsson & Lohmander, 2003) included preoperative, 1-year, and 3.6-year WOMAC and SF-36 scores. No difference in WOMAC scores between the cemented or hybrid groups at any timepoint was noted. The SF-36 subscales of “role physical” and “general health” showed statistically significant differences ($p < 0.05$) preoperatively, and in all but one subscale (i.e., “bodily pain”) at 1-year, and two subscales (i.e., “bodily pain” and “general health”) at 3.6 years with hybrids indicating better scores. However, when the scores were adjusted for age, sex, follow-up time and baseline values, no statistically significant differences were revealed. See Table 7 for detailed results of each study.

2.3.3.4. Narrative synthesis

With very low certainty of evidence, in three heterogeneous studies using assorted PROMs tools at inconsistent timepoints, drawing secondary outcome conclusions regarding superiority is challenging. All three studies report PROM improvements in both cemented and hybrid THAs at their chosen follow-up periods, and no significant differences in PROMs between the two THA options. Despite differences in instruments and follow-up durations, the consistent direction of effect (i.e., no observed or statistically significant difference) supports the conclusion that PROMs may be similar between the two fixation types. While formal data synthesis was not feasible, the narrative synthesis suggests that across different instruments and timepoints, PROMs do not appear to differ meaningfully between cemented and hybrid THA. However, due to high risk of bias and very low certainty of evidence, these findings must be interpreted with caution. The lack of observable difference may be due to study limitations and imprecision.

Table 7. Outcomes of patient-reported outcome studies comparing hybrid and cemented primary total hip arthroplasty for osteoarthritis

Article	Prosthesis type	PROM (mean ± SD)						HRQOL(mean ± SD)					
		Instrument	Sub level	Preop	1 year	2 years	3.6 years	Instrument	Sub level	Preop	1 year	3.6 years	
Nilsdotter and Lohmander (2003) n = 245 Age: NR	Cemented (n = 177) Mean age: 75 (61-92)¶ M: 73; F: 104	WOMAC						SF-36	PF	30.43±20.4	61.6±22.4	56.5±24.2	
									RP	6.8±17.1	51.7±42.3	39.7±42.9	
									BP	30.5±15.6	72.3±24.9	64.9±25.6	
				Pain	45.3±17.9	84.4±17.1	-		81.0±20.1	GH	66.4±19.6	68.9±20.5	64.4±21.1
				Stiffness	37.7±16.6	75.8±20.5	-		76.1±22.0	VT	47.8±21.3	68.7±22.0	61.0±24.0
				Function	37.1±15.5	75.4±18.0	-		71.3±20.4	SF	62.6±26.5	84.7±23.5	81.0±23.0
									RE	33.6±41.0	63.3±40.7	56.8±44.0	
									MH	68.3±19.8	80.2±19.3	76.5±19.8	
	Hybrid (n = 68) Mean age: 62 (50-72)¶ M: 39; F: 29						PF		30.4±17.7	74.2±19.7*	68.2±25.3*		
							RP		15.5±28.7*	72.4±37.1*	63.9±41.6*		
							BP		30.3±20.0	78.0±21.7	69.2±27.9		
			Pain	44.8±15.9	84.1±18.1	-	84.2±21.0		GH	72.4±20.3*	78.7±21.6*	70.1±23.9	
			Stiffness	42.0±15.7	81.8±16.6	-	80.7±22.3		VT	51.2±20.2	78.0±20.8*	70.0±24.1*	
			Function	41.8±12.5	83.0±16.1	-	81.2±20.4*		SF	67.0±25.3	92.7±17.2*	90.6±20.5*	
							RE		43.8±44.3	86.3±29.2*	83.6±32.0*		
							MH		71.6±23.8	87.3±15.7*	83.4±20.1*		
Norman-Taylor and Villar (1997) n = 80	Cemented (n = 40) Mean age: 58.22y ± 6.7 (40-65) M: 19, F: 21	Harris Hip†							A B C D	A B C D			
									I	-	15, 3, 3,	-	
									II	8, 3	4, 10, 2, 1	-	
									III	1, 8	'1, 1	-	
									IV	3, 17	-	-	
									V	-	-	-	
									VI	-	-	-	
										A B C D	A B C D	-	

Article	Prosthesis type	PROM (mean ± SD)						HRQOL(mean ± SD)					
		Instrument	Sub level	Preop	1 year	2 years	3.6 years	Instrument	Sub level	Preop	1 year	3.6 years	
Age: <70y	Hybrid (n = 40)		Pain	-	-	-	-		I	-	24, 6	-	
	Mean age: 52.90y ± 6.6		Hip	-	-	-	-		II	5, 10	5, 3, 1	-	
	(39-67)								III	2, 8	1	-	
	M: 22, F: 18								IV	2, 13	-	-	
							V		-	-	-		
							VI		-	-	-		
Onsten and Carlsson (1994) n = 60 Age: 40-70y	Cemented (n =30)	Harris Hip±¶¶	Pain	-	-	42	-						
	M: 16; F: 14		Hip	-	-	91	-						
	Mean age: 63 ± 6‡												
	Hybrid (n = 30)		Pain	-	-	42	-						
	M: 17; F: 13		Hip	-	-	93	-						
	Mean age: 62 ± 6‡												

* $p < 0.05$ between hybrid and cemented mean outcome score. Abbreviations: BP, bodily pain; GH, general health; HRQOL, health related quality of life; MH, mental health; PROM, patient-reported outcome measure; PF, physical function; RE, role emotional; RP, role physical; SD, standard deviation; SF, social function; SF-36, 36 Item Short Form Survey; VT, vitality; WOMAC, Western Ontario and McMaster Universities Arthritis Index. † Actual scores not reported, used to determine Rosser index. ‡ No range provided. ¶ No standard deviation provided. ¶¶ The Rosser index derives scores from the Harris hip score; the matrix allocates scores from -1.486 to 1.000. A score of 1 indicates complete normality; death is given a score of 0.000. Numbers reported are the distribution of patients within each category with AI being the best score and DVI being the worst quality of life score.

2.4. Discussion

This review focused on studies comparing implant survival, PPF rate, and PROMs between hybrid and cemented primary THA for end stage osteoarthritis. From the eight retrieved studies (Bloemheuveel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Nilsson & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994; Pedersen et al., 2014), five observational studies (Bloemheuveel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014) compared the primary outcomes of survival and two studies compared PPF rate (Bloemheuveel et al., 2022; Jämsen et al., 2014). Two RCTs (Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) and one observational study (Nilsson & Lohmander, 2003) analysed PROMs.

2.4.1. Survival

While the overall number of observations in the survival studies was substantial ($n = 283,100$), lack of clinical and methodological homogeneity led to variability in findings. Three studies (Bloemheuveel et al., 2022; Jämsen et al., 2014; Mäkelä et al., 2008) found no survival difference between hybrid and cemented THA over 1, 3, and 5 years, while two (Kandala et al., 2015; Pedersen et al., 2014) reported marginally better 10-year cemented survival and one study (Pedersen et al., 2014) better 16-year cemented survival. However, neither of the latter studies confirmed whether the observed differences reached statistical significance. Survival outcomes appeared to vary by patient group, follow-up duration, and implant type. Studies examined patients from under 55 years only (Pedersen et al., 2014) to those over 80 years only (Bloemheuveel et al., 2022; Jämsen et al., 2014). In some studies, survival seemed to be better in specific cemented subgroups (e.g., ceramic-on-polyethylene bearings) (Kandala et al., 2015), suggesting that individual implant characteristics may be more important than fixation type alone.

Broad category classifications of THA fixation groups include multiple implant brands (stems and acetabular cups), designs (geometry), materials, and coatings, which can behave differently in terms of longevity, wear, and complications (Boyle et al., 2022). Examining broad categories can highlight general trends, but lacks the detail needed to guide implant selection. Research on specific implant comparison may allow more accurate assessment of variability in patient outcomes, improve implant selection for patients, provide more clinically relevant outcomes, and avoid misleading conclusions (Campbell et al., 2021). Focusing on specific implant comparisons risks reduced sample sizes and statistical power, compromising inference, but the continued use of regional or national registry data could mitigate this limitation by leveraging access to larger and more generalisable patient populations.

Only two studies reported PPF rates (Bloemheuveel et al., 2022; Jämsen et al., 2014), both in patients 80 years and older but at different timepoints. One study indicated higher PPF rates in cemented THA (Bloemheuveel et al., 2022). Still, this difference did not translate into poorer implant survival in cemented THA overall. The available data do not support PPFs as the most common cause of revision in either cemented or hybrid THA.

More importantly, clinical failures that did not result in revision were not documented. Since some PPFs are managed without revision (e.g., with fixation), and these cases were not reported, the true incidence of PPFs may be underestimated in both fixation types. This lack of reporting lowers the proportion outcome of PPF in cemented and hybrid fixation in THA. A study analysing data from the UK National Joint Registry found that 56% of postoperative PPFs were not captured by the registry, as the cases were treated without the replacement of components (Lamb et al., 2024). Lamb et al. (2024) noted PPF as the leading cause of major reoperation (but not necessarily component replacement) following THA and that the prevention and treatment of PPF requires further research. It may be prudent to include, at a minimum, PPFs requiring surgical intervention within revision registry data collection.

All survival studies (Bloemheuvel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014) used national registry derived data for survival analysis. The lack of consistent reporting of statistical significance, follow-up periods, and patient stratification reduces the overall ability to determine meaningful inferences from findings. While national joint registries are invaluable for monitoring and improving the outcomes of joint replacement surgeries, they do have some limitations. National registries provide broad standardised data that help identify overall trends in outcomes, implant longevity, and patient demographics (Lubbeke et al., 2017; Sutton & Murray, 2025). However, they mask regional disparities by averaging data across different populations and may not capture variations, for example, between wealthier and deprived regions or populations of different ethnicities. Regional joint registries may offer more detailed insights into regional population characteristics, specific access barriers, rural versus urban areas, and variations in surgical and funding outcomes (private versus public) (Burt, 2024). For surgeons, regional data analysis may be more effective at determining the most successful THA for a specific demographic of patient.

Methodological heterogeneity between the survival studies complicated comparison and inference. Standardising survival analysis models, the handling of missing data, statistical adjustments, and definition of outcomes affected the validity and comparison of results. Methodological homogeneity in registry data analysis would allow opportunity for easier comparison and evaluation of survival outcomes.

2.4.2. Patient-reported outcome measures

Although limited, all PROMs studies (Nilsson & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) reported improvements in HRQOL following primary THA for osteoarthritis, regardless of fixation type. One RCT (Norman-Taylor & Villar, 1997) found a statistically significant advantage for hybrid THA at 1-year using the HRQOL Rosser Index. The observational study (Nilsson & Lohmander, 2003) reported differences in SF-36 subscales, favouring hybrid THA at 1-year and 3.6-years, but these differences were not statistically significant after adjusting for age, sex, follow-up time, and baseline values. Overall, both hybrid and cemented PROMs improved substantially and appeared similar between groups, but due to a small number of studies and no follow-up beyond 3.6 years, no difference in PROMs between hybrid and cemented THA could be identified in the medium-term to long-term. The included studies spanned a 30-year period and dated

timeframe (1988-1998) and offer valuable historical perspectives. However, their relevance to contemporary practice is limited due to outdated measurement tools, evolving surgical techniques, and shifting patient expectations. Interpretation should be cautious, particularly when comparing to modern cohorts. In all three studies (Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) included in the systematic review, younger, likely more active patients, were selected for hybrid THA, possibly reflecting surgeon preference rather than a truly random comparison. This bias creates indirectness of evidence as outcomes may reflect patient characteristics rather than implant design.

The absence of comparable PROM data of more than 3.6 years also highlights a major evidence gap. A seven-year prospective international multicentre study observed that while patients experienced significant improvements in PROMs within the first-year post THA, certain factors like obesity and postoperative difficulties in self-care were associated with a gradual decline in outcomes over the subsequent years (Galea et al., 2019). This study highlights the importance of continued monitoring to assess the sustainability of surgical benefits. Research also indicates that PROMs tend to plateau after 1-to-2 years post-surgery, but that attrition over time may affect study sensitivity (Spece et al., 2025). This attrition rate could be mitigated by using prospective national or regional population PROMs data rather than smaller sample groups (Faber & Fonseca, 2014). A longitudinal cohort study by Schwartz et al. (2022) emphasised that cognitive and mental health assessment significantly influence recovery trajectories post THA and suggested that long-term PROMs are essential for identifying patients at risk of poorer outcomes and for tailoring postoperative care accordingly. Such information is vital for setting realistic patient expectations and facilitating informed decision making regarding the procedures available. Although one RCT reported statistically significant HRQOL differences at 1 year favouring hybrid THA (Norman-Taylor & Villar, 1997), this finding was not consistently observed across other studies or timepoints.

There is a pressing need for contemporary, high-quality research evaluating patient-centred outcomes across different fixation types using standardised PROMs. Future studies should standardise the selection, collection and reporting of PROMs ideally in alignment with internationally agreed guidelines. While the Oxford hip score is one of the most used hip-specific PROM tool for THA (Holmenlund et al., 2021), valued for its simplicity, validation and strong correlation with patient satisfaction and outcomes, the WOMAC is considered the highest quality PROMs tool for osteoarthritis (Gagnier et al., 2018). The author proposes the use of at least one of these tools as an international standard. Transparency on missing data, loss to follow-up, and selection bias is essential. Lack of studies could reflect a systematic under collecting and underreporting of PROMs in this area contributing to uncertainty and limiting evidence-based decision making. Recommendations would be to collect PROMs preoperatively, at 6 months to 1-year, and then at 5 yearly intervals, in line with the NZJR (McKie et al., 2024).

Although RCTs are the gold standard for evaluating the efficacy and safety of medical interventions, Pakvis et al. (2011) argued that RCT studies are challenging to conduct in THA and may not always reflect the complexities

of real-world orthopaedic care. These authors suggested that well-designed non-randomised studies with adequate follow-up and rigorous outcome measurement could serve as a benchmark for high-quality evidence in orthopaedics (Pakvis et al., 2011). These benchmark studies would involve comparing similar populations, interventions and follow-up durations, using consistent outcome tools, data collection timelines, methodologies, and standardised statistical analyses.

Both survival and PROMs studies suffered from common limitations, including clinical and methodological homogeneity and inconsistent reporting. There are key limitations in the current literature, notably few published studies; heterogeneity in study design, outcome measures, and follow-up durations; and all studies conducted in European countries. The fact that all studies in the review were European limits the international generalizability of the findings due to potential differences in healthcare systems, surgical techniques, patient demographics, and ethnic variations in hip anatomy (Kim et al., 2011; Thiesen et al., 2022). Broadening the evidence base to include studies from regions such as North America, Canada, Africa, Asia and Oceania would promote more equitable and optimal patient outcomes across diverse global populations. Furthermore, there is more recent data suggesting that larger femoral heads improve stability, thus reducing dislocation risk, however, produce comparable PROMs function (Darden et al., 2025). Head size was not addressed as part of this review. Of the articles reviewed, one study stratified for head size, indicating a decrease in PROMs long-term in smaller head sizes in univariate analyses, but not when considering other factors (Hesseling et al., 2019).

Bias assessments identified moderate-to-high and high risk of bias across studies, with concerns related to confounding, prognostic factor measurement, randomisation and missing outcome data. Additionally, publication bias is suspected due to the low number of eligible studies. Taken together, the evidence comparing hybrid and cemented THA is limited by study quality, short follow-up in PROM studies, and inconsistent methodology in survival studies. While both fixation types appear to offer good early PROMs and comparable implant longevity, further research is required, particularly longer-term PROMs studies and implant survival at the prosthesis level (Boyle et al., 2023) rather than broad fixation categories. Standardised methods, adjusted analyses, and stratification by patient and implant characteristics are essential for informed decision making.

2.5. Conclusion

The review of the literature identified primary survival and PPF rates and secondary PROMs outcomes between hybrid and cemented THA for patients with end stage osteoarthritis from eight available studies. The studies do not clearly demonstrate a superior fixation category between hybrid and cemented THA. Both THA options showed improvements in early PROMs, exceeding 98% survival at 1 and 2 years and at least 90% survival at 10-years. All studies identified were European and evaluated outcomes from 1980 to 2019, suggesting that earlier studies might not relate to current surgical practices. Indeed, changes in practice over time may influence the

heterogeneity of this review. The included studies were also inconsistent in reporting similar patient demographics, particularly age, PROMs, study time periods, length of follow-up, statistical methods, and THA implant components. A further limitation of the included studies was the inconsistent reporting of femoral head size; head diameter was not universally documented, categorised, or standardised across the survival and PROM literature reviewed, precluding any systematic assessment of its contribution to the outcomes reported. European only studies are limited in their ability to reflect outcomes in non-European settings, due to regional variations in clinical practice and patient demographics. The absence of longer-term PROM data is a significant gap and likely the biproduct of short-term focus, resource, and time constraints. Future research should focus on product specific outcomes, standardized methodologies, and longer PROMs follow-up to provide clearer insights. Regional joint registry data can enhance decision making by considering demographic and socioeconomic factors for more personalised treatment procedures. This review is the first to attempt to summarise literature contrasting survival, PPF, and PROM outcomes between cemented and hybrid primary THA for osteoarthritis, identifying comparable outcomes between methods when considering the few studies available.

2.6. Limitations

This review is limited by the quality and heterogeneity of the included studies, which constrained the strength and interpretability of the findings. The potential for publication bias exists, as studies reporting null or negative outcomes may remain unpublished. Much of the available evidence is dated and may not reflect modern surgical techniques or implant designs. As with all observational evidence, residual confounding and selection bias cannot be excluded. The exclusion of non-English language studies and grey literature may have introduced additional bias. Femoral head size was included in one study only.

Chapter 3. Ten-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis

Prelude: The preceding systematic review identified a lack of comparative evidence addressing primary and secondary outcomes of cemented and hybrid THA. No high-quality evidence was found to determine whether cemented or uncemented acetabular cups with cemented stems translated into measurable differences in implant performance. All reviewed studies were performed on national registry data and heterogeneous implants in each category limiting comparability of outcomes.

Although the overarching objective of this Thesis is to compare outcomes between modern cemented and hybrid primary THA for OA, it was first necessary to establish the performance of the modern cemented comparator itself. The cemented acetabular component in routine clinical use in NZ changed in 2010, when early generation ECF use diminished in favour of the modern HXLPE Rimfit implant. While the ECF has a positive established reputation for long-term survival, the survival performance of its successor has not been independently compared within the same population and stem construct.

Given both cemented implants under investigation incorporate the same cemented Exeter V40 femoral stem, any comparison implicitly assumes stability and equivalence within each cohort. Establishing comparative survival and reasons for revision between the two cemented acetabular components was therefore a necessary methodological step to validate the cemented construct as a reliable reference before proceeding to hybrid–cemented comparisons of survival and patient-reported outcomes.

3.1. Introduction

In 1962 Sir John Charnley pioneered the first fully cemented, low friction total hip arthroplasty (THA) using a cemented stainless-steel stem, cemented polyethylene cup (PE) and polymethylmethacrylate bone cement (Satalich et al., 2022). Since then designers have introduced substantial improvements such as flanged cups to improve cement pressurisation (Boote et al., 2022) and improved cement formulations (Niculescu et al., 2015). The early generation Exeter® Contemporary Flanged Cup™ (Stryker Orthopaedics, Mahwah, NJ, USA) (ECF), developed in 1998 reports excellent survival outcomes up to 15 years (Lamberton et al., 2023; Maggs et al., 2016) with extremely low dislocation (Partridge et al., 2016) and aseptic loosening rates (Kristof et al., 2024). From 2010 the focus became the reduction of PE wear and improvement in cement mantle consistency (Bota et al., 2021). New cemented components, such as the highly cross-linked polyethylene (HXLPE) Exeter® X3® Rimfit™ (Stryker Orthopaedics, Mahwah, NJ, USA) (Rimfit) were introduced, proposed to reduce wear and lower osteolysis risk (Migliorini et al., 2023). Key improvements in the Rimfit included polymethylmethacrylate spacers; a rimcutter for mantle control; a slim curved flange to match the rim; and built in radiographic marker wire (*Exeter X3 RimFit Socket*, 2025). Many high volume hospitals and public settings gradually discontinued use of the ECF (Maggs et al., 2016) in favour of the more durable Rimfit (Migliorini et al., 2023). The recommended stem for both the ECF and Rimfit is the cemented Exeter® V40™ with excellent survival outcomes (Daoub et al., 2022; Kristof et al., 2024; Mahon et al., 2020) and a low rate of revision (Evans et al., 2023; Kristof et al., 2024). The ECF/V40 combination is the most prominent cemented THA in NZ, representing nearly 8,000 of the 93,487 THA surgeries recorded between 1999 and 2013 (McKie et al., 2024). The Rimfit/V40 combination is the second most prevalent cemented THA with over 3,000 surgeries from 2010 to 2022 (McKie et al., 2024).

There are few studies on survival outcomes of the ECF (Kristof et al., 2024; Lamberton et al., 2023; Maggs et al., 2016; Partridge et al., 2016) or the Rimfit (Boyle et al., 2023; Boyle et al., 2022; Junnila et al., 2016), and none restricted to osteoarthritis. There is no study directly comparing their survival, reasons for revision, or revision predictors of interest in osteoarthritis. In the only published comparison study (vanWinterswijk et al., 2017), both displayed “similar 5-year outcomes” in radiotranslucent lines and clinical scores, but survival was not reported. Such comparison is essential to justify the transition from the ECF to the Rimfit in clinical practice.

An ideal comparison between the ECF and the Rimfit would control for fixation, stem type or approach, handling, and instrumentation. Comparing these THA components in the same region with the same group of surgeons also eliminates variations in surgical skill, experience, and preferred technique. Therefore, this analysis focused on data from a regional registry. This study compared and reported patient characteristics, 10-year survival, reasons for revision, and effects of patient-specific predictors (age, sex, BMI, ethnicity, ASA rating, and funding source) on survival outcomes in the two cemented implants for primary THA for osteoarthritis in the Bay of Plenty region of NZ to identify implant superiority in survival and revision reasons, and meaningful predictors of poorer survival.

3.2. Methods

3.2.1. Data source and collection

Ethical approval was obtained from The University of Waikato Human Research Ethics Committee (HREC2023#12). The NZOA supplied anonymised data from the mandatory national joint registry (NZJR) for the Bay of Plenty region of NZ from 1 January 2003 up to and including 30 June 2023. All primary THAs for osteoarthritis with an Exeter V40 stem and either an Exeter Contemporary flanged Cup (Stryker Orthopaedics, Mahwah, NJ) made of ultra-high molecular weight polyethylene, or Exeter X3 Rimfit Cup (Stryker Orthopaedics, Mahwah, NJ) of highly cross-linked polyethylene, were included in analysis with follow-up to 30 June 2023 or a maximum of 10 years. This study elected to report outcomes at 10 years as this represents a clinically meaningful and widely accepted benchmark in arthroplasty research. THAs were performed in three hospitals and 93% performed by four surgeons using the same modern, third generation cementing technique. Both cemented cups are widely used, intended for the same patient populations but differ in features such as flange geometry and rim configuration. This study was conducted and reported in accordance with the STROBE guidelines (von Elm et al., 2007).

Adverse events (revision) were categorised as a “1” and included censored data up until the date of death or end of the observation period or upon 10 years of follow-up and categorised as “0”. Patient-specific predictors were treated as categorical variables, and included sex, age, BMI, ethnicity, ASA rating, and funding source. Predictors and subcategories are summarised in Table 8. Age at surgery was classified to align with the NZ, Australia, England-Wales, and Finland national joint registry categories. Only a small number of ≤55y observations (2%) in both implants were noted (ECF: n = 8; Rimfit: n =28) and were combined with the 56–64y age group creating a <65y category. BMI at surgery was classified into five categories as per the Centre for Disease Control (*Assessing your weight | Healthy weight, nutrition, and physical activity | CDC*). ASA ratings are graded into four categories. However, eight ASA 4 observations between both implants (ECF: n = 1; Rimfit, n = 7) were recoded as ASA 3 for analysis. Ethnicities are self-reported and extracted via the National Health Index (unique identifier assigned to each person in NZ).

Table 8. Classification of patient categorical variables

Sex	
Male	Assigned male at birth
Female	Assigned female at birth
Funding	
Public	Public health system funding source
Private	Insurance or self-paid funding source
Age (years)	
<65	Under but not including 65 years
65-74	Including 65 and up to and including 74 years
≥75	Including and over 75 years
BMI (kg/m ²)	
<25	Normal BMI
25-29.9	Overweight
30-34.9	Obese Class I
35-40	Obese Class II
>40	Obese Class III
ASA rating	
ASA 1	Patient is a completely healthy, fit patient.
ASA 2	Patient has mild systemic disease.
ASA 3	Patient has severe systemic disease that is not incapacitating.
ASA 4	Patient has incapacitating disease that is a constant threat to life.
Ethnicity ‡	
NZ European	New Zealanders of European descent
Māori	A person of the Māori race and includes any descendant
Other	All other ethnicities and undetermined ethnicities

Abbreviations: ASA, American Society of Anesthesiologists Physical Status classification system; BMI, body mass index; NZ, New Zealand

‡ NZ Government Stats NZ, Tatauranga Aotearoa

3.2.2. Survival

A pairwise deletion approach was implemented to handle missing data so that all available data were used in statistical analysis. Revision and death were identified through the compulsory national joint registry, which captures all primary procedures, revision operations, and mortality through national data linkage. As a result, loss to follow-up was negligible. Patients who had not experienced the event of interest (revision) were right censored at the earliest of the study end date. Standard Kaplan-Meier analysis was performed on the dataset using the R studio 2024.09.0 “Cranberry Hibiscus” statistical package (Posit, 2023). Kaplan-Meier assumptions of independent, non-informative censoring; time-to-event data; homogeneity of survival and no influential events affecting survival were met. Competing risk of death analysis was considered; however, standard Kaplan-Meier analysis was chosen as the population below 75 years where death is less likely to be a competing risk exceeded the older population group of above 75 years. *T*-tests were used to determine differences in mean age or BMI between the implant groups, and Chi square tests to compare proportions for each categorical predictor between implants.

3.2.3. Reasons for revision

Reasons for revision were categorised into dislocations, infection, periprosthetic fracture, pain, aseptic loosening of acetabulum, aseptic loosening of both components, loosening of acetabulum due to infection, fall, and broken stem. Chi square tests compared proportions of revision types between implants.

3.2.4. Regression

Uni- and multivariate Cox regressions were performed on the overall cemented sample as well as for each implant. To assess the robustness of findings, proportional hazards assumption was evaluated using Schoenfeld residuals and log-log survival plots. The results were consistent across methods, supporting the validity of the primary analysis. Across statistical analyses, the 95% confidence intervals [lower, upper] of estimates were extracted and significance set to $p < 0.05$. All analyses were conducted using R studio 2024.09.0.

3.3. Results

Patient variables and revisions per component are shown in Table 9. THA surgeries for OA from 1 January 2003 and 30 June 2023 ($n = 1630$, age: 71.7 ± 8.5 y, BMI: 28.1 ± 5.2 kg/m²) included ECF in 363 instances (22.3%, age: 71.3 ± 8.5 y, BMI: 28.2 ± 4.8 kg/m²) and Rimfit in 1267 instances (77.7%, age: 71.7 ± 8.5 y, BMI: 28.1 ± 5.3 kg/m²), with no statistically significant difference between implant groups in mean age ($p = 0.427$) or BMI ($p = 0.812$) at surgery. Chi square tests revealed no statistically significant differences in proportion of men and women ($p = 0.095$), BMI categories ($p = 0.555$), or age categories ($p = 0.596$) between implants. Statistically significant differences of proportion in ASA ratings ($p < 0.001$), ethnicities ($p < 0.001$) and funding pathways ($p = 0.004$) between implants (Table 10) were noted. The Rimfit reported a higher proportion of Māori, ASA 3 rating, and publicly funded surgeries. The vast majority of the 363 ECF cohort (98%) featured a 28 mm head size, the remainder 32 mm, with the Rimfit cohort featuring 28 mm in 38%, 32 mm in 56% and 36 mm in 6% of the cohort. Chromium cobalt head type represented 100% of ECF observations and 95% of Rimfit observations, the remaining being ceramic.

Table 9. Patient variables and revisions per component in contemporary and modern cemented primary total hip arthroplasty for osteoarthritis

		Both Implants				ECF				Rimfit			
		n	%	Revisions	Revision %	n	% of Total Implants	Revisions	Revision %	n	% of Total implants	Revisions	Revision %
Total		1630		43	2.6%	363	22.3%	14	3.9%	1267	77.7%	29	2.3%
Sex	Male	648	39.8%	19	2.9%	158	43.5%	3	0.8%	490	38.7%	16	3.3%
	Female	982	60.2%	24	2.4%	205	56.5%	11	3.0%	777	61.3%	13	1.7%
Age (years)	≤64	337	20.7%	15	4.5%	81	20.1%	4	4.9%	256	20.2%	11	4.3%
	65-74	670	41.1%	16	2.4%	150	41.3%	5	3.3%	520	41.0%	11	2.1%
	≥75	623	38.2%	12	1.9%	132	36.4%	5	3.8%	491	38.8%	7	1.4%
BMI (kg/m²)	<25	367	25.4%	7	1.9%	61	23.8%	3	4.9%	306	19.7%	4	1.3%
	25-29.9	618	42.7%	15	2.4%	120	46.9%	2	1.7%	498	32.1%	13	2.6%
	30-34.9	322	22.3%	10	3.1%	53	20.7%	3	5.7%	269	17.3%	7	2.6%
	35-39.9	94	6.5%	4	4.3%	13	5.1%	0	0.0%	81	5.2%	4	4.9%
	≥40	45	3.1%	1	2.2%	9	3.5%	0	0.0%	36	2.3%	1	2.8%
	Missing†	184	NA	6	3.3%	107	NA	6	5.6%	77	NA	0	0.0%
ASA	1	216	14.0%	4	1.9%	59	20.7%	1	1.7%	157	12.4%	3	1.9%
	2	946	61.1%	25	2.6%	175	61.4%	6	3.4%	771	61.0%	19	2.5%
	3 & 4	386	24.9%	10	2.6%	51	17.9%	3	5.9%	335	26.5%	7	2.1%
	Missing†	82	NA	4	4.9%	78	NA	4	5.1%	4	NA	0	0.0%
Funding	Public	566	40.5%	16	2.8%	118	33.8%	7	5.9%	448	42.7%	9	2.0%
	Private	833	59.5%	24	2.9%	231	66.2%	7	3.0%	602	57.3%	17	2.8%
	Missing†	231	NA	3	1.3%	14	NA	0	0.0%	217	NA	3	1.4%
Ethnicity	NZEU	1455	89.3%	39	2.7%	304	83.7%	12	3.9%	1151	90.8%	27	2.3%
	Māori	110	6.7%	3	2.7%	14	3.9%	1	7.1%	96	7.6%	2	2.1%
	Other	65	4.0%	1	1.5%	45	12.4%	1	2.2%	20	1.6%	0	0.0%

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup

† Missing values have not been included in proportion calculations

Table 10. Tests of factor proportion for a contemporary and modern cemented total hip arthroplasty component for osteoarthritis

Variable	Group	ECF			Rimfit			Model comparison	
		Actual	Expected	χ^2	Actual	Expected	χ^2	χ^2	p-value
Sex	Male	158	144	1.3	490	504	0.37	2.57	0.095
	Female	205	217	0.86	777	763	0.25		
Age (years)	≤64	81	75	0.47	256	262	0.14	1.03	0.596
	65-74	150	149.00	0	520	521	0		
	≥75	132	139	0.33	491	484	0.09		
BMI (kg/m ²)	<25	61	65	0.24	306	302	0.05	3.01	0.555
	25-29.9	120	109	1.02	498	509	0.22		
	30-34.9	53	57	0.28	269	265	0.06		
	35-39.9	13	17	0.8	81	77	0.17		
	≥40	9	8.00	0.13	36	37.00	0.03		
ASA	1	59	40	9.3	157	176	2.1	18.4	<0.001 *
	2	175	174	0	771	772	0		
	3 & 4	51	71.00	5.67	335	315.00	1.28		
Funding	Public	118	141	3.81	448	425	1.27	8.16	0.004 *
	Private	231	208	2.59	602	625	0.86		
Ethnicity	NZEU	304	324	1.24	1151	1131	0.35	90.2	<0.001 *
	Māori	14	25	4.5	96	85.5	1.29		
	Other	45	15	64.4	20	50.52	18.4		

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup

*Significance set at $p < 0.05$

Missing values have not been included in overall proportion calculations

3.3.1. Survival

A total number of 1630 implants for the observation period were included in analysis, 495 in situ for 10 years (ECF: $n = 245$; Rimfit: $n = 250$, Table 11) with a median follow-up of seven years. Kaplan-Meier analysis revealed a combined 10-year survival rate of 96.5% [95.5, 97.6] with log-rank revealing no statistical difference in

survival between the implants (ECF: 95.6% [93.4, 97.9]; Rimfit: 97% [95.9, 98.2], $p = 0.334$) (Figure). No statistically significant difference in survival between patient predictors was noted (Table 11).

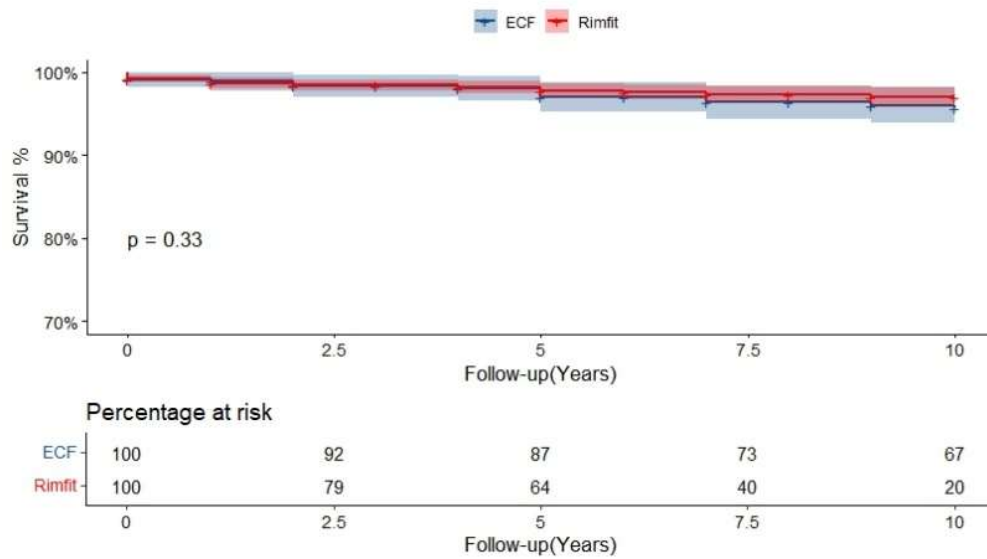


Figure 8. Kaplan-Meier survival curve for a contemporary and modern cemented implant in primary total hip arthroplasty for osteoarthritis up to 10 years

Table 11. Contemporary and modern cemented implant survival in primary total hip arthroplasty for osteoarthritis at 10 years

Factor		Both Implants				ECF				Rimfit			
		At risk (n)	Events (n)	Survival % [95%CI]	log-rank <i>p</i> -value †	At risk (n)	Events (n)	Survival % [95%CI]	log-rank <i>p</i> -value †	At risk (n)	Events (n)	Survival % [95%CI]	log-rank <i>p</i> -value †
Component		495	43	96.5 [95.5, 97.6]	—	245	14	95.6 [93.4, 97.9] §	—	250	29	97.0 [95.9, 98.2] §	0.334 §
Sex	Male	215	19	96.4 [94.8, 98.1]	0.628	105	3	98.0 [95.7, 100]	0.113	110	16	95.8 [93.6, 98.0]	0.089
	Female	280	24	96.6 [95.1, 98.0]		140	11	94.0 [90.5, 97.5]		140	13	97.9 [96.8, 99.1]	
Age (years)	<65	154	15	94.5 [91.7, 97.3]	0.172	71	4	94.8 [90.0, 99.9]	0.854	83	11	94.7 [91.6, 97.9]	0.103
	65-74	229	16	97.1 [95.7, 98.5]		120	5	96.3 [93.2, 99.5]		109	11	97.5 [96.0, 99.0]	
	≥75	112	12	97.7 [96.3, 99.0]		54	5	95.9 [92.4, 99.2]		58	7	98.3 [96.9, 99.6]	
Ethnicity	NZEU	417	39	96.5 [95.4, 97.7]	0.748	201	12	95.6 [93.2, 98.1]	0.696	216	27	96.9 [95.7, 98.1]	0.744
	Māori	34	3	95.2 [89.3, 100]		11	1	90.9 [75.4, 100]		23	2	97.8 [94.8, 100]	
	Other	44	1	98.3 [95.1, 100]		33	1	97.7 [93.4, 100]		11	0	100 [100, 100]	
BMI (kg/m²)	<25	83	7	97.2 [95.2, 99.4]	0.784	37	3	94.7 [89.1, 100]	0.487	46	4	97.7 [95.5, 100]	0.527
	25-29.9	175	15	97.0 [95.4, 98.6]		79	2	98.2 [95.7, 100]		96	13	96.6 [94.6, 98.6]	
	30-34.9	82	10	95.5 [92.6, 98.5]		35	3	93.3 [86.3, 100]		47	7	96.5 [93.9, 99.2]	
	35-39.9	30	4	95.7 [91.6, 99.9]		10	0	100 [100,100]		20	4	95.0 [90.3, 99.9]	
	≥40	20	1	97.8 [93.6, 100]		9	0	100 [100,100]		11	1	97.2 [92.0, 100]	
	missing	184	6			107	6			77	0		
ASA	1	85	4	97.3 [94.7, 100]	0.705	49	1	98.2 [94.6, 100]	0.336	36	3	96.5 [92.2, 100]	0.892
	2	267	25	96.8 [95.5, 98.0]		114	6	96.2 [93.3, 99.3]		153	19	96.9 [95.5, 98.3]	
	3 & 4	83	10	95.7 [92.6, 99.0]		22	3	89.8 [79.1, 100]		61	7	97.7 [96.1, 99.4]	
	missing	82	4			78	4			4	0		
Funding	Public	160	16	96.4 [76.3, 94.9]	0.917	65	7	92.6 [87.4, 98.1]	0.128	95	9	97.8 [96.3, 99.3]	0.314
	Private	292	24	96.4 [98.5, 94.4]		170	7	96.7 [94.4, 99.2]		122	17	96.1 [94.2, 98.1]]	
	missing	231	3			14	0			217	3		

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; CI, confidence interval; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup

* *p*-value set at < 0.05; † log rank *p*-value for main effect of a given predictor; § log rank *p*-value for survival rates of ECF and Rimfit

3.3.2. Reasons for revision

Forty-three revisions (2.6%) performed over the period (ECF n = 14, Rimfit n = 29). Most revisions were due to dislocation (30%) followed by infection (23%). No statistically significant difference in proportion of dislocation ($p = 0.08$) or any other revision reason was noted (Table 12). Of the 43 revisions, 24 (56%) occurred in females and 19 (44%) in males reflecting the overall cohort distribution. By funding status, 24 (56%) were privately funded, 16 (37%) publicly funded, and 3 (7%) had missing data. Regarding ethnicity, 29 (67%) were NZ European, 3 (7%) Māori and 1 (2%) Other, with the remaining missing or uncategorised. These distributions provide context for subsequent revision patterns. Notably, 15 (35%) revisions occurred in patients under 65 years, 16 (37%) in those 65-74 years and 12 (28%) in patients ≥ 75 years. Compared with the overall cohort, patients under 65 were overrepresented (20.7% of the total sample), whereas those ≥ 75 were underrepresented (38.2% of the total sample). However, these differences were not statistically significant in either univariate or multivariate Cox regression. BMI data were missing for 13 revision cases, limiting interpretation across categories.

Table 12. Reasons for revision of a contemporary and modern cemented total hip arthroplasty for osteoarthritis

	Both Implant revisions		ECF revisions		Rimfit revisions		χ^2
	(n = 43)	% total	(n = 14)	% total	(n = 29)	% total	p-value *
Dislocations	13	0.80%	6	1.65%	7	0.55%	0.08
Infection	10	0.61%	2	0.55%	8	0.63%	1
Periprosthetic fracture	8	0.49%	2	0.55%	6	0.47%	1
Pain	5	0.31%	2	0.55%	3	0.24%	0.68
Aseptic loosening (Acetabulum)	3	0.18%	1	0.28%	2	0.16%	1
Aseptic loosening (Femur & Acetabulum)	1	0.06%	1	0.28%	-	-	-
Loosening acetabulum (infection)	1	0.06%	-	-	1	0.08%	-
Fall	1	0.06%	-	-	1	0.08%	-
Broken stem	1	0.06%	-	-	1	0.08%	-

**Chi square* tests of proportion with significance set at $p < 0.05$

3.3.3. Regression

Multivariate Cox regression for both implants found no statistically significant effect of any predictor on 10-year survival (Table 13). Certain subgroups (BMI 35-39.9 and ≥ 40 , NZ Māori) had small sample sizes, which should be considered when interpreting these findings.

Table 13. Cox multiple regression for a contemporary and modern cemented primary total hip arthroplasty implant for osteoarthritis

	Both Implants				ECF				Rimfit					
Covariate	Coeff (OR)	HR	95% [CI] ‡	p-value	Coeff (OR)	HR	95%CI ‡	p-value	Coeff (OR)	HR	95%CI ‡	p-value		
ASA 2	0.48	1.62	[0.54, 4.87]	0.388	0.83	2.30	[0.25, 20.90]	0.461	0.37	1.45	[0.41, 5.16]	0.562		
ASA 3	0.59	1.8	[0.49, 6.64]	0.376	1.30	3.60	[0.31, 44.06]	0.303	0.38	1.46	[0.31, 6.72]	0.624		
Age ≥75	-0.83	0.43	[0.17, 1.10]	0.079	-0.64	0.53	[0.10, 2.88]	0.460	-0.83	0.44	[0.14, 1.31]	0.139		
Age 65-74	-0.81	0.44	[0.19, 1.00]	0.505	-0.12	0.31	[0.05, 1.97]	0.213	-0.69	0.5	[0.20, 1.25]	0.141		
BMI≥40	-0.17	<0.001	[0.00, inf]	0.997	-0.2	<0.001	[0.00, inf]	0.999	-0.17	<0.001	[0.00, inf]	0.997		
BMI 25.29.9	0.07	1.07	[0.43, 2.72]	0.877	-1.03	0.36	[0.06, 2.27]	0.276	0.44	1.56	[0.49, 4.93]	0.451		
BMI 30-34.9	0.20	1.22	[0.44, 3.42]	0.703	0.01	1.01	[0.18, 5.57]	0.987	0.30	1.35	[0.37, 5.03]	0.652		
BMI 35-39.9	0.38	1.46	[0.39, 5.49]	0.567	-19.7	<0.001	[0.00, inf]	0.999	1.01	2.73	[0.61, 12.31]	0.191		
Sex Female	-0.22	0.79	[0.39,1.59]	0.527	0.72	2.04	[0.38, 11.00]	0.404	-0.49	0.62	[0.28, 1.36]	0.228		
Ethnicity Māori	-0.46	0.63	[0.14, 2.80]	0.544	-18.3	<0.001	[0.00, inf]	0.999	-0.29	0.74	[0.16, 3.46]	0.706		
Ethnicity Other	-17.00	<0.001	[0.00, inf]	0.997	-18.1	<0.001	[0.00, inf]	0.999	-17.34	<0.001	[0.00, inf]	0.998		
Funding Public	-0.09	0.92	[0.44, 1.93]	0.821	0.39	1.48	[0.32, 6.77]	0.613	-0.27	0.77	[0.32, 1.84]	0.550		
Implant ECF	-2.14	8.08	[0.36,1.08]	0.602										
†Log-rank test of model for both implants				p = 0.645	† Log-rank test of model for ECF				p = 0.658	† Log-rank test of model for Rimfit				p = 0.584

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; CI, confidence interval; Coeff, coefficient; ECF, Exeter Contemporary Flanged cup; HR, hazard ratio; OR, odds ratio; Rimfit, Exeter X3 Rimfit cup

* p-value significance set at <0.05; † log-rank reference predictors are ASA1; Age <65; BMI <25; Implant Exeter Contemporary flanged cup; Sex Male; Ethnicity NZ European; and Funding Private; ‡ Represents 95% confidence intervals of the hazard ratio

3.4. Discussion

3.4.1. Survival

Combined survival rates exceed 95% at 10 years, suggesting durable outcomes with both implants using the V40 stem. This benchmark outcome is consistent with the 10-year performance of broad cemented implants in NZ (McKie et al., 2024) and internationally (Bissias et al., 2021; Clar et al., 2024; Kunutsor, Barrett, et al., 2019; Kunutsor, Beswick, et al., 2019; Mäkelä et al., 2014). For example, the 10-year 97% Rimfit survival rate aligns with the UK national joint registry and the Australian Orthopaedic association broad cemented category (97.2% and 96.6%, respectively) (Clar et al., 2024), substantiating it as a suitable replacement for the ECF. The Rimfit was introduced almost decade after the ECF, yet equivalent survival rates suggest implant design/material changes did not translate into measurable differences in long-term fixation. Both designs provide robust outcomes across different eras of surgical practice and support the generalisability of these findings.

3.4.2. Reasons for revision

Both implants demonstrated no statistically significant difference in survival up to 10 years and low rates of dislocation, infection, and aseptic loosening. This finding suggests that implant design differences did not substantially influence the underlying mechanisms of failure. From a clinical perspective, this lack of difference indicates both designs are comparable in terms of stability, infection risk, and fixation durability, with other surgical and/or patient factors potentially influencing revision risk. Comparing revision cases with overall cohort distribution revealed that patients under 65 years were overrepresented and those over 75 years were underrepresented. This pattern suggests younger, more active patients may face a relatively higher risk of revision, consistent with registry evidence linking activity levels and implant demand to early failure (Bayliss et al., 2017). BMI comparisons were less reliable due to missing data in 13 revision cases, limiting firm conclusions.

3.4.3. Regression

Sex, age, BMI, ethnicity, ASA rating, and funding did not significantly influence the 10-year survival of implants individually or when combined. It is worthwhile noting that no variables significantly impacted on the time until the event of interest in either the overall cemented sample or when stratified by implant design. The variables considered did not have a meaningful association with revision in this population, indicating possible weak or non-existent relationship. A low number of Māori and Other ethnicity patients, patients with BMI categories of 35 to 39.9 kg/m² and >40 kg/m², and those <55 years reduced precision of survival and Cox regression analysis. Hence, the lack of significance should be interpreted with caution. The extended analysis provide insight in a NZ context, indicating that the two implants perform well across a broad range of patients, regardless of sex, age, ethnicity, BMI, ASA rating, or funding source. Future research could explore additional patient variables not included in this model, such as pre- and post-surgical activity and smoking status.

3.4.4. Decline in cemented total hip arthroplasty

Despite their proven durability, however, there has been a noticeable decline in the use of fully cemented THAs, particularly in NZ, Australia, the UK, and the USA (Paxton et al., 2019; Zhang, 2017). One key reason is the rise of cementless and hybrid implants, perceived to offer easier revisions and better long-term bone integration (Matthias et al., 2021) particularly in younger patients (Boyle et al., 2022). The move from cemented to cementless fixation was driven by the promise of biological ingrowth, anticipated simpler revision, and influence from training and industry (Diaz Dileria et al., 2025; Karuppal, 2016; Ryan et al., 2022). But registry evidence shows cementless fixation is not universally superior particularly in elderly women (Humez et al., 2024), and many systems are rebalancing toward a selective, patient-specific fixation choice (Khanuja et al., 2022). The extremely low periprosthetic fracture rate of both the ECF and Rimfit cohorts indicate the cemented V40 stem offers reduced fracture risk, which is especially important in osteoporotic and fragile bone by offering immediate fixation and uniform load transfer, reducing micromotion and early loosening (Gjertsen et al., 2024) particularly those over the age of 65 (Kelly et al., 2023). A growing body of evidence suggests that hybrid implants with cemented stems and cementless acetabular components might offer advantages over fully cemented or cementless options due to the combined benefits of stem stability and acetabular osseointegration (Boyle et al., 2023; Boyle et al., 2022; Erivan et al., 2019; Evans et al., 2023; Fowler et al., 2019; Karuppal, 2016). Pearce, Butcher, et al. (2025) noted there exists limited definitive evidence of specific hybrid implant superiority for osteoarthritis.

3.4.5. Patient-reported outcomes

Other than survival, PROMs are an important consideration in determining THA success. Extended THA survival, yet poor quality of life, pain, and impaired function, indicates a poor outcome regardless of implant longevity (Golinelli et al., 2022). Comparative PROMs studies for broad category cemented implants versus other categories show inconsistent outcomes (Abdulkarim et al., 2013; Jameson, Mason, Baker, Gregg, Deehan, et al., 2015; Nilsson & Lohmander, 2003; Onsten et al., 1994) with studies investigating heterogeneous populations and a selection of different PROMs tools (Pearce, Butcher, et al., 2025). Pearce, Joshi, et al. (2025b) identified excellent long-term PROMs up to 10 years for this ECF cohort in a recent study with a mean Oxford Hip score >41 and very good mean score >39 up to 15 years, with no significant difference in scores at 1, 5, 10 and 15 years. A similar study of Rimfit PROMs and comparison to the ECF would offer a strong comparison of these cemented implants. Future THA research should incorporate PROMs to better capture functional recovery and quality of life crucial for a comprehensive evaluation of implant success (Okafor & Chen, 2019). Specific instruments such as the Oxford Hip Score, Western Ontario and McMaster Universities Osteoarthritis index and a health-related quality of life tool, with domains including pain, function and overall patient satisfaction could be used to complement registry-based data alongside comparison of homogenous patient populations.

Considering the predominant use of hybrid fixation (51%) over cemented (4%) (McKie et al., 2024) in NZ, a comparative survival and Cox regression analysis of high-use hybrid implants; with consistent V40 stem use and

highly cross-linked PE liners; with the cemented Rimfit in this population, over the same observation period is recommended, and a closer inspection and comparison of 10-year PROMs. Such a study may identify patient subgroups more susceptible to poor THA survival but also poorer PROMs outcomes.

3.5. Conclusion

The 10-year survival of both the ECF and Rimfit in this region of NZ is positive. The favourable survival rate of the Rimfit supports its continued use and justifies it as a replacement of the ECF in this region, with 10-year survival outcomes not affected by age, sex, BMI, ethnicity, ASA rating, or funding source. Future studies should include PROMs comparison between the Rimfit and ECF to identify whether Rimfit PROMs are at a minimum consistent with the ECF. With the increased use of hybrid THA in NZ, a survival and PROMs comparison of the Rimfit with a commonly used hybrid implant; with the same V40 stem; analysing the same patient predictors, is also recommended.

3.6. Limitations

This study is observational thus causal influences cannot be made. While overall survival success is an important outcome, it is acknowledged that it is not the sole indicator of a successful THA. Also, it is acknowledged that patient characteristics are not the only predictors of outcomes. Potential confounders such as differences in surgical approach, cement brands and intraoperative technique may influence outcomes but could not be fully accounted for in this study. However, as 93% of surgeries were performed by the same surgeons the possibility of confounding is less likely. The relatively small sample sizes representing Māori and Other ethnicities, patients under 55 years, and individuals with greater BMI may lead to less reliable analyses and increases risk of error. Lack of statistical significance therefor warrants cautious interpretation. This uncertainty may not accurately reflect the true population values. In the comparison of ECF and Rimfit cemented constructs, head size was not included as a covariate given the near universal use of 28 mm heads in the former and the distribution of 28 and 32 mm heads in the latter. The effect of head size cannot be entirely excluded, though it is unlikely to alter the findings of the comparison in survival between ECF and Rimfit. Following survivorship beyond 10 years may reveal differential rates between implant types.

Chapter 4. Fifteen-year patient-reported outcomes of a cemented flanged cup and stem combination in primary total hip arthroplasty: A New Zealand study

Prelude: The preceding chapter demonstrated no statistically significant differences in survival or reasons for revision between the two cemented acetabular cups used with the Exeter V40 stem despite a 10-year difference in observation periods. Before cemented THA could be meaningfully compared with hybrid THA, it was necessary to determine long-term PROMs for the well-established cemented ECF implant to establish essential reference points against which the performance of modern designs can be compared. Accordingly, this study was undertaken to characterise long-term PROMs for this earlier generation cemented implant combination within a defined regional population. In addition, examining patient characteristics, as well as funding resource type, allowed identification of subgroups at risk of poorer PROMs, ensuring that later implant-level comparisons are interpreted within a broader patient- and system-level context.

4.1. Introduction

Surgical success for joint replacement procedures has long been evaluated using implant survivorship models (Dobbs, 1980). With current healthcare shifting focus to patient wellbeing and quality of life (Yamate et al., 2023), patient-reported outcome measures (PROMs) have become an important metric in quantifying surgical success. PROMs allow surgeons to quantify patients' health-related quality of life and make decisions regarding optimal patient care, shifting the focus from surgeon-centred to patient-centred models of care.

The early generation, cemented, all-polyethylene flanged cup chosen for analysis in this study, the Exeter Contemporary Flanged cup (Stryker Orthopaedics, Mahwah, NJ), has been in use since 1991 (Stryker, 2023) and was the cemented cup most used in NZ between 2003 and 2013 (McKie et al., 2024). Schmitz et al. (2013) reported good results for this cup in THA patients under 50 years with a component survival rate of 90% after 10 years. Furthermore, Maggs et al. (2016) identified an 97.8% survivorship at 12.5 years in patients 46 years and above. In environments where THAs are completed in high volumes, the polished, stainless steel, tapered, and collarless cemented stem, the Exeter V40 stem (Stryker Orthopaedics, Mahwah, NJ) included in this study, has demonstrated excellent functional outcomes based Western Ontario and McMaster Universities Arthritis Index (WOMAC) (WOMAC, 2021) scores and 97.8% survivorship at 10 years (Mahon et al., 2020). This stem has a reported 15-year survivorship of 96.6% (CI95% 98.3, 94.8) and rare periprosthetic fracture rates of 0.6% (CI95% 0.3, 0.9) at 15 years (Mancino et al., 2023), although this may be underestimated in studies where periprosthetic fractures requiring alternative reoperations (such as open reduction and internal fixation, and where there is no stem exchange) (Baryeh et al., 2023; Chatziagorou et al., 2019; Jain et al., 2024), have not been reported. In NZ, over 54,000 of these particular stems were used between 1999 and 2022 (McKie et al., 2024) and currently represents 60% of all stems used in the UK (Mahon et al., 2020). This cemented combination maintained a top 10 position of all hip combinations implanted in NZ between 2003 and 2013.

Although studies have reported survivorship of this Exeter Contemporary Flanged cup with Exeter V40 stem (Stryker Orthopaedics, Mahwah, NJ) combination (Maggs et al., 2016), few have examined PROMs. A more thorough investigation of this cemented cup-and-stem combination specific to osteoarthritis that includes short, medium, and long-term PROMs evaluated against patient characteristics, comorbidities, and funding pathways may identify specific predictors affecting PROMs and populations susceptible to poorer outcomes.

Prospectively gathered data from a regional registry were used to examine preoperative, 1-year, 5-year, 10-year, and 15-year PROMs in primary THA for osteoarthritis with this cup-and-stem cemented combination against patient characteristics age, sex, and body mass index (BMI); comorbidities based on American Society of Anesthesiologist (ASA) rating; and funding pathways. Oxford Hip (Murray et al., 2007), WOMAC, and health related quality of life Veterans Rand 12-item (VR-12) (Iqbal et al., 2009) scores were analysed. The VR-12 has been validated by cross-system comparisons (Kazis et al., 2017).

This study aimed to report PROMs for this implant combination up to 15 years, establish a benchmark methodology for future studies of other implant combinations in this region, and determine predictors of these PROMs to guide THA management in this region of interest.

4.2. Methods

4.2.1. Data source and collection

Tauranga Orthopaedic Research (TOR) is a non-profit organisation in the Bay of Plenty region of NZ that maintains a mandatory registry of all regional joint arthroplasty surgeries. The TOR registry is independent of the NZJR and includes procedures from 2 public and 1 private hospital. Data are collected with patient consent and entered into the Standardized Orthopaedic Cartilage Repair and Treatment Evaluation Software (SOCRATES version 3.5.8.26 10150). The TOR registry collects Oxford, WOMAC, and VR-12 as their routine standard of care for THA preoperatively, at 1-year postoperatively, at 5-year postoperatively, and every 5 years thereafter. The University of Waikato's Human Research Ethics Committee granted ethical approval to analyse the database for this study (HREC2023#12). This study was conducted and reported in accordance with the STROBE guidelines (von Elm et al., 2007).

Anonymised prospective observational data from 1 January 2003 to 30 June 2023 were retrieved in July 2023. Data were eligible for analysis when patients underwent primary THA for osteoarthritis and received an Exeter Contemporary Flanged cup with Exeter V40 stem (Stryker Orthopaedics, Mahwah, NJ) combination within the set observational period. Patient data needed to contain at least 1 of the PROMs at any of the timepoints of interest to meet inclusion. A pairwise deletion approach was implemented to handle missing PROM scores at any timepoint (questionnaires not returned, incomplete questionnaires or withdrawal from the study at that timepoint) so that all available data were used in statistical analysis (Mirzaei et al., 2022) (Figure 9).

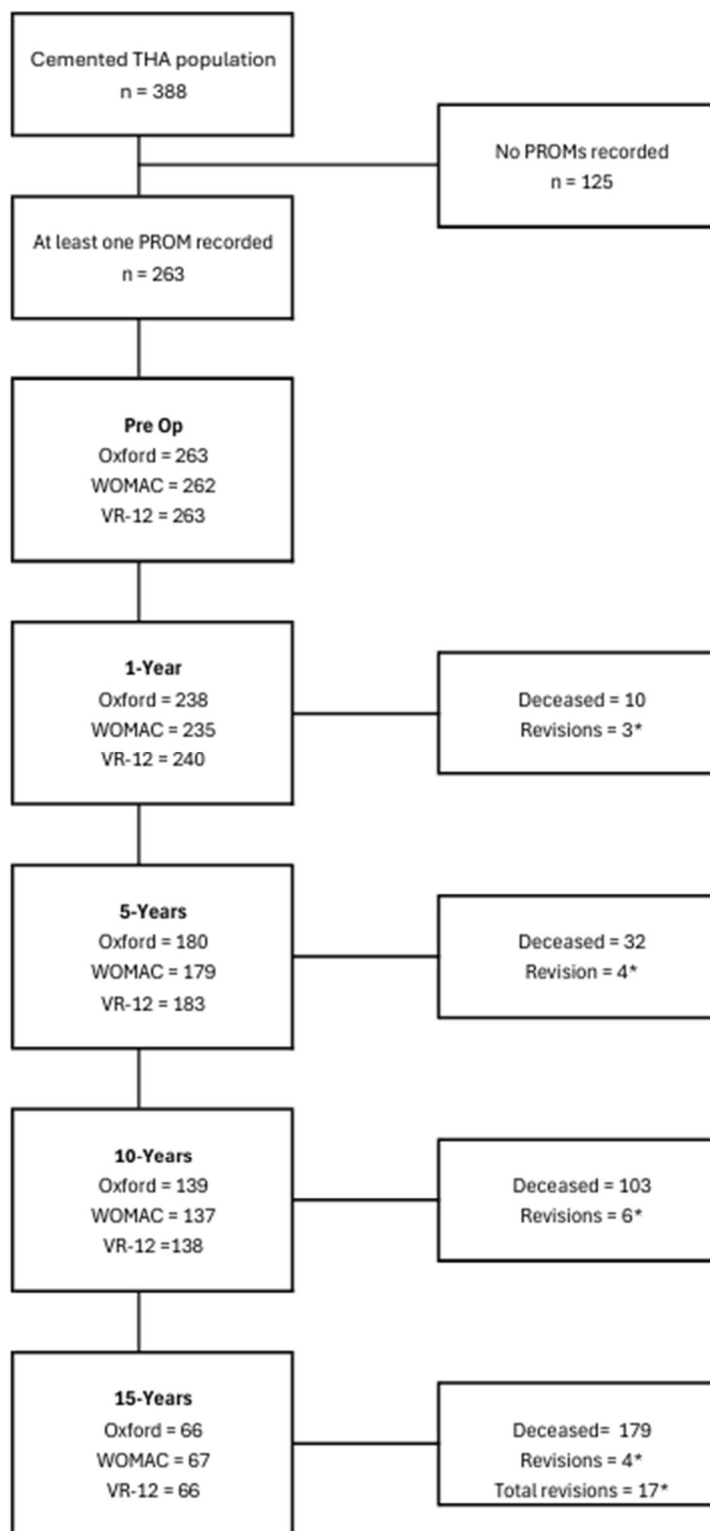


Figure 9 Flow chart depicting sample sizes, deaths and revisions of a contemporary cemented primary total hip arthroplasty for osteoarthritis at each follow-up period

*See Supplementary Table 1 for detailed reasons for revision and revisions type

4.2.2. Patient-reported outcome measures

Preoperative PROM data was considered as scores recorded at any point preoperatively; 1-year data as scores recorded from 10-14 months postoperatively; 5-year data as scores recorded from 4-6 years postoperatively; 10-year data as scores recorded from 9-11 years postoperatively; and 15-year data as scores recorded from 14-16 years postoperatively. Although 15-year data were available for some patients, not all measures of interest had observations. Consequently, comparison of PROMs up to 10 years postoperatively were included in subgroup analysis.

4.2.3. Patient characteristics

The predictors extracted from the database included patient age, sex, BMI, ethnicity, ASA rating, and funding pathway. Age and BMI were treated as continuous variables. Other predictors were treated as categorical or rank variables, and included sex (female, male), funding pathway (public, private), ethnicity (NZ European, Māori, Other), and ASA rating (a single ASA 4 observation was recoded as ASA 3 for analysis). “Other” ethnicity included “undetermined”, “undisclosed”, and any ethnicity not recorded as Māori or NZ European.

4.2.4. Statistical analysis

Data were inspected and normality of distribution verified. Descriptive statistics were computed for all variables, including counts, means, standard deviations (SD), and ranges (minimum, maximum). Continuous numeric dependent variables were compared using two-sample t-tests when normally distributed. Normal sampling mean distribution was assumed in samples ≥ 30 according to central limit theorem given parametric tests produce more accurate and precise estimates with higher statistical powers.(Kwak & Kim, 2017) Where variances were unequal, Welch two-sample t-tests were performed. Analysis of variance (ANOVA) tests were performed to compare predictors with more than 2 categories, dependent on ANOVA assumptions being met (Mishra et al., 2019). Tukey method was used in post-hoc testing.

Multiple linear regression analyses were performed on preoperative and postoperative PROMs to determine if any of the predictors correlated to any of the PROMs. The Bayesian Information Criterion was used to determine best model fit.(Schwarz, 1978) Estimates and coefficients of determination (R^2) were extracted from the regressions to quantify the association between predictors and outcomes, as were standard errors to quantify uncertainty of estimates. Possible predictors of preoperative scores included age, ethnicity, sex, funding pathway, BMI, and ASA rating. Postoperative predictors included the same factors, but also preoperative scores as these have been identified as possible predictors of postoperative scores (Golinelli et al., 2022). Collinearity was investigated with variance inflation factor and condition index. Significance levels were set to $p < 0.05$ and confidence intervals to 95% [lower, upper]. All statistical tests were performed using RStudio® 2023.09.1 build 494 “Desert Sunflower” statistical software(Posit, 2023).

4.3. Results

A total of 388 THAs met inclusion for the defined period. Observations that did not have at least 1 PROM recorded were excluded leaving 263 THAs for analysis (Table 14), with follow-up rates of 91%, 68%, 53%, and 26% at 1, 5, 10, and 15 years, respectively. Of the 263 observations with at least 1 PROM recorded, females accounted for 54.3% (n = 143), ASA 2 rated patients for 62% (n = 164) and NZ Europeans for 92.1% (n = 242). The mean age of patients at surgery was 71.4 years (range: 46, 92) and mean BMI 28.01 kg/m² (range: 18.2, 50.4). Five males and seven females received bilateral THAs. The standard 150mm stem length accounted for 92.3% (n = 358) of all stems implanted, with 125 mm accounting for 4.6% (n = 18) and 205 mm at 0.7% (n = 3). Stem length was not recorded in 2.4% (n = 9) of observations. No statistically significant differences in mean age, BMI or factor proportions between the total sample of 388 and the evaluated 263 observations were noted (Supplementary Table 2). Seventeen revisions during the observation period were noted. (Supplementary Table 1). All observations recorded a bearing size of 28 mm and a femoral head of chromium cobalt.

Table 14. Descriptive statistics of preoperative patient characteristics for observations with at least one patient-reported outcome measure in a contemporary cemented primary total hip arthroplasty for osteoarthritis

Variable	Sample n= 263	Sex		Funding Pathway		Ethnicity		
		Male n = 120 (45.6%)	Female n = 143 (54.4%)	Public n= 87 (33.1%)	Private n = 176 (66.9%)	NZEU n = 242 (92.1%)	Māori n = 9 (3.4%)	Other n = 12 (4.5%)
Age †	71.38 ± 8.67	70.84 ± 8.35	71.83 ± 8.94	71.75 ± 8.78	71.20 ± 8.64	71.90 ± 8.40	66.00 ± 8.47	64.83 ± 10.87
BMI †	28.01 ± 4.75	28.14 ± 3.57	27.90 ± 5.58	28.68 ± 4.24	27.75 ± 4.92	27.95 ± 4.84	30.95 ± 2.54	27.62 ± 3.77
ASA Grade ‡								
1	49 (19%)	22 (18%)	27 (19%)	13 (15%)	36 (20.5%)	46 (19%)	2 (2.2%)	1 (8.3%)
2	164 (62%)	72 (60%)	93 (65%)	46 (52.5%)	118 (67%)	151 (62%)	3 (3.3%)	10 (83.4%)
3	46 (18%)	26 (22%)	20 (14%)	24 (28%)	22 (12.5%)	41 (17%)	4 (4.5%)	1 (8.3%)
4	-	-	-	-	-	-	-	-
Not recorded	4 (2%)	1 (0%)	3 (2%)	4 (3.5%)	-	4 (2%)	-	-

† Continuous variable values are given as the mean and the standard deviations.

‡ Values are given as the number of patients, with percentage (number of patients divided by the total) in parentheses. Due to missing values, some categories do not equal the total number of patients for each column.

Abbreviations: ASA, American Society of Anesthesiologists Physical Status classification; BMI, body mass index; NZEU, New Zealand European.

4.3.1. Patient-reported outcome measures

Descriptive statistics of PROMs, including the subscales of both WOMAC and VR-12, are reported in Table 15 for preoperative, 1-, 5-, 10-, and 15-year timepoints. One-way ANOVA revealed statistically significant differences in mean Oxford, WOMAC, and VR-12 scores between at least 2 timepoints. Post-hoc testing revealed preoperative PROMs were statistically significantly different to their respective 1-, 5-, 10- and 15-year postoperative PROMs. There were no significant differences in postoperative PROMs between their respective 1-, 5-, 10-, and 15-year timepoints. Mean postoperative VR-12-physical scores for the sample were worse with scores less than the standardised T-score metric mean of 50 ± 10 SD) across timepoints. In contrast, mean postoperative VR-12-mental scores were better, with scores greater than the standardised score of 50.

All mean preoperative PROMs were statistically significantly poorer in females than males ($p \leq 0.041$, Table 16). Postoperatively, WOMAC-total and function scores for females were also statistically significantly poorer 1-year and 5-years postoperatively, as were WOMAC-motion and VR-12-physical scores 1-year postoperatively. Males and females showed no statistically significant difference in postoperative Oxford, WOMAC-pain, or VR-12-mental scores at 1-, 5-, and 10-years postoperatively. Publicly funded patients had statistically significantly poorer preoperative PROMs and poorer postoperative PROMs than privately funded patients across most outcomes. Mean WOMAC-pain at 10 years, VR-12-mental at 1-year, and WOMAC-motion at 1-, 5-, and 10-years postoperatively were still poorer in publicly funded patients, although not reaching statistical significance ($p \geq 0.053$, Table 17).

One-way ANOVA revealed no statistically significant differences in any preoperative PROMs, postoperative WOMAC-pain, or postoperative VR-12-mental scores at any timepoint between ASA ratings. However, postoperative Oxford, WOMAC-function, WOMAC-motion, and VR-12-physical scores were typically poorer with higher ASA ratings at various timepoints. There were no statistically significant differences in any outcomes between ethnicities.

Table 15. Descriptive statistics of patient-reported outcomes in a contemporary cemented primary total hip arthroplasty for osteoarthritis

PROM	Sample (n)	Mean ± SD	Range (min, max)	ANOVA (<i>p</i> -value)	diff [95% CI]	Post hoc (<i>p</i> -value) ¶
Oxford (0-48) †						
Preop	263	17.75 ± 8.73	2, 47	<0.001*		
1-year	238	41.30 ± 7.06	8, 48		-23.38 [-25.35, -21.42]	<0.001*
5-year	180	41.62 ± 7.48	12, 48		-0.49 [-2.66, 1.68]	0.970
10-year	139	41.30 ± 8.46	9, 48		-0.13 [-2.64, 2.39]	0.990
15-year	66	39.44 ± 9.58	13, 48		-2.05 [-5.36, 1.26]	0.440
WOMAC total (0-96) ‡						
Preop	262	54.82 ± 19.27	0, 96	<0.001*		
1-year	235	12.36 ± 12.68	0, 67		42.46 [38.41, 46.52]	<0.001*
5-year	179	13.18 ± 14.47	0, 68		0.82 [-3.66, 5.30]	0.987
10-year	137	14.66 ± 16.32	0, 78		1.47 [-3.65, 6.60]	0.935
15-year	67	18.91 ± 21.01	0, 89		-4.25 [-10.98, 2.48]	0.417
WOMAC pain (0-20) ‡						
Preop	262	11.02 ± 4.01	0, 20	<0.001*		
1-year	235	1.69 ± 2.49	0, 14		9.33 [8.49, 10.16]	<0.001*
5-year	180	1.87 ± 3.04	0, 15		0.17 [-0.76, 1.09]	0.990
10-year	139	2.45 ± 3.58	0, 14		0.59 [-0.47, 1.64]	0.550
15-year	67	3.15 ± 4.24	0, 18		-0.70 [-2.09, 0.69]	0.650
WOMAC function (0-68) ‡						
Preop	262	39.05 ± 14.35	29, 68	<0.001*		
1-year	235	9.30 ± 9.68	0, 48		29.74 [26.71, 32.78]	<0.001*
5-year	180	10.00 ± 11.20	0, 53		0.70 [-2.64, 4.05]	0.980
10-year	138	10.88 ± 12.07	0, 58		0.87 [-2.95, 4.69]	0.970
15-year	67	13.87 ± 15.39	0, 63		-2.99 [-8.02, 2.04]	0.480
WOMAC motion (0-8) ‡						
Preop	262	4.76 ± 1.71	0, 8	<0.001*		
1-year	235	1.36 ± 1.43	0, 6		3.39 [3.01, 3.78]	<0.001*
5-year	179	1.25 ± 1.39	0, 6		-0.12 [-0.54, 0.31]	0.950
10-year	137	1.35 ± 1.56	0, 6		0.11 [-0.38, 0.59]	0.980
15-year	67	1.90 ± 1.96	0, 8		-0.55 [-1.19, 0.09]	0.140
VR-12 physical ($\bar{x}$ = 50) §						
Preop	263	26.52 ± 8.22	8.5, 54.6	<0.001*		
1-year	240	43.36 ± 10.98	8.1, 62.6		-16.85 [-19.34, -14.35]	<0.001*
5-year	183	43.55 ± 11.76	7.6, 60.3		0.18 [-2.56, 2.93]	0.990
10-year	138	43.51 ± 10.49	9.9, 60.7		0.03 [-3.19, 3.12]	0.990
15-year	66	41.59 ± 9.46	17.8, 56.4		1.92 [-2.26, 6.11]	0.720
VR-12 mental ($\bar{x}$ = 50) §						
Preop	263	43.82 ± 12.85	15.6, 68.2	<0.001*		
1-year	240	51.91 ± 9.41	14.6, 67.4		-8.09 [-10.61, -5.57]	<0.001*
5-year	183	51.78 ± 8.31	15.7, 64.7		-0.13 [-2.90, 2.64]	0.990
10-year	138	53.87 ± 9.26	26.4, 70.0		2.09 [-1.09, 5.28]	0.376
15-year	66	54.86 ± 9.31	18.8, 71.0		0.98 [-5.21, 3.24]	0.970

* Significance is set at $p < 0.05$

† Oxford hip score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

‡ WOMAC minimum scores are 0 with 0 being the better score.

§ VR-12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

¶ Post hoc *p*-value represents the pairwise comparison of the previous timepoint to the current timepoint

Abbreviations: CI, confidence interval; Diff, difference; Pre Op, preoperative; PROMs, patient-reported outcome measures; SD, standard deviation; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey

Table 16. Male versus female patient-reported outcomes in a contemporary cemented primary total hip arthroplasty for osteoarthritis

PROM	Male		Female		diff [95% CI]	p-value
	n	Mean ± SD	n	Mean ± SD		
Oxford (0-48) †						
Preop	120	19.17 ± 8.70	143	16.55 ± 8.62	-2.62 [-4.73, -0.50]	0.015*
1-year	114	41.97 ± 6.31	134	40.47 ± 7.56	-1.50 [-3.31, 0.31]	0.104
5-year	83	42.77 ± 6.63	97	40.63 ± 8.02	-2.14 [-4.33, 0.05]	0.055
10-year	72	42.26 ± 7.43	71	40.82 ± 8.72	-1.44 [-4.24, 1.36]	0.311
WOMAC total (0-96) ‡						
Preop	120	51.77± 19.20	142	57.40 ± 19.02	5.63 [0.96, 10.29]	0.018*
1-year	103	10.51 ± 11.81	132	13.81 ± 13.18	3.30 [0.04, 6.57]	0.047*
5-year	82	10.66 ± 13.01	97	15.32 ± 15.81	4.66 [0.34, 8.98]	0.034*
10-year	63	13.63 ± 15.21	74	15.53 ± 17.27	1.72 [-3.65, 7.44]	0.501
WOMAC pain (0-20) ‡						
Preop	120	10.38 ± 3.77	142	11.56 ± 4.13	1.18 [0.21, 2.15]	0.017*
1-year	103	1.46 ± 2.29	132	1.88 ± 2.62	0.42 [-0.23, 1.06]	0.207
5-year	82	1.52 ± 2.69	98	2.15 ± 3.30	0.63 [-0.27, 1.53]	0.168
10-year	63	2.29 ± 3.37	76	2.59 ± 3.75	0.3 [-0.90, 1.51]	0.617
WOMAC function (0-68) ‡						
Preop	120	36.92 ± 14.29	142	40.85 ± 14.21	3.93 [0.45, 7.41]	0.027*
1-year	103	7.90 ± 9.02	132	10.39 ± 10.07	2.49 [-0.00, 4.98]	0.050
5-year	82	7.99 ± 9.62	98	11.69 ± 12.17	3.70 [0.50, 6.91]	0.023*
10-year	63	10.13 ± 11.40	75	11.51 ± 12.64	1.38 [-2.71, 5.47]	0.505
WOMAC motion (0-8) ‡						
Preop	120	4.75 ± 1.80	142	4.99 ± 1.61	0.24 [0.10, 0.93]	0.015*
1-year	103	1.14 ± 1.28	132	1.54 ± 1.51	0.40 [0.03, 0.77]	0.032*
5-year	82	1.15 ± 1.37	97	1.33 ± 1.40	0.18 [-0.23, 0.60]	0.380
10-year	63	1.22 ± 1.46	74	1.46 ± 1.63	0.24 [-0.29, 0.77]	0.376
VR-12 physical ($\bar{x}$ = 50) §						
Preop	120	28.13 ± 8.56	143	25.16 ± 7.70	-2.97 [-4.94, -0.99]	0.003*
1-year	104	45.98 ± 9.75	136	41.36 ± 11.47	-4.62 [-7.39, -1.87]	0.001*
5-year	82	44.97 ± 11.61	101	42.39 ± 11.83	-2.58 [-6.02, 0.86]	0.141
10-year	62	43.64 ± 9.93	76	43.41 ± 10.99	-0.23 [-3.79, 3.34]	0.901
VR-12 mental ($\bar{x}$ = 50) §						
Preop	120	45.59 ± 12.68	143	42.34 ± 12.86	-3.25 [-6.36, -0.13]	0.041*
1-year	104	52.85 ± 7.52	136	51.20 ± 10.61	-1.65 [-3.96, 0.66]	0.160
5-year	88	53.02 ± 7.67	101	50.78 ± 8.70	-2.24 [-4.66, 0.19]	0.070
10-year	61	52.67 ± 8.94	76	54.85 ± 9.46	2.18 [-0.95, 5.30]	0.170

Significance is set at $p < 0.05$.

† Oxford hip score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

‡ WOMAC minimum scores are 0 with 0 being the better score.

§ VR- 12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

Abbreviations: CI, confidence interval; Diff, difference; Pre Op, preoperative; PROMs, patient-reported outcome measures; SD, standard deviation; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey

Table 17. Public versus private patient-reported outcomes in a contemporary cemented primary total hip arthroplasty for osteoarthritis

PROM	Public		Private		diff [95% CI]	p-value
	n	Mean ± SD	n	Mean ± SD		
Oxford (0-48) †						
Preop	87	10.89 ± 5.66	176	21.14 ± 7.97	10.25 [8.57, 11.93]	<0.001*
1-year	73	38.60 ± 8.46	165	42.44 ± 6.05	3.84 [1.47, 5.81]	0.001*
5-year	58	39.43 ± 9.11	122	42.66 ± 6.32	3.23 [0.586, 5.86]	0.017*
10-year	32	37.53 ± 9.56	101	42.74 ± 7.25	5.21 [1.502, 8.920]	0.006*
WOMAC total (0-96) ‡						
Preop	86	69.72 ± 14.06	176	47.55 ± 17.19	-22.17 [-26.38, -17.97]	<0.001*
1-year	70	16.69 ± 14.91	165	10.53 ± 11.14	-6.16 [-10.093, -2.224]	0.002*
5-year	56	18.11 ± 17.09	123	10.94 ± 13.01	-7.17 [-12.27, -2.06]	0.006*
10-year	32	21.56 ± 17.20	105	12.55 ± 15.53	-9.01 [-15.37, -2.65]	0.005*
WOMAC pain (0-20) ‡						
Preop	86	13.81 ± 3.13	176	9.66 ± 3.68	-4.15 [-5.06, -3.25]	<0.001*
1-year	70	2.54 ± 3.02	165	1.34 ± 2.13	-1.20 [-1.99, -0.42]	0.003*
5-year	57	2.63 ± 3.75	123	1.51 ± 2.59	-1.12 [-2.21, -0.03]	0.045*
10-year	32	3.41 ± 3.61	107	2.17 ± 3.53)	-1.24 [-2.65, 0.18]	0.086
WOMAC function (0-68) ‡						
Preop	86	50.07 ± 10.43	176	33.66 ± 12.86	-16.41 [-19.34, -13.48]	<0.001*
1-year	70	12.59 ± 11.15	165	7.91 ± 8.65	-4.68 [-7.64, -1.72]	0.002*
5-year	57	13.61 ± 13.12	123	8.33 ± 9.81	-5.28 [-9.16, -1.40]	0.008*
10-year	32	16.47 ± 12.76	107	9.19 ± 11.38	-7.28 [-11.95, -2.61]	0.003*
WOMAC motion (0-8) ‡						
Preop	86	5.84 ± 1.54	176	4.23 ± 1.54	-1.61 [-2.01, -1.21]	<0.001*
1-year	70	1.56 ± 1.52	165	1.28 ± 1.38	-0.28 [-0.68, 0.12]	0.173
5-year	56	1.57 ± 1.59	123	1.10 ± 1.26	-0.47 [-0.95, 0.01]	0.053
10-year	32	1.69 ± 1.67	105	1.25 ± 1.51	-0.44 [-1.06, 0.18]	0.162
VR-12 physical ($\bar{x}$ = 50) §						
Preop	87	23.04 ± 5.74)	176	28.23 ± 8.72	5.19 [3.42, 6.97]	<0.001*
1-year	74	39.92 ± 11.06	166	44.90 ± 10.62)	4.98 [2.01, 7.93]	0.001*
5-year	59	38.97 ± 13.18	124	45.72 ± 10.40	6.75 [2.88, 10.63]	0.001*
10-year	32	37.19 ± 10.82	106	45.43 ± 9.65	8.24 [4.28, 12.20]	<0.001*
VR-12 mental ($\bar{x}$ = 50) §						
Preop	87	34.64 ± 11.53	176	48.36 ± 10.92	13.72 [10.85, 16.59]	<0.001*
1-year	74	50.27 ± 10.76	166	52.64 ± 8.68	2.37 [-0.44, 5.18]	0.098
5-year	59	49.29 ± 10.26	124	52.97 ± 6.93	3.68 [0.74, 6.60]	0.015*
10=year	32	48.94 ± 8.85	106	55.36 ± 8.90	6.42 [2.88, 9.97]	<0.001*

Significance is set at $p < 0.05$.

† Oxford hip score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

‡ WOMAC minimum scores are 0 with 0 being the better score.

§ VR-12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

Abbreviations: CI, confidence interval; Diff, difference; Pre Op, preoperative; PROMs, patient-reported outcome measures; SD, standard deviation; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey

4.3.2. Linear regression: Preoperative patient-reported outcome measures

No statistically significant collinearity between predictors was identified. Regression analysis indicated preoperative Oxford and WOMAC scores were negatively influenced when funding pathway was public, patients were females, and BMI was greater (Table 18). Preoperative scores for VR-12 were also negatively influenced when funding pathway was public, and patients were females.

Table 18. Multiple linear regression results for preoperative patient-reported outcomes in a contemporary cemented primary total hip arthroplasty for osteoarthritis

PROMs	n	Model <i>p</i> -value	<i>R</i> ²	Estimate	<i>STD Error</i>	<i>p</i> -value
Oxford preop	263	<0.001*	0.33			
(intercept)				26.91	2.94	<0.001*
BMI				-0.25	0.10	0.015*
Sex (Male)				3.20	0.98	0.001*
Funding (Public)				-10.46	1.10	<0.001*
WOMAC total preop	262	<0.001*	0.34			
(intercept)				22.55	7.80	0.004*
BMI				0.95	0.28	<0.001*
Sex (Male)				-7.80	2.45	0.002*
Funding (Public)				22.85	2.81	<0.001*
WOMAC pain preop	262	<0.001*	0.29			
(intercept)				5.14	1.67	0.002*
BMI				0.17	0.06	0.005*
Sex (Male)				-1.46	0.52	0.006*
Funding (Public)				4.37	0.60	<0.001*
WOMAC function preop	262	<0.001*	0.33			
(intercept)				14.59	5.84	0.014*
BMI				0.73	0.21	<0.001*
Sex (Male)				-5.67	1.83	0.002*
Funding (Public)				16.76	2.11	<0.001*
WOMAC motion preop	262	<0.001*	0.24			
(intercept)				2.92	0.77	<0.001*
BMI				0.05	0.03	0.053
Sex (Male)				-0.71	0.24	0.004*
Funding (Public)				1.79	0.28	<0.001*
VR12 physical preop	263	<0.001*	0.12			
(intercept)				27.30	0.88	<0.001*
Funding (Public)				-5.82	1.33	<0.001*
Sex (Male)				2.92	1.19	0.015*
VR12 mental preop	263	<0.001*	0.30			
(intercept)				47.18	1.18	<0.001*
Sex (Male)				5.50	1.60	<0.001*
Funding (Public)				-14.48	1.79	<0.001*

Significance set at *p* < 0.05

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; DF, degrees of freedom; F-Stat, f-statistic;

Preop, preoperative; PROMs, patient-reported outcome measures; STD, standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

4.3.3. Linear regression: Postoperative patient-reported outcome measures

As ANOVA testing of PROMs revealed no statistically significant difference in scores from 1-year to 15-year postoperatively, 1-year scores were used as the main outcome in regression analysis given the greater number of observations. As sex, funding pathway, and BMI were significant predictors of preoperative scores, they were removed as postoperative predictors. Therefore, regression models considered preoperative score, age, ethnicity, and ASA rating. Preoperative score was a statistically significant predictor of postoperative score for all PROMs (Table 19). Increased age and ASA 3 category were additional statistically significant predictors of poorer postoperative WOMAC-function and VR-12-physical scores.

Table 19. Multiple linear regression results for postoperative patient-reported outcomes in a contemporary cemented primary total hip arthroplasty for osteoarthritis

PROM	n	Model <i>p</i> -value	<i>R</i> ²	Estimate	STD Error	<i>p</i> -value
Oxford postop	238	<0.001*	0.07			
(intercept)				36.81	1.12	<0.001*
Oxford preop				0.22	0.05	<0.001*
WOMAC total postop	235	<0.001*	0.15			
(intercept)				3.29	2.74	0.232
WOMAC total preop				-0.70	2.08	<0.001*
ASA 2				-1.11	2.04	0.586
ASA 3				7.66	2.85	0.008*
WOMAC pain postop	235	<0.001*	0.07			
(intercept)				0.12	0.46	0.796
WOMAC pain preop				0.15	0.04	<0.001*
WOMAC function postop	235	<0.001*	0.20			
(intercept)				-10.77	5.97	0.073
WOMAC function preop				0.18	0.04	<0.001*
Age				0.19	0.08	0.024*
ASA 2				-1.40	1.59	0.380
ASA 3				5.67	2.23	0.012*
WOMAC motion postop	235	0.005*	0.04			
(intercept)				0.65	0.29	0.024*
WOMAC motion preop				0.17	0.06	0.005*
VR12 physical postop	240	<0.001*	0.28			
(intercept)				58.54	6.66	<0.001*
VR12 physical preop				0.53	0.08	<0.001*
Age				-0.40	0.09	<0.001*
ASA 2				-0.66	1.82	0.717
ASA 3				-5.56	2.52	0.029*
VR12 mental postop	240	<0.001*	0.11			
(intercept)				40.77	2.48	<0.001*
VR12 mental preop				0.25	0.05	<0.001*

Postop scores are represented by the 1-year PROMs data as ANOVA testing indicated no significant difference between 1-, 5-, 10- and 15-year scores

Significance set at *p* < 0.05

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; Postop, postoperative; Preop, preoperative; PROM, patient-reported outcome measures; STD, standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

4.4. Discussion

These results indicate that primary THA with the specified cemented cup-and-stem combination for osteoarthritis improves PROMs in patients at 1-year postoperatively and that improvement is maintained in those without revision to 15 years post-surgery. Patients who were female, in the public system, and who had greater BMIs presented with poorer preoperative PROMs. Poorer preoperative PROMs negatively influenced postoperative scores across timepoints. For some outcomes, postoperative PROMs were negatively affected by higher comorbidity status (based on ASA rating) and increased age.

The substantial improvement in PROMs seen post-surgery up to 15 years with this cemented cup-and-stem combination sets a benchmark against which PROMs from other cemented or alternative implant combinations in the same or similar populations can be measured. Mean 1-, 5-, and 10-year Oxford scores were over 41, corresponding to a Kalairajah category 1 (excellent) rating (Kalairajah et al., 2005). Mean 15-year Oxford scores were 39.44, corresponding to a category 2 (very good) rating (Kalairajah et al., 2005). Poor 6-month Oxford

scores have been identified as a risk factor for early revision within 2 years (Rothwell et al., 2010); thus, the implant combination's Oxford score suggests low early-revision risk, which needs confirmation via survivorship analysis. The mean difference in pre- and postoperative Oxford scores (>23) is substantially higher for this implant than the estimated minimally important change value of 11 (Beard et al., 2015), suggestive of meaningful improvements for patients.

Preoperative PROMs significantly influenced postoperative PROMs, consistent with previous studies (Appiah et al., 2023; Orr et al., 2022). Poor preoperative scores across multiple PROMs increase likelihood of patient dissatisfaction postoperatively. (Orr et al., 2022) The regression models revealed patients who are female, in the public system, and have higher BMIs were associated with poorer preoperative functional and mental scores, which may predispose them to postoperative dissatisfaction. Studies show that females are more likely opposed to surgery due to competing responsibilities, need more information before deciding, and are less likely to be sent to a specialist; therefore, females drop to a lower preoperative functional level than males (Jüni et al., 2010). These observations align with these findings, wherein females' preoperative scores were lower than males. Alongside poorer functional and mental preoperative scores, females also tend to have higher rates of depression, lower back pain, and comorbidities than males (Clement et al., 2020). In the TOR registry, there was a greater number of females undergoing surgery than males, consistent with national THA surgery data from NZ (McKie et al., 2024) and other parts of the world. In the USA, not only are more females having THA surgeries (Appiah et al., 2023), they are also more likely to be older, have higher BMIs, and need preoperative support than males (Patel et al., 2020). In a Korean study of over 1.15 million females, reproductive factors (e.g., later onset of menarche, longer time breastfeeding, hormone replacement treatment, and oral contraceptive use) were associated with higher risk for severe osteoarthritis and need for THA (Eun et al., 2022). Further investigation into sex differences in THA is required to improve patient care, particularly of females, and may need to be considered in future risk-stratification models (Patel et al., 2020), which should include more detailed reproductive history notetaking. Sex disparity in referral for surgery also warrants consideration.

Consistent with this study's observations, Greene et al. (2021) identified that patients using public funding pathways for THA report poorer preoperative and postoperative PROMs than those using private funding. Poorer public outcomes are often attributed to longer wait times; however, literature indicates the effect of increased waiting time on THA outcome is unclear or inconsistent (Hirvonen et al., 2009), and that sex, age, and certain modifiable risk factors (e.g., BMI, income level, and comorbidities) impact postoperative outcomes to a greater extent (Seddigh et al., 2021). Higher BMI has also been identified as a risk factor for increased complications and poorer postoperative THA outcomes (Onggo et al., 2020). Taken together, these findings support existing literature that women, public patients, patients with higher BMI, older patients, and patients with comorbidities (i.e., higher ASA ratings) are at greater risk of poorer postoperative THA outcomes and require greater preoperative and postoperative support. Specifically, these patients may benefit from additional mental and functional prehabilitation and rehabilitation support. It is worth noting, however, that

the difference between PROM scores of public and private patients (Table 17) were highest pre-operatively than post-operatively, suggesting greater improvements in baseline scores for public, despite not reaching the same level of function as private. Furthermore, recording comorbidities in more detail than relying on ASA ratings within registry data may also help discern more specifically those conditions that may increase risk of poor THA outcomes.

Although preoperative PROMs, ASA rating, and age were identified as significant predictors of postoperative PROMs, these factors only explained between 7 and 28% of the variance (Table 5). Hence, other factors not included in this analysis likely influence the variation in postoperative scores within this population. One such factor may be smoking status. Yue et al. (2022) identified 4 studies where smoking negatively affected postoperative THA PROMs between 6 months and 1 year. Smokers are reported to exhibit lower postoperative Oxford (Matharu et al., 2019) and Harris hip (Khan et al., 2009) scores and an increased use of painkillers and anti-inflammatories (Matharu et al., 2019) than non-smokers and ex-smokers. In smokers, PROMs were more likely to stagnate initially, and decline over time (Hesseling et al., 2019). It may be beneficial to record smoking status in future THA studies and registries.

Few THA patients in the TOR registry were Māori (4%), with a lower representation than the NZJR at 7% (McKie et al., 2024). Considering Māori make up 29% of the Bay of Plenty region, 17% of the NZ population, and 16% of Māori are over 55 years, uptake of surgery by Māori is relatively poor (*Māori Population estimates: At 30 June 2022*). Bourke et al. (2023) identified competing responsibilities (prioritising work and family), disrupted mana² (feeling disempowered), and systemic abdication (inconsistent information/diagnosis) as contributing factors to healthcare accessibility for Māori, which may explain their under-representation as THA patients. Social deprivation and socioeconomic inequities are potential sources of health inequity for Māori (Loring, 2022), which can extend to THA. Low numbers of Māori and “Other” patients made it challenging to discern differences based on ethnicity, which is further complicated due to the diversity of “Other” ethnicities.

4.5. Conclusion

The cemented combination studied demonstrated excellent PROMs out to 15 years with the association of poorer preoperative PROMs in THAs that were publicly funded, in females and those with higher BMIs, and association of poorer preoperative PROMs, older age and ASA 3 rating variables to poorer postoperative PROMs. Patients with poorer preoperative PROMs may require additional preoperative support to improve their postoperative outcomes, encompassing both functional and mental strategies. These patients, as well as those who are older and present with higher ASA ratings, may require additional postoperative support. These associated variables, sex, ethnic disparity and accessibility to surgery need further research in NZ.

² Mana- Power, authority, or prestige; *spec.* (in Polynesian and Melanesian religions) an impersonal supernatural power which can be associated with people or with objects and which can be transmitted or inherited. Press, O. U. (2023). *Oxford English Dictionary*. Oxford University Press. <https://www.oed.com/dictionary/mana> .

4.6. Limitations

Observational studies are limited in their ability to define causation; however, they can identify associations between risk factors and a response variable. Additional variables, such as smoking status, physical activity, analgesic and anti-inflammatory use, rehabilitation programmes, and specific comorbidities were not documented in the registry and therefore not analysed. Older age was identified as a predictor of poorer health scores. However, health scores also tend to deteriorate over time as age increases regardless of surgery, and this was noted most likely due to small sample sizes at 15 years. Two thirds (66%) of all surgeries within the TOR registry were privately funded, which is higher than the 2023 NZ rate of 49% (McKie et al., 2024). Hence, generalisation of these findings is not ensured to regions where the proportion of publicly funded surgeries is greater. Further, PROMs recorded by patients are subjective, susceptible to bias, and dependent on accurate recall.

Chapter 5. Ten-year patient-reported outcome measure comparison of two cemented primary total hip arthroplasty implant combinations for osteoarthritis: A regional New Zealand study.

Prelude: The preceding chapter demonstrated that the earlier generation ECF paired with the Exeter V40 stem was associated with sustained PROMs up to 15 years following primary THA for OA. The analysis also identified specific patient and resource factors associated with poorer PROMs, including lower preoperative scores among publicly funded patients, females, and those with higher body mass index, as well as poorer postoperative outcomes among patients with worse preoperative status, higher ASA class, and older age. These findings highlighted that PROMs are influenced by patient characteristics and healthcare context which needs consideration when comparing implant outcomes. Given that the ECF has been superseded in clinical practice by the Rimfit, and given it produced no different survival, it was necessary to determine whether the modern cemented acetabular component produced comparable PROMs when used with the same Exeter V40 femoral stem. Establishing no difference in PROMs between the early generation and modern cemented constructs was a required step before the Rimfit could be considered a valid reference implant for subsequent PROMs comparisons with hybrid THA for OA.

Accordingly, this next study compared PROMs between the ECF and Rimfit implants, incorporating patient characteristics as well as funding resource type, to ensure that observed differences in outcomes were appropriately contextualised. This sequential approach provided confidence that the cemented construct used in later hybrid–cemented comparisons was associated with both stable implant survival and durable patient-reported outcomes across patient subgroups.

5.1. Introduction

Total hip arthroplasty (THA) is widely performed, highly successful, and significantly improves quality of life in patients with advanced hip osteoarthritis (Evans et al., 2019). While literature has traditionally focused on implant survival and radiographic outcomes (Pearce, Butcher, et al., 2025), there is a growing emphasis on patient-reported outcome measures (PROMs) as critical success indicators of hip arthroplasty (Quiceno et al., 2024; Yamate et al., 2023). When new or upgraded implants are introduced, they are often assumed to perform at least as well as their predecessors, and studies rightly focus on survivorship. However, it remains to be determined whether they offer comparable patient reported clinical benefit over time, despite survival outcomes.

The Exeter® Contemporary Flanged cup (ECF) was the most popular cemented cup in NZ until the introduction of the Exeter® X3 Rimfit cup (Rimfit) in 2010, which was intended to improve wear (Langlois & Hamadouche, 2023) with the introduction of highly-cross-linked polyethylene. A single centre study (n = 108) reported excellent (>41) (Kalairajah et al., 2005) 10-year ECF Oxford hip scores, with a median OHS of 43 out of 48 (Maggs et al., 2016); and a 15-year NZ regional joint registry study on the ECF (n = 263) reported a good (34-41) (Kalairajah et al., 2005) mean OHS score of 39.5 ± 9.58 (Pearce, Joshi, et al., 2025b) The Rimfit has also performed well in studies, exhibiting a good mean OHS (mean $\pm$ SD). (Kalairajah et al., 2005) of 38.5 ± 7.9 (mean $\pm$ SD). (n = 178) at 6 months and an excellent (Kalairajah et al., 2005) score of 42.4 ± 6.2 (mean $\pm$ SD) (n = 44) at 5 years in a NZJR study in elderly patients (Boyle et al., 2023).

The previous study (Chapter 4) identified no evidence of significant differences in survival, or reasons for revision between these two cemented implants (Pearce, Joshi, et al., 2025a), and while both implants provide good-to-excellent OHS outcomes at 6 months and 5 years (n = 261) (vanWinterswijk et al., 2017) no long-term PROMs comparison has been identified. No difference in short- and medium-term PROMs was noted, and no predictors of outcomes were investigated (vanWinterswijk et al., 2017). To address this long-term PROMs gap, PROMs up to 10 years between the implants were compared using a relatively large NZJR dataset (n = 1339) and investigated the influence of six patient characteristics on PROM outcomes.

5.2. Methods

5.2.1. Data source and collection

Ethical approval for this study was obtained from The University of Waikato Human Research Ethics Committee (HREC2023#12). Observational, anonymised, prospectively collected PROM data of all cemented primary THAs for osteoarthritis performed between 1 January 2003 and 30 June 2023 (ECF 2003-2013, Rimfit 2010-2023) in the Bay of Plenty region of NZ were retrieved in January 2024 from the Tauranga Orthopaedic Research (TOR) regional joint registry. TOR is a non-profit organisation that maintains a registry of all Bay of Plenty joint arthroplasty surgeries separate from the NZJR. With consent, patient data are entered into SOCRATES software (version 3.5.8.26 10150). The OHS, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC),

and Veterans RAND 12-Item Health Survey (VR-12) physical and mental scores are routinely collected preoperatively and at 1-year, 5-year, and every 5 years thereafter. The University of Waikato's Human Research Ethics Committee (HREC2023#12) granted ethical approval for this study. All analyses were conducted in RStudio (Vienna, Austria) (Posit, 2023), with methodological oversight from a specialist in public health and biostatistics. Observations were eligible for analysis when at least one PROM was recorded for patients who underwent a primary THA for osteoarthritis with a cemented Exeter® V40 stem and either a highly cross-linked polyethylene Exeter® X3 Rimfit cup or an Exeter® Contemporary Flanged cup (Stryker Orthopaedics, Mahwah, NJ) with conventional polyethylene. Follow-up windows were necessarily broad due to the registry-based nature of PROM collection; however, given the stability of PROMs beyond 12 months following THA, variation in response timing within each window is unlikely to have materially influenced outcomes. This study was reported following the Strengthening the Reporting of Observational Studies (STROBE) guidelines (von Elm et al., 2007).

5.2.2. Patient-reported outcome measures

Preoperative PROM data comprised scores recorded prior to surgery. Follow-up data were defined as: 1-year (10-14 months postoperatively), 5-year (4-6 years postoperatively), and 10-year (9-11 years postoperatively). To aid interpretation of differences between implant cohorts and patient subgroups (sex, age, body mass index [BMI], American Society of Anesthesiologists [ASA] physical status classification, funding, and ethnicity), minimal clinically important difference (MCID) thresholds derived from distribution-based estimates were applied (Molino et al., 2022) using the preoperative scores from each cohort. Although anchor-based MCIDs for OHS and WOMAC have been published, MCID values are known to be population and context dependent. Given differences in population characteristics, health system structure, and baseline PROM distributions, externally derived MCIDs may not be directly applicable to the NZ arthroplasty population. In addition, anchor-based methods often rely on patient satisfaction measures not available in registry data. Therefore, a distribution-based approach was used (0.5 SD of baseline scores) to derive internally consistent MCID thresholds relevant to the study population. While MCID is primarily designed to assess within-patient changes over time (Deckey et al., 2023), it can offer contextual insight into whether observed, between-group differences are likely to be clinically meaningful (Beard et al., 2015). A clinically meaningful difference in score was deemed one that exceeded the established MCID thresholds. For patients undergoing bilateral THA during the study period, PROMs were collected and recorded separately for each hip and corresponded to the specific surgical episode.

5.2.3. Patient characteristics

Patient characteristics included sex (male, female), ethnicity (NZ European, Māori, Other), ASA rating (1, 2, 3, 4), and funding source (public, private) treated as categorical or rank variables, with age and BMI treated as continuous variables. "Other" ethnicity represented a small, heterogeneous subgroup (n=5) and was thus removed from further analysis. The small number of ASA 4 observations (n = 10) were converted to ASA 3 for analysis. Funding source was included as a marker of healthcare access pathway. While funding source may be

associated with socioeconomic factors, it does not capture the multidimensional nature of socioeconomic status and was not interpreted as a direct surrogate for socioeconomic status.

5.2.4. Statistical analysis

Baseline categorical (sex, ethnicity, ASA, funding) and mean continuous (age, BMI) patient characteristics; and preoperative, 1-year, 5-year, and 10-year OHS, WOMAC, VR-12 physical and mental health scores were determined for each component. Missing data were handled using pairwise deletion, meaning that all available observations were used for each analysis without requiring complete data across all variables. Missing data may be due to incomplete questionnaires, non-returned questionnaires, or study withdrawal. Because implant use was strongly structured by calendar time, with the early generation implant predominantly used between 2003–2013 and the modern implant between 2010–2023, the two cohorts were not exchangeable in time. As a result, implant group was highly correlated with era-related factors including patient selection, perioperative care, rehabilitation pathways, registry completeness, and PROM collection practices. To avoid conflating implant effects with secular trends, we did not perform a pooled regression with implant as a single exposure across eras. Instead, analyses were conducted within each implant era to evaluate outcome trajectories and prognostic factors in the clinical context in which each implant was used. Categorical variable proportions between implants were compared using Chi-squared and Fisher's exact tests. Mean age, BMI, and preoperative, 1-year, 5-year, and 10-year PROMs between implants were compared using independent Student's or Welch's *t*-tests in presence of unequal variance. Because not all patients had both preoperative and postoperative scores available, comparisons between preoperative and postoperative means were conducted using independent samples *t*-tests rather than paired analyses. Mean preoperative, 1-year, 5-year, and 10-year PROMs within each cohort were compared using ANOVA and post-hoc Tukey. Postoperative observations with OHS <27 categorised as "poor" (Kalairajah et al., 2005) were extracted to investigate distinct patient characteristics.

To determine influential patient characteristics on preoperative and postoperative PROMs in each cohort, multiple linear regression with post-hoc residual analysis, influence statistics, variance inflation factor, and Durbin-Watson was performed. Preoperative scores were included as predictors of postoperative scores and thus significant predictors of preoperative scores were removed from postoperative analysis to prevent confounding. Statistical significance was set at $p < 0.05$ with 95% confidence intervals (CI) derived for all testing.

5.3. Results

A total of 1630 (Rimfit $n = 1,267$; ECF $n = 363$) primary THAs met the inclusion criteria. Of these, 1365 patients (84%) (Rimfit $n = 1,102$; ECF $n = 263$) had at least one completed PROM and were included in the analyses (Table 20). Due to variable follow-up completion and missing covariate data, the number of patients included differed between analyses and time points; the sample size for each analysis is reported in the corresponding tables. Assumptions of multiple linear regression were checked and met. Normality was evaluated visually

using Q-Q plots of residuals. Initial models using untransformed outcome data in the Rimfit cohort's postoperative OHS and WOMAC PROMs showed deviations from normality in the residuals. However, the analysis was not intended for prediction, but rather to examine associations between patient variables and PROMs. Results are considered robust despite this noted departure from normality. The large sample size improves the precision of the estimates and statistical power but does not eliminate the potential for residual confounding or other sources of bias inherent in observational registry data.

There was a significantly higher proportion of ASA 2 ($p = 0.004$), ASA3 ($p = 0.007$), and publicly funded patients ($p < 0.001$) in the Rimfit than the ECF cohort. No significant difference in mean age or BMI between cohorts or between any of their six subgroups (sex, age, BMI, ethnicity, funding, or ASA rating) was noted, except for where the ECF mean BMI was statistically higher in ASA 3 patients ($p = 0.031$) (Table 20). All 263 ECF hips (100%) featured a 28 mm head size, with the Rimfit being 28 mm in 38%, 32 mm in 56% and 36 mm in 6% of the cohort. Chromium cobalt head type represented 100% of ECF observations and 95% of Rimfit observations, the remaining being ceramic.

Table 20. Patient characteristic comparison between contemporary and modern cemented implant in primary total hip arthroplasty for osteoarthritis

	Both implants	Rimfit	ECF	<i>p</i> -value
Total, n (%)	1365 (100%)	1102 (80.73%)	263 (19.27%)	-
Age (mean $\pm$ SD)	71.39 $\pm$ 8.60	71.39 $\pm$ 8.52	71.38 $\pm$ 8.67	0.991
BMI (mean $\pm$ SD)	28.00 $\pm$ 4.85	28.00 $\pm$ 4.93	28.01 $\pm$ 4.75	0.970
Sex, n (%) ‡				
Male	543 (39.78%)	423 (38.38%)	120 (45.63%)	0.031
Female	822 (60.02%)	679 (61.62%)	143 (54.37%)	0.031
ASA, n (%) ‡				
1	195 (14.52%)	146 (13.46%)	49 (18.63%)	0.041*
2	824 (60.37%)	660 (60.88%)	164 (62.36%)	0.401
3 & 4	324 (24.12%)	278 (25.65%)	46 (17.49%)	0.007*
Missing	22	18	4	-
Funding, n (%) ‡				
Public	588 (43.17%)	501 (45.59%)	87 (33.08%)	<0.001*
Private	774 (57.63%)	598 (54.41%)	176 (66.92%)	<0.001*
Missing	3	3	-	-
Ethnicity, n (%) ‡				
NZEU	1258 (94.80%)	1016 (94.43%)	242 (92.02%)	0.102
Māori	64 (4.82%)	55 (5.11%)	9 (3.42%)	0.315
Other	5 (0.38%)	5 (0.46%)	0	0.180
Missing	26	26	0	-

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, Body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup; SD, standard deviation

‡ Values represent the number and percentage of males and females, ASA 1, 2, 3 & 4, public and private funding, and NZ European, Māori and other ethnicity within each cohort.

* Significance set at $p < 0.05$

Missing values have not been included in proportion calculations

5.3.1. Patient-reported outcome measures

PROM comparisons between implants can be found in Table 21. No significant difference in mean preoperative, 1-year, 5-year, or 10-year OHS, WOMAC, or VR-12 physical function scores between implants was noted. VR-12 mental scores were significantly higher preoperatively (2.5 points, $p = 0.005$), at 1-year (1.4 points, $p = 0.042$),

and at 5-year (2.1 points, $p = 0.004$) in the Rimfit. Both implants achieved significant improvements from baseline PROMs ($p < 0.001$). ANOVA demonstrated no statistically significant differences in mean PROMs within implant cohorts at 1, 5, or 10 years, supporting the absence of divergence in longer-term outcomes. Given the limited sample size at 10 years and lack of significant difference between 1, 5 and 10-year PROMs, 1-year PROMs were used as the postoperative score for further comparisons due to its substantial sample size.

5.3.2. Poor postoperative patient-reported outcome measures

There were 67 patients with poor postoperative OHS (<27) (Kalairajah et al., 2005) scores ($n = 60$, Rimfit $n = 53$, 6.3%; ECF $n = 7$, 3.4%). There was no significant difference in patient characteristic proportions of poor postoperative scores, mean age (ECF 74.9 ± 10.1 ; Rimfit 71.6 ± 8.3 years, $p = 0.566$) or BMI (ECF 26.6 ± 3.6 kg/m²; Rimfit 29.3 ± 4.7 kg/m², $p = 0.106$), ethnic groups ($p = 0.580$), ASA ratings ($p = 0.217$), or funding ($p = 0.684$) between the cohorts. The small number of observations in the ECF cohort made it challenging to analyse in further detail (Supplementary Table 3).

Table 21. Comparison of preoperative and postoperative patient-outcome measures between contemporary and modern cemented implant in primary total hip arthroplasty for osteoarthritis

PROM	n	Mean	Rimfit			n	Mean	SD	ECF			p-value ¶
			SD	Diff [95% CI] †	MCID ‡				Diff [95% CI] †	MCID ‡		
Oxford (0-48)												
Preop	837	18.23	±8.96		4.48	263	17.75	±8.73		4.37	0.446	
Postop 1-year	842	41.29	±7.42	23.06 [22.25, 23.82]		238	41.30	±7.06	22.43 [21.06, 23.81]		0.985	
Postop 5-year	490	42.88	±6.85			180	41.62	±8.46			0.074	
Postop 10-year	124	41.64	±8.67			139	41.30	±9.58			0.763	
WOMAC total (0-96)												
Preop	827	54.23	±18.51		9.26	262	54.82	±19.27		9.64	0.663	
Postop 1-year	810	14.12	±14.09	40.15 [38.60, 41.71]		235	12.36	±12.68	40.40 [37.65, 43.15]		0.069	
Postop 5-year	483	12.41	±14.29			179	13.18	±14.47			0.540	
Postop 10-year	124	15.38	±17.23			137	14.66	±16.32			0.730	
VR-12 physical (x̄ = 50)												
Preop	836	27.61	±8.21		4.11	263	26.52	±8.22		4.11	0.058	
Postop 1-year	840	44.01	±10.57	17.05 [16.12, 17.97]		240	43.36	±10.98	16.37 [14.88, 17.87]		0.405	
Postop 5-year	487	44.43	±10.37			183	43.55	±11.76			0.280	
Postop 10-year	125	42.23	±11.34			138	43.51	±10.49			0.344	
VR-12 mental (x̄ = 50)												
Preop	836	46.36	±12.76		6.38	263	43.82	±12.85		6.43	0.005*	
Postop 1-year	840	53.31	±9.40	6.49 [5.49, 7.48]		240	51.91	±9.41	7.23 [5.41, 9.04]		0.042*	
Postop 5-year	487	53.97	±10.00			183	51.78	±8.31			0.004*	
Postop 10-year	125	55.16	±8.86			138	53.87	±9.26			0.250	

Abbreviations: CI, confidence interval; ECF, Exeter Contemporary Flanged cup; MCID, Minimal clinically important difference (distribution-based); Preop, preoperative; Rimfit, Exeter X3 Rimfit cup; SD, standard deviation; VR-12, Veterans Rand 12-item health survey; WOMAC, Western Ontario and McMaster Universities Index.

† Difference calculated between the mean preoperative score and the mean 1-year postoperative score

‡ MCID calculated using the distribution method of 0.5 x SD of the preoperative score

¶ p-value represents the comparison of the Rimfit score to the ECF score for that period.

* Significance level set at $p < 0.05$

5.3.3. Linear regression: Preoperative patient-reported outcomes

Detailed preoperative regression results are provided in Table 22 and Table 23. Funding source was the strongest predictor (i.e., largest coefficient) of baseline PROMs in both cohorts. Publicly funded patients reported substantially worse preoperative scores than privately funded patients, including ~8-10 lower OHS, ~16-23 higher WOMAC, ~5-6 lower VR-12 physical, and ~7-14 lower VR-12 mental scores. These differences exceeded the predetermined distribution-based MCID across all PROMs. Sex was also a significant predictor, with males scoring ~2-3 points better in OHS and VR-12 mental and physical, and ~4-8 points better on WOMAC compared to females. BMI showed a small statistically significant effect on preoperative scores (OHS $\approx$ -0.25; WOMAC $\approx$ 0.5-0.9) per 1 BMI unit increase, in both cohorts. In the Rimfit, other significant preoperative predictors included higher ASA ratings (i.e., higher comorbidity burden) associated with ~2-8 worse WOMAC and ~3-6 worse VR-12 physical and mental scores, and Māori ethnicity associated with ~6 points lower preoperative VR-12 mental scores compared with NZ Europeans.

5.3.4. Linear regression: Postoperative patient-reported outcomes

Linear regression for postoperative PROMS (Table 24 and Table 25) was performed using the 1-year postoperative scores for regression due to its larger sample size and lack of significant difference between 1-year, 5-year, and 10-year postoperative scores. Preoperative PROMs consistently exhibited the largest predictive contribution to postoperative scores across PROMs in both cohorts, with each 1-point worse preoperative score associated with a 0.18-0.53-point worse postoperative score depending on the PROM and implant type. In the Rimfit cohort, age at surgery was an additional significant predictor of poorer postoperative OHS, WOMAC, and VR-12 physical scores ($\approx$ -0.1 to -0.3 per year). In the Rimfit cohort, ethnicity was also a clinically meaningful predictor, with Māori patients having significantly worse postoperative OHS ($\approx$ -5 points), WOMAC ($\approx$ +6 points), and VR-12 physical ($\approx$ -8 points) scores compared with NZ European. In the Rimfit cohort, BMI was significant only for postoperative VR-12 mental scores, with higher BMI associated with poorer postoperative outcomes. In the ECF cohort, age at surgery predicted worse postoperative VR-12 physical scores ($\approx$ -0.40 per year). ASA 3 was also associated with worse postoperative WOMAC (7.7 points) and VR-12 physical (5.6 points) scores compared to ASA 1. The R^2 values (0.08-0.34) from the regression analyses indicate that the included predictors explain only a modest proportion of outcome variance.

Table 22. Exeter X3 Rimfit multiple linear regression results for preoperative patient-reported outcomes in primary total hip arthroplasty for osteoarthritis

Exeter X3 Rimfit									
Predictor	Sample (n)	R ²	F-statistic	DF	Estimate (β)	STD Error	t-value	p-value	Interpretation
Oxford preop (0-48)	767	0.31	67.07	5, 762				<0.001*	
(intercept)					30.91	1.61	19.23	<0.001*	Baseline: Female, private funding, ASA I
BMI					-0.27	0.06	-4.73	<0.001*	↑ BMI → ↓ Oxford score
Sex (Male)					1.98	0.57	3.53	<0.001*	Males score ~ 2 points better than females
Funding (Public)					-8.25	0.58	-14.28	<0.001*	Public patients score ~ 8 pts worse than private
ASA (2)					-2.10	0.80	-2.64	0.009*	ASA 2 score ~ 2 points worse than ASA 1
ASA (3)					-3.50	0.94	-3.70	<0.001*	ASA 3 score ~ 3.5 points worse than ASA 1
WOMAC total preop (0-96)	758	0.29	60.45	5, 753				<0.001*	
(intercept)					28.71	3.38	8.47	<0.001*	Baseline: Female, private funding, ASA (1)
BMI					0.52	0.12	4.36	<0.001*	↑ BMI → ↑ (worse) WOMAC
Sex (Male)					-3.98	1.18	-3.37	<0.001*	Females score ~ 4 points worse than males
Funding (Public)					16.25	1.22	13.35	<0.001*	Public patients score ~ 16 points worse than private
ASA (2)					5.10	1.66	3.06	0.002*	~ 5 points worse than ASA (1)
ASA (3)					7.85	1.99	3.96	<0.001*	~ 8 points worse than ASA (1)
VR-12 physical preop (x̄ = 50)	763	0.20	38.37	5, 764				<0.001*	
(intercept)					38.08	1.60	23.74	<0.001*	Baseline: Female, private funding, ASA (1)
BMI					-0.20	0.06	-3.64	<0.001*	↑ BMI → ↓ physical HRQOL
Sex (Male)					2.05	0.56	3.64	<0.001*	Males score 2 points better physical HRQOL than female
Funding (Public)					-5.56	0.58	-9.64	<0.001*	Public funding ~5.5 points worse physical HRQOL to private
ASA (2)					-3.56	0.79	-4.50	<0.001*	~3.5 points worse physical HRQOL than ASA (1)
ASA (3)					-4.21	0.94	-4.47	<0.001*	~4 points worse physical HRQOL than ASA (1)
VR-12 mental preop (x̄ = 50)	824	0.15	29.16	5, 819				<0.001*	
(intercept)					52.28	1.11	47.00	<0.001*	Baseline: Female, private funding, non-Māori, ASA (1)
Sex (Male)					2.79	0.86	3.25	0.001*	Males score ~ 3 points better mental HRQOL than females
Funding (Public)					-6.80	0.88	-7.76	<0.001*	Public funding ~7 points poorer mental HRQOL to private
ASA (2)					-3.30	1.22	-2.70	0.007*	~ 3 points worse mental HRQOL than ASA (1)
ASA (3)					-6.48	1.42	-4.56	<0.001*	~ 6.5 points worse mental HRQOL than ASA (1)
Ethnicity (Māori)					-6.25	1.82	-3.44	<0.001*	Māori score ~ 6 points worse mental HRQOL

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, F-statistic; HRQOL, health related quality of life; Preop, preoperative; STD, standard; WOMAC, Western Ontario and McMaster Universities; Arthritis Index; VR-12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$

Table 23. Exeter Contemporary Flanged multiple linear regression results for preoperative patient-reported outcomes in primary total hip arthroplasty for osteoarthritis

Exeter Contemporary Flanged cup									
Predictor	Sample (n)	R ²	F-Statistic	DF	Estimate (β)	STD Error	t-value	p-value	Interpretation
Oxford preop (0-48)	263	0.33	36.91	3, 222				<0.001*	
(intercept)					26.91	2.94	9.16	<0.001*	Baseline: Female, private funding
BMI					-0.25	0.10	-2.44	0.015*	↑ BMI → ↓ Oxford score
Sex (Men)					3.20	0.98	3.28	0.001*	Males score ~ 3 points better than females
Funding (Public)					-10.46	1.10	-9.56	<0.001*	Public patients score ~ 10 pts worse than private
WOMAC total preop (0-96)	262	0.34	30.68	3, 172				<0.001*	
(intercept)					22.55	7.80	2.89	0.004*	Baseline: Female, private funding
BMI					0.95	0.28	3.42	<0.001*	↑ BMI → ↑ (worse) WOMAC
Sex (Men)					-7.80	2.45	-3.19	0.002*	Females score ~ 8 points worse than males
Funding (Public)					22.85	2.81	8.12	<0.001*	Public patients score ~ 23 points worse than private
VR12 physical preop (x̄ = 50)	263	0.12	12.28	2, 177				<0.001*	
(intercept)					27.30	0.88	31.20	<0.001*	Baseline: Female, private funding
Funding (Public)					-5.82	1.33	-4.39	<0.001*	Public funding ~6 points worse physical HRQOL to private
Sex (Men)					2.92	1.19	2.46	0.015*	Males score ~6 points better physical HRQOL than female
VR12 mental preop (x̄ = 50)	263	0.30	37.69	2, 177				<0.001*	
(intercept)					47.18	1.18	40.02	<0.001*	Baseline: Female, private funding
Sex (Men)					5.50	1.60	3.44	<0.001*	Males score 5.5 points better mental HRQOL
Funding (Public)					-14.48	1.79	-8.09	<0.001*	Public funding linked to ~14 points poorer mental HRQOL

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, F-statistic; HRQOL, health related quality of life; Preop, preoperative; STD, standard; WOMAC, Western Ontario and McMaster Universities; Arthritis Index; VR-12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$

Table 24. Exeter X3 Rimfit multiple linear regression results for postoperative patient reported outcomes in primary total hip arthroplasty for osteoarthritis

Exeter X3 Rimfit cup									
Predictor	Sample (n)	R ²	F statistic	DF	Estimate (β)	STD Error	t-value	p-value	Interpretation
Oxford postop (0-48)	607	0.08	18.55	3, 604				<0.001 *	
Intercept					44.77	2.671	16.76	<0.001*	Baseline: Ethnicity (NZEU)
Oxford preop					0.181	0.034	5.36	<0.001*	↑ preop score → higher postop Oxford → better postop outcome
Age at surgery					-0.093	0.035	-2.63	0.009*	↑ age → lower postop Oxford → worse postop outcome
Ethnicity (Māori)					-4.925	1.441	-3.42	<0.001*	NZ Māori score ~5 points lower → worse postop outcome
WOMAC postop (0-96)	585	0.08	18	3, 582				<0.001 *	
Intercept					-13.14	5.032	-2.61	0.009*	Baseline: Ethnicity (NZEU)
WOMAC preop					0.18	0.03	5.63	<0.001*	↑ Preop WOMAC → ↑ postop WOMAC → worse postop outcome
Age at surgery					0.24	0.07	3.52	<0.001*	Each 1 year ↑ is a 0.24 ↑ postop WOMAC → worse postop outcome
Ethnicity (Māori)					5.83	2.69	2.17	0.031*	NZ Māori score ~ 6 points higher → worse postop outcome
VR-12 physical postop (x̄ = 50)	612	0.11	27.14	3, 609				<0.001 *	
Intercept					58.06	3.85	15.07	< 0.001 *	Baseline: Ethnicity (NZEU)
VR-12 physical preop					0.23	0.05	4.75	< 0.001 *	↑ Preop VR12 Physical → ↑ postop VR12 Physical → better postop outcome
Age at surgery					-0.27	0.05	-5.65	< 0.001 *	Each 1-year ↑ is a 0.27 ↓ in postop → worse postop outcome
Ethnicity (Māori)					-7.56	1.88	-4.03	< 0.001 *	Māori associated with ~8 point lower postop → worse postop outcome
VR-12 mental postop (x̄ = 50)	563	0.14	45.76	2, 561				<0.001 *	
Intercept					46.54	2.77	16.83	< 0.001 *	Baseline
VR12 mental preop					0.26	0.03	8.73	< 0.001 *	Each 1-point ↑ preop → 0.26-point ↑ postop → better postop outcome
BMI					-0.19	0.08	-2.48	0.014*	↓ BMI → 0.19 point ↑ postop → better postop outcome

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; DF, Degrees of freedom; F-Stat, F-statistic; Preop, preoperative; Postop, postoperative; PROMs, Patient reported outcome measures; STD, Standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

* Significance is set at $p < 0.05$

Table 25. Exeter Contemporary Flanged multiple linear regression results for postoperative patient reported outcomes in primary total hip arthroplasty for osteoarthritis

Exeter Contemporary Flanged									
Predictor	Sample (n)	R ²	F statistic	DF	Estimate	STD Error	t-value	p-value	Interpretation
Oxford postop (0-48)	238	0.07	16.07	1, 202				<0.001*	
(intercept)					36.81	1.12	32.84	<0.001*	Baseline
Oxford preop					0.22	0.05	4.01	<0.001*	Each 1-point ↑ preop → 0.22-point ↑ postop → better postop outcome
WOMAC postop (0-96)	235	0.15	10.36	3, 172				<0.001*	
(intercept)					3.29	2.74	1.20	0.232	Baseline: ASA 1
WOMAC preop					-0.70	2.08	-0.337	<0.001*	Each 1-point ↑ preop → 0.22-point ↑ postop → poorer postop outcome
ASA (2)					-1.11	2.04	-0.546	0.586	no significant difference compared to ASA 1
ASA (3)					7.66	2.85	2.69	0.008*	ASA 3 ↓ postop scores than ASA 1 by ~7.7 points → poorer postop outcome
VR12 physical postop ($\bar{x}$ = 50)	240	0.28	17.34	4, 175				<0.001*	
(intercept)					58.54	6.66	8.78	<0.001*	Baseline: ASA 1
VR12 physical preop					0.53	0.08	6.23	<0.001*	↑ preop physical scores ↑ postop → better postop outcome
Age at surgery					-0.40	0.09	-4.31	<0.001*	Each year ↑ is a 0.4 ↓ in postop → worse postop outcome
ASA (2)					-0.66	1.82	-0.36	0.717	no significant difference vs. ASA 1.
ASA (3)					-5.56	2.52	-2.21	0.029*	ASA 3 ↓ postop score than ASA1 by ~5.6 points → worse postop outcome
VR12 mental postop ($\bar{x}$ = 50)	240	0.11	22.29	1, 178				<0.001*	
(intercept)					40.77	2.48	16.46	<0.001*	Baseline
VR12 mental preop					0.25	0.05	4.72	<0.001*	higher preop mental health scores predict better postop mental scores.

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; DF, Degrees of freedom; F-Stat, F-statistic; Preop, preoperative; Postop, postoperative; PROMs, Patient reported outcome measures; STD, Standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

* Significance is set at $p < 0.05$

5.4. Discussion

A strength of this study is the consistency in key operative factors minimising variation in surgical technique, including the same cemented stem, hospitals, and overlapping surgical personnel. The shared geographic catchment confirms similar underlying demographics, which reinforces cohort comparability.

5.4.1. Preoperative patient-reported outcome measures

This study addresses an important evidence gap by evaluating the Rimfit 10-year suitability as a replacement for the ECF cemented cup. Distribution-based MCID estimates provide a useful benchmark to interpret the clinical meaningfulness of observed PROM changes (Deckey et al., 2023; Langenberger et al., 2023). The OHS, WOMAC, and VR-12 physical scores all demonstrated substantial and statistically significant improvements from preoperative to postoperative PROMs, far exceeding MCID thresholds of ~4.5, ~9, and ~6 respectively in both cohorts. Previous research by Yeo et al. (2020) indicated improved physical function after THA, with OHS and WOMAC improvements being good indicators of THA success (Yeo et al., 2020). The VR-12 mental scores in this study showed more modest clinical changes but also exceeded the MCID of ~6 and ~7 in the Rimfit and ECF, respectively.

5.4.2. Postoperative patient-reported outcome measures

No statistically significant differences between 1-year, 5-year, and 10-year mean physical postoperative scores within each cohort were noted. All mean postoperative OHS scores exceeded the excellent threshold score of 41 (Kalairajah et al., 2005). These findings indicate positive PROM outcomes are achieved using both implants, which are sustained over a 10-year period. This consistency reinforces the implants provide comparable physical outcomes, despite surgeries occurring in two different 10-year intervals. Significantly better preoperative mental health scores in the Rimfit cohort strongly suggest baseline differences in psychological wellbeing between groups that cannot be attributable to implant characteristics. The persistence of higher mental health scores at 1 and 5 years postoperatively is therefore most plausibly explained by the strong influence of preoperative outcomes on postoperative outcomes, rather than an effect of the implant itself (Aspari & Lakshman, 2018). The absence of differences at 10 years further supports this interpretation, suggesting that early postoperative disparities reflect baseline psychological profiles and early recovery trajectories, which converge over time as longer-term mental wellbeing becomes increasingly influenced by aging and broader psychosocial factors (O'Connor et al., 2022). Registry-based literature cautions that comorbidity prevalence and patient health status often change over time, demonstrated by an increase in comorbidity rates and rising prevalence of specific conditions (e.g., diabetes and renal disease) over recent decades in THA populations (Penfold et al., 2022). The higher proportion of ASA 3 patients within the Rimfit cohort aligns with documented temporal trends in arthroplasty populations (Reisinger et al., 2025), with the comorbidity differences between the cohorts likely reflecting evolving patient health profiles (Penfold et al., 2022; Reisinger et al., 2025). The relatively small sample of poor OHS scores (<27) investigated revealed no

difference between the cohorts other than the increased proportion of ASA 2 in the Rimfit cohort, reaffirming no stark differences between cohorts other than comorbidities.

5.4.3. Linear regression preoperative patient-reported outcome measures

Funding source, as well as female sex and BMI, appear to consistently impact preoperative outcomes. Publicly funded patients showed worse preoperative scores, likely due to longer wait times (Karayiannis et al., 2023), limited supportive care, higher comorbidities, barriers to health literacy, unemployment (Hoelen et al., 2023), and systemic inequities that result in patients needing greater disease severity to become eligible for surgery (Alvarez et al., 2022b). Female sex has frequently been associated with poorer pre- and postoperative PROMs in THA. Females tend to present for surgery with greater pain, functional limitations, and comorbidity burden (Zhang et al., 2023), which may partly reflect differences in pain perceptions, bone morphology, and delayed access to surgery (Jüni et al., 2010). Alongside these factors, higher rates of obesity and osteoporosis can influence surgery (Grant et al., 2024), recovery, and perceived outcomes (Solarino et al., 2022). Females need to be considered a priority in future risk stratification models (Patel et al., 2020) with female-specific management potentially beneficial (Solarino et al., 2022).

Body mass index as a predictor of poorer preoperative PROMs in both cohorts, and higher ASA ratings in the Rimfit cohort, also suggests that comorbidity burden may significantly impact recovery trajectories, aligning with findings that a higher number of comorbidities introduces a higher risk of postoperative complications. Several studies (Jämsen et al., 2013; Podmore et al., 2018; Reisinger et al., 2025) highlighted the value of documenting comorbidities in greater detail. While indices such as ASA correlate with THA outcomes, they provide limited guidance for individualised treatment. Podmore et al (2018) noted that specific conditions influence recovery differently, and Jämsen et al (2013) found that implant survival hazard ratios are affected by cardiac, endocrine, oncologic, and mental health conditions in both univariate and multivariate analysis. It may be prudent for regional registries like the one analysed here to record more detailed comorbidity data and to pursue future comorbidity specific THA research to determine which comorbidities may predict the poorest outcomes.

Preoperatively, Māori presented significant and clinically meaningful poorer preoperative VR-12 mental scores, indicating ethnic disparity in health outcomes even before surgery. Such disparities could be related to psychosocial, cultural, and systemic factors (Loring, 2022). Results must be interpreted with caution, however, given the limited number of NZ Māori in the ECF group (n=9), restricting the ability to robustly analyse preoperative PROMs.

5.4.4. Linear regression postoperative patient-reported outcome measures

In both cohorts, preoperative PROMs consistently demonstrated the largest predictive contribution to postoperative outcomes, consistent with previous studies (Appiah et al., 2023; Orr et al., 2022; Pearce, Joshi, et al., 2025b). Outside of preoperative scores, age at surgery influenced both cohorts while NZ Māori ethnicity predicted poorer physical postoperative outcomes in the Rimfit cohort, and ASA 3 comorbidity status in the ECF

cohort. The limited number of Māori in this study hinders the robustness of analyses, limits regression modelling, and precludes assessment of ethnicity as a true, independent predictor, highlighting Māori underrepresentation in THA surgery. In this study, Māori represented <5% of the cohort, a clear underrepresentation considering Māori represent 30.6% of the population in the Bay of Plenty region (Stats-NZ, 2023). Contributing factors for Māori under representation may include structural (colonisation, governance, socioeconomic) and intermediary (education, work, accessibility, lifestyle) determinants, highlighting the need to address upstream systemic and cultural barriers, not just surgical implants (Gleeson, 2023; Rahiri et al., 2018).

Whether preoperatively or postoperatively, all patient factors investigated influenced patient outcomes to a certain extent. Although these results provide some insight, the low coefficient of determination of the models ($R^2 \sim 0.34$ at best) indicates that other potential influencers may affect scores more readily or assist in explaining a greater proportion of PROM variance, such as smoking status (Yue et al., 2022), activity levels (Reine et al., 2022), postoperative rehabilitation, health literacy, education, and care (Nicolau et al., 2022). Considering the ECF implant is no longer used in NZ, the outcomes of the Rimfit linear regression models may be more relevant to future comparative studies with other specific implants.

The rationale for examining 10-year PROMs was to assess whether incremental advances in polyethylene design translate into sustained patient-perceived benefit over the longer term. Given the similarity in implant geometry and fixation, large early differences were not anticipated; rather, any potential differences were hypothesised to emerge with longer follow-up, where polyethylene durability may plausibly influence pain, function, or activity (Ronda & Wojnarowski, 2013). While radiographic outcomes and implant survivorship are critical measures of implant performance, PROMs capture the patient experience of that performance.

5.5. Conclusion

From a patient outcome's perspective, the Rimfit cup shows no significant difference in PROMs to the ECF at 10 years, with both implants demonstrating sustained improvements in PROMs and no statistically significant differences in physical function outcomes over 10 years. The Rimfit cohort presented with superior VR-12 mental scores preoperatively, sustained at 1-year, and at 5-year suggesting baseline differences in mental wellbeing. Socioeconomic status, sex, and comorbidity status (i.e., ASA) were identified as significant clinical predictors of poorer preoperative physical outcomes in both cohorts. For the Rimfit, Māori ethnicity was a predictor of poorer preoperative mental health and postoperative physical PROM scores. Postoperatively, older age at surgery was detrimental to PROMs outcomes in both cohorts. Findings should be interpreted within the temporal and health-system context in which each implant was used. Further study beyond 10-years may be required to determine possible differences over an extended period.

5.6. Limitations

Analyses were restricted to patients with at least one completed PROM, which may introduce response bias. Patients who completed PROMs may differ systematically from those who did not, potentially influencing outcome estimates. This limitation is inherent to PROMs-based registry analyses and should be considered when interpreting the results. However, at least 84% (1360 out of 1630) of THA observations completed at least one PROM reducing response bias.

While the large sample size improves precision and statistical power, it does not eliminate the possibility of bias or residual confounding. Differences in funding status and temporal changes in referral patterns, surgical practice, and PROM collection may also influence baseline characteristics and observed outcomes independent of implant choice. These factors should be considered when interpreting the findings, and causal inferences should be made with caution.

The width of follow-up windows reflects the pragmatic nature of registry-based PROM collection, where follow-up timing is not fixed but occurs within predefined intervals. To minimise potential bias, 1-year follow-up was selected as the primary analytical endpoint due to the largest sample size, greatest temporal clustering of responses and lack of statistically significant differences observed in mean PROMs across 1-, 5-, and 10-year follow-up, suggesting that variation in follow-up timing did not meaningfully influence comparative conclusions.

In the comparison of ECF and Rimfit constructs, head size was not included as a covariate; given the near universal use of 28 mm heads in the UHMWPE cohort and the distribution of 28 and 32 mm heads in the HXLPE cohort (38% and 56% respectively), head size effect is unlikely to influence the outcomes of our PROMs investigation between ECF and Rimfit.

The difference in sample size between cohorts (ECF $n = 263$; Rimfit $n = 1,102$) reflects the real-world transition in clinical practice from UHMWPE to HXLPE during the study period, with the ECF representing an implant that was progressively replaced from 2010 onward. This imbalance is acknowledged as a limitation; however, both cohorts exceeded sample sizes sufficient for linear regression analysis, and group size inequality does not violate the assumptions of the statistical methods employed.

Chapter 6. Ten-year survival between a hybrid and cemented implant in primary total hip arthroplasty for osteoarthritis: A New Zealand regional study

Prelude: The preceding chapter demonstrated that PROMs for the Rimfit acetabular component paired with the Exeter V40 stem were comparable to those of the early generation ECF, over a 10-year follow-up. Both cemented constructs were associated with sustained improvements in pain, function, and health-related quality of life, with no statistically significant differences in physical function outcomes over 10 years despite a 10-year difference in observation period. Although differences in mental health scores were observed at selected time points, these did not exceed established MCID thresholds. Importantly, this analysis further confirmed that PROMs were influenced by patient characteristics and health system factors, including funding source, sex, comorbidity burden, age at surgery, and, in the Rimfit cohort, Māori ethnicity. These findings reinforced that implant-level comparisons must be interpreted within a broader patient-centred and equity-informed framework.

Having established that the Rimfit demonstrates no significant difference in PROMs to a well-performing early generation cemented implant and having previously demonstrated comparable implant survival between the cemented designs, the Rimfit could be considered a valid modern cemented reference implant. This validation was a prerequisite before undertaking comparisons with hybrid THA. Accordingly, the final stage of this Thesis compared survival outcomes between the hybrid Trident Series 1 implant and the cemented Rimfit implant, allowing evaluation of hybrid versus cemented performance in the Bay of Plenty region using a cemented comparator with demonstrated survival stability and durable patient-reported outcomes.

6.1. Introduction

Cemented total hip arthroplasty (THA) in NZ has fallen below 5% since 2021 (McKie et al., 2024) despite its affordability (Abdulkarim et al., 2013; Van Praet & Mulier, 2019; Veldman et al., 2021) and excellent survival outcomes (Van Praet & Mulier, 2019). Hybrid THAs have become increasingly popular and are the most used THA option in Australia and the United Kingdom (CeramTec, 2025). Hybrid implants were developed to mitigate concerns about early loosening of cemented cups and technical challenges of cementing in the acetabulum (Van Praet & Mulier, 2019), while maintaining the proven stability and durability of a cemented stem (González Della Valle et al., 2016) and is particularly appealing in patients where femoral bone quality may be variable, but acetabular bone can support osseointegration (González Della Valle et al., 2016) and demonstrates cost-effectiveness (Van Praet & Mulier, 2019).

A recent literature review of hybrid and cemented THA outcomes for osteoarthritis (Pearce, Butcher, et al., 2025) identified inconclusive survival evidence of superiority for either combination. Limitations of studies reviewed included a large variation in observation periods (1980-2019); broad category classification of THA implants including multiple brands, designs, materials and coatings; heterogeneity in patient characteristics such as age group studied (e.g. over 80 years only, under 55 years only); overlapping registry data; as well as variations in statistical survival calculation (Pearce, Butcher, et al., 2025). The review identified the need for more recent, standardised survival comparison studies of homogenous populations for THA in osteoarthritis, preferably in specific high-use components (Boyle et al., 2023; Boyle et al., 2022; Pearce, Butcher, et al., 2025). Generic cohort studies can identify generalised trends in survival (Boyle et al., 2023; Boyle et al., 2022), but lack the detail needed to guide implant selection, whereas comparison of specific implants allows a more accurate assessment of variability in survival outcomes (Boyle et al., 2022; Pearce, Butcher, et al., 2025). Additionally, a homogenous population of observations (same diagnosis, region, hospital groups, surgeons, observation periods, cemented stems) would allow surgeons to distinguish whether any observed differences in survival are attributed to fixation type. This would support evidence-based selection (Boyle et al., 2023; Boyle et al., 2022; Pearce, Butcher, et al., 2025). Identifying patient predictors of survival such as sex (Nugent et al., 2021), age (Boyer et al., 2019), body mass index (BMI) (Davis et al., 2011; Mouchti et al., 2018), ethnicity (Alvarez et al., 2022a), American Society of Anesthesiologists Physical Status classification (ASA) (Nugent et al., 2021), and funding (Alvarez et al., 2022b) pathway, may also identify characteristics of patients with poorer survival outcomes.

Fully cemented THA implants such as the highly cross-linked polyethylene (HXLPE) Exeter® X3 Rimfit™ cup with Exeter® V40™ stem are providing 10-year survival outcomes of 97% in osteoarthritis patients (Pearce, Joshi, et al., 2025a) in the Bay of Plenty region of NZ, superior to the NZJR broad cemented survival of 95% (McKie et al., 2024). Comparison of this fully cemented implant with a high use uncemented cup with a HXLPE liner (minimising confounding), and same cemented stem, in the same region, would reduce heterogeneity present in existing literature (Pearce, Butcher, et al., 2025).

The uncemented Exter® Trident™ Series 1 acetabular cup is known for its multi-bearing design and hydroxyapatite coating to promote bone ingrowth for improved fixation (Stryker, 2004) and accepts either polyethylene or ceramic liners. Studies show favourable mid- to long-term survival outcomes of this cup. McHale et al. (2024) observed a 94% implant survival at mean follow-up of 12.5 years with ceramic liners, Bonicoli et al. (2012) noted no revisions or loosening of this cup at a median of 6.2 years, and Dammerer et al. (2021) reported no migration in the cup over a 4-year follow-up. These studies did not isolate primary THA surgery for osteoarthritis, cemented stems or cups with polyethylene liners.

Given the substantial economic burden of osteoarthritis in NZ (estimated at NZD12.2 billion in 2018) (Van der Merwe et al., 2018), implant-specific evaluation is essential. Analysis limited to broad implant categories may obscure clinically important differences between individual implants (Pearce, Butcher, et al., 2025). Implant level evaluation enables more precise, evidence-based selection that influences survival outcomes (Pearce, Butcher, et al., 2025; Van Praet & Mulier, 2019) and guides procurement policy.

Survival outcomes of the modern cementless cup with HXLPE liner were compared to the cemented HXLPE cup, both with the same cemented stem, in primary THA for osteoarthritis in the Bay of Plenty region of NZ. Additionally, patient predictors of survival (age, sex, body mass index (BMI), ethnicity, comorbidity rating, and funding type) were investigated in each cup to determine influencing factors and compared reasons for revision.

6.2. Methods

6.2.1. Data source and collection

Anonymised primary THA data from the mandatory NZJR for the Bay of Plenty region, performed between 1 January 2003 and 30 June 2023 was analysed. Ethical approval was obtained from The University of Waikato Human Research Ethics Committee (HREC2023#12) and conducted and reported in accordance with the STROBE guidelines (von Elm et al., 2007). The national registry captures all primary procedures, revisions, and mortality through national data linkage. Therefore, loss to follow-up is negligible. Primary THAs for osteoarthritis using an Exeter® V40™ stem with either a cemented HXLPE Exeter® X3™ Rimfit cup (using a standardised, third generation cementing technique) (hereafter referred to as cemented) or uncemented Exeter® Trident™ 1 series (highly porous and hydroxyapatite -coated porous titanium Peripheral Self Locking, Hemispheric or Tritanium™) cup (Stryker Orthopaedics, Mahwah, NJ) with HXLPE liner (hereafter referred to as hybrid) were followed up to 30 June 2023 or a maximum of 10 years, a widely accepted benchmark in arthroplasty research (Clar et al., 2024). Surgeries occurred across three hospitals. Revision events were coded as “1” and censored observations (death, end of follow-up, or 10 years) as “0”. Missing data were handled using pairwise deletion. Patient specific factors (sex, age, BMI, ethnicity, ASA rating, and funding source) were treated as categorical variables. Age categories aligned with UK, NZ and Australian national joint registry

standards, with <65 combining the <55 and 56-64 age groups due to lower numbers in the cemented category. BMI categories followed national registry and Centre for Disease Control standards, and ASA 4 ratings were recoded as ASA 3 due to a low number of ASA 4 observations ($n = 19$). Ethnicity was self-reported by patients and categorised into NZ European, NZ Māori, or Other. Funding source was indicated as either public or private (Table 26). *T*-tests assessed differences in mean age and BMI, and chi-square tests compared proportions of categorical predictors between implant groups.

Table 26. Classification of patient variables

Sex	
Male	Assigned male at birth
Female	Assigned female at birth
Funding	
Public	Public health system funding source
Private	Insurance or self-paid funding source
Age (years)	
<65	Under but not including 65 years
65-74	Including 65 and up to and including 74 years
≥75	Including and over 75 years
BMI (kg/m²)	
<25	Normal BMI
25-29.9	Overweight
30-34.9	Obese Class I
35-40	Obese Class II
>40	Obese Class III
ASA rating	
ASA 1	Patient is a completely healthy, fit patient.
ASA 2	Patient has mild systemic disease.
ASA 3	Patient has severe systemic disease that is not incapacitating.
ASA 4	Patient has incapacitating disease that is a constant threat to life.
Ethnicity ‡	
NZ European	New Zealanders of European descent
NZ Māori	A person of the Māori race and includes any descendant
Other	All other ethnicities and undetermined ethnicities

Abbreviations: ASA, American Society of Anesthesiologists Physical Status classification system; BMI, body mass index; NZ, New Zealand
‡ NZ Government Stats NZ, Tatauranga Aotearoa

6.2.2. Survival

Kaplan–Meier analysis was performed with log-rank testing and verified assumptions of independent censoring, time-to-event data, survival homogeneity, and absence of influential events. Competing risk of death was considered, but not applied, as most patients were under 75 years. Proportional hazards assumption was evaluated using Schoenfeld residuals and log-log survival plots. Results were consistent across methods, which supported validity of the primary analysis. STROBE (von Elm et al., 2007) reporting guidelines were followed and R Studio 2025.09.0 (“Cucumberleaf Sunflower”) (Posit, 2023) used to conduct all statistical tests.

6.2.3. Reasons for revision

In a secondary analysis, reasons for revision were categorised into dislocations, infection, periprosthetic fracture, pain, aseptic loosening of acetabulum, loosening of acetabulum due to infection, and other. Chi-square tests compared proportions of revision reasons between implants. Descriptive data are reported as counts, percentages, and means $\pm$ standard deviations. Across analyses, 95% confidence intervals [lower, upper] were extracted and significance set at $p < 0.05$.

6.2.1. Regression

Propensity scores were estimated using logistic regression including age category, sex, BMI category, ethnicity, funding source, and ASA class. Stabilized inverse probability of treatment weights was applied and truncated at the 99th percentile. Covariate balance was assessed using standardized mean differences. Weighted Cox proportional hazards models with robust standard errors were used to compare revision risk between hybrid and cemented THA.

6.3. Results

6.3.1. Patient variables

During the period analysed, there were 2,823 primary THA surgeries for osteoarthritis, encompassing 1,566 hybrid and 1,267 cemented instances (Table 27). The hybrid cohort included 47.88% female, (age 68.26 ± 9.96 y, BMI 29.44 ± 5.89 kg/m²) and the cemented cohort 61.30% female (age 71.39 ± 8.52 y, mean BMI 28.00 ± 4.93 kg/m²) with hybrid patients younger ($p < 0.001$) and with greater mean BMI at surgery ($p < 0.001$). See Table 27. Chi-square tests identified a higher proportion of male ($\Delta 13.42\%$), privately funded ($\Delta 22.21\%$), and Māori ($\Delta 4.48\%$) patients in the hybrid cohort ($p < 0.001$). A higher proportion of younger patients <65 years ($\Delta 14.05\%$), patients with 25-29.9 BMI ($\Delta 5.02\%$), 30-34.9 BMI ($\Delta 6.09\%$), 35-39.9 BMI ($\Delta 5.17\%$) and >40 BMI ($\Delta 3.16\%$) were identified in the hybrid cohort ($p < 0.001$). Cobalt chromium represented 85% and 95% of hybrid and cemented femoral heads respectively, with 15% of hybrid femoral heads made of ceramic. In the Rimfit cohort 56% of femoral heads were size 32 mm with 38% size 28 mm. In the Trident cohort 83% of femoral heads were 32 mm 21% 28 mm and 36 mm even at 8% each.

6.3.2. Survival

Survival analysis included 389 observations *in situ* at 10 years with a median follow-up of five years for the hybrid (range 2-7 y) and seven years for the cemented (range 3-9 y). Standard Kaplan-Meier analysis demonstrated a 10-year survival rate of 95.9% (95% CI 94.7–97.0) for hybrid fixation and 97.0% (95% CI 95.9–98.2) for cemented fixation (Figure 10). Unadjusted comparison using the log-rank test suggested superior survival in the cemented group ($p = 0.048$) (Table 28), consistent with unadjusted Cox regression which indicated a lower hazard of revision for cemented fixation (HR 0.46; $p = 0.0497$). However, following propensity score weighting, all baseline covariates achieved adequate balance (standardised mean differences <0.1). In the weighted Cox proportional hazards model including 2,395 patients and 76 revision events, fixation

type was not associated with revision risk, with hybrid fixation showing a non-significant increase in hazard compared with cemented fixation (HR 1.41; 95% CI 0.85–2.33; $p = 0.179$).

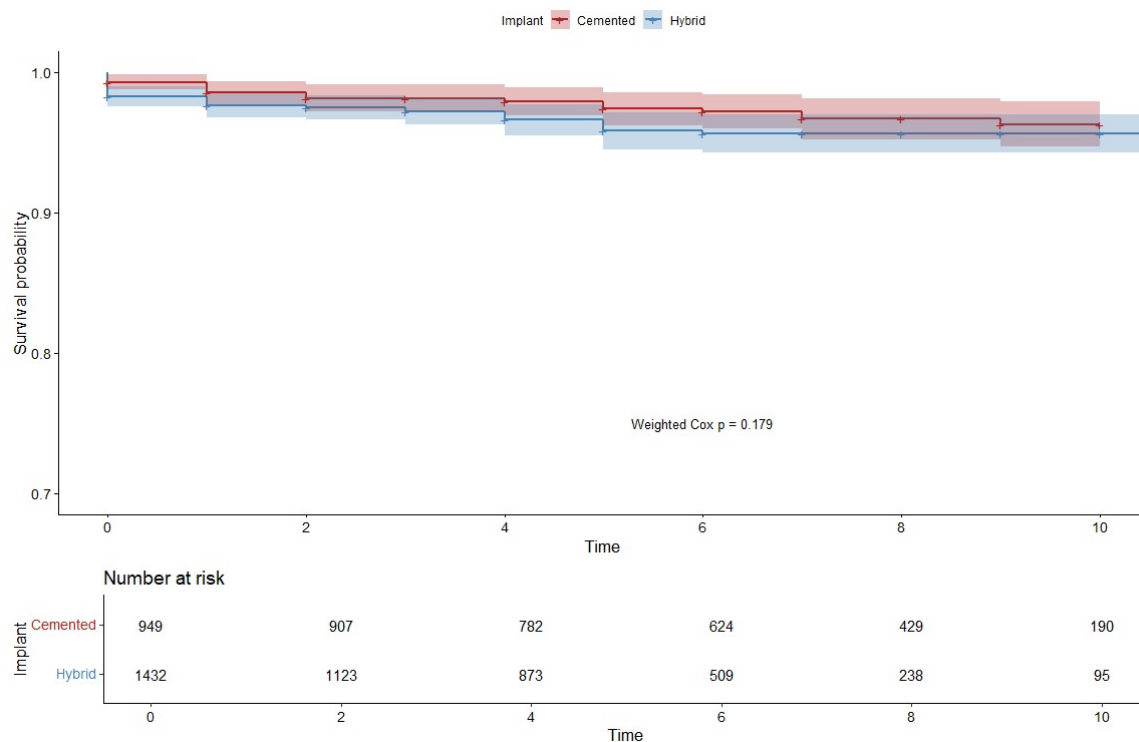


Figure 10. Inverse probability weighted Kaplan–Meier survival curves for revision-free survival by implant fixation up to 10 years

Note: (significance set at $p = 0.05$)

6.3.3. Reasons for revision

A total of 81 revisions (2.9%) (hybrid $n = 52$, 3.3%; cemented $n = 29$, 2.3%) were recorded over the observation period from the 2823 THA instances (Table 29). The hybrid demonstrated a higher proportion of revisions compared with cemented ($\Delta 1.3\%$, 95% CI [0.04%, 2.56%], $p = 0.046$). Most revisions were due to infection followed by dislocation. Aseptic loosening of implants accounted for 8.64% of revisions. There was no statistically significant difference in proportion of any revision type between the two implants.

6.3.1. Regression

No significant predictors of revision were identified in Cox regression analysis.

Table 27. Patient characteristics, proportions, and revisions per cemented and hybrid primary total hip arthroplasty for osteoarthritis

		Both Implants				Hybrid				Cemented				Proportion comparison	
		n	%	Revision n	Revision %	n	Proportion	Revision n	Revision %	n	Proportion	Revision n	Revision %	χ^2	p-value
Total		2823	100%	81	2.87%	1556	55.12%	52	3.34%	1267	44.88%	29	2.30%		
Sex	Male	1301	46.09%	44	3.38%	811	52.12%	28	3.45%	490	38.70%	16	3.30%	50.28	<0.001*
	Female	1522	53.91%	37	2.43%	745	47.88%	24	3.22%	777	61.30%	13	1.70%		
Age (years)	≤64	789	27.95%	22	2.79%	533	34.25%	11	2.06%	256	20.20%	11	4.30%	80.17	<0.001*
	65-74	1123	39.78%	32	2.85%	603	38.75%	21	3.48%	520	41.00%	11	2.10%		
	≥75	911	32.27%	27	2.96%	420	26.99%	20	4.76%	491	38.80%	7	1.40%		
BMI (kg/m ²)	<25	578	20.47%	11	1.90%	272	17.48%	7	2.57%	306	19.70%	4	1.30%	39.68	<0.001*
	25-29.9	1075	38.08%	34	3.16%	577	37.08%	21	3.64%	498	32.10%	13	2.60%		
	30-34.9	633	22.42%	18	2.84%	364	23.39%	11	3.02%	269	17.30%	7	2.60%		
	35-39.9	237	8.40%	9	3.80%	156	10.03%	5	3.21%	81	5.20%	4	4.90%		
	≥40	121	4.29%	5	4.13%	85	5.46%	4	4.71%	36	2.30%	1	2.80%		
	Missing †	179	NA	4	2.23%	102	NA	4	-	77	NA	0	-		
ASA	1	373	13.21%	9	2.41%	216	13.88%	6	2.78%	157	12.40%	3	1.90%	3.85	0.146
	2	1737	61.53%	49	2.82%	966	62.08%	30	3.11%	771	61.00%	19	2.50%		
	3 & 4	700	24.80%	23	3.29%	365	23.46%	16	4.38%	335	26.50%	7	2.10%		
	Missing †	13	NA	0	0.00%	9	NA	0	-	4	NA	0	-		
Funding	Public	1458	51.65%	42	2.88%	1010	64.91%	33	3.27%	448	42.70%	9	2.00%	125.86	<0.001*
	Private	1146	40.60%	35	3.05%	544	34.96%	18	3.31%	602	57.30%	17	2.80%		
	Missing †	219	NA	4	1.83%	2	NA	1	-	217	NA	3	-		
Ethnicity	NZEU	2503	88.66%	72	2.88%	1352	86.89%	45	3.33%	1151	90.80%	27	2.30%	14.82	<0.001*
	Māori	284	10.06%	9	3.17%	188	12.08%	7	3.72%	96	7.60%	2	2.10%		
	Other	36	1.28%	0	0.00%	16	1.03%	0	0.00%	20	1.60%	0	0.00%		

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; Cemented, Exeter X3 Rimfit cup with V40 stem; Hybrid, Exeter Trident I series with V40 stem; NZEU, New Zealand European;

* Significance set at $p < 0.05$; † Missing values have not been included in proportion calculations

Table 28. Implant survival between hybrid and cemented primary total hip arthroplasty for osteoarthritis at 10 years

Factor		Hybrid				Cemented			
		At risk (n)	Events (n)	Survival % [95%CI]	Log-rank <i>p</i> -value†	At risk (n)	Events (n)	Survival % [95%CI]	Log-rank <i>p</i> -value†
Component		145	52	95.9 [94.7, 97.0]	—	244	29	97.0 [95.9, 98.2]	0.179 ‡*
Sex	Male	86	28	95.9 [94.4-97.5]	0.843	105	16	95.7 [93.5, 98.0]	0.089
	Female	59	24	95.8 [94.1, 97.6]		139	13	97.9 [96.8, 99.1]	
Age (years)	<65	52	11	97.9 [96.63, 99.1]	0.047*	83	11	94.7 [91.6, 97.9]	0.103
	65-74	70	21	95.7 [93.8, 97.6]		105	11	97.5 [96.0, 99.0]	
	≥75	23	20	93.3 [90.2, 96.4]		58	7	98.3 [96.9, 99.6]	
BMI (kg/m ²)	<25	26	7	97.4 [95.5, 99.3]	0.885	44	4	97.7 [95.5, 100]	0.527
	25-29.9	47	21	95.3 [93.2, 97.4]		94	13	96.6 [94.6, 98.6]	
	30-34.9	18	11	96.2 [94.0, 98.5]		47	7	96.5 [93.9, 99.2]	
	35-39.9	7	5	96.2 [92.8, 99.7]		20	4	95.0 [90.3, 99.9]	
	≥40	5	4	95.3 [90.9, 99.9]		10	1	97.2 [92.0, 100]	
ASA	1	24	6	96.9 [94.4, 99.4]	0.307	36	3	96.4 [92.2, 100]	0.892
	2	97	30	96.4 [95.1, 97.6]		149	19	96.9 [95.5, 98.3]	
	3 & 4	24	16	93.5 [90.0, 97.0]		59	7	97.7 [96.1, 99.4]	
Funding	Public	107	33	95.9 [94.5, 97.4]	0.826	91	9	97.8 [96.3, 99.3]	0.314
	Private	37	18	95.2 [94.0, 97.9]		120	17	96.2 [94.2, 98.1]]	
Ethnicity	NZEU	126	45	95.8 [94.6, 97.1]	0.789	216	27	96.9 [95.7, 98.1]	0.744
	Māori	18	7	95.8 [92.8, 99.0]		23	2	97.8 [94.8, 100]	

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; Cemented, Exeter X3 Rimfit cup with V40 stem; CI, confidence intervals; Hybrid, Exeter Trident Series I cup with V40 stem; NZEU, New Zealand European.

* Significance set at $p < 0.05$; † log rank *p*-value for main effect of a given predictor; ‡ log rank *p*-value for survival rates of hybrid and cemented- unadjusted

Table 29. Total number of, and reasons for revision between hybrid and cemented primary total hip arthroplasty for osteoarthritis

Revision reason	Both Implants (n = 81)		Hybrid (n = 52)		Cemented (n = 29)		χ^2	p-value
Total (n)	81		52		29			0.046*
Infection (n, %)	25	30.86	17	32.69	8	27.59		0.8
Dislocations (n, %)	21	25.93	14	26.92	7	24.14		1
Periprosthetic fracture (n, %)	17	20.99	11	21.15	6	20.69		1
Pain (n, %)	6	7.41	3	5.77	3	10.34		0.66
Aseptic loosening (acetabulum) (n, %)	7	8.64	5	9.62	2	6.90		1
Loosening acetabulum (infection) (n, %)	2	2.47	1	1.92	1	3.45		1
other (fall, broken stem, hematoma, loosening stem) (n, %)	4	4.94	2	3.85	2	6.90	0.37	0.54

Abbreviations: Cemented, Exeter X3 Rimfit cup with V40 stem; Hybrid, Exeter Trident Series 1 cup with V40 stem; χ^2 , Chi squared

* Significance set at $p < 0.05$

6.4. Discussion

6.4.1. Survival

The 10-year crude implant survival indicated superior survival in the modern cemented THA. After accounting for baseline differences between groups using propensity score weighting, no evidence of an association between fixation type and revision risk was observed. Although the point estimate favoured cemented fixation, the confidence interval was wide and included the null value, reflecting limited precision due to the small number of revision events. As such, a clinically meaningful difference in revision risk cannot be excluded, but the available data do not support a statistically significant difference in survival between fixation types. These findings suggest broadly comparable medium- to long-term revision-free survival between hybrid and cemented total hip arthroplasty in this cohort.

Median follow-up time differed between groups, with hybrid implants followed for a median of five years compared with seven years for the cemented ones. This discrepancy reflects the later introduction of hybrid fixation during the study period. Although time-to-event methods account for censoring, a shorter observation window reduces the opportunity for revisions to occur and may overestimate early survivorship for the hybrid group (Serge Somda, 2021). However, the minimum acceptable number of at risk patients (>10%) at the end of the observation period for survival analysis (Pocock et al., 2002) was met, which is more likely to affect overall survival estimates. The consistency of adjusted findings nevertheless suggests that fixation type did not independently influence 10-year survival within the available follow-up period.

Although patients receiving the hybrid implant were significantly younger and had higher mean BMI than those receiving the cemented, these variables did not independently predict revision risk. While higher BMI (Onggo et al., 2020; Sayed-Noor et al., 2019) has traditionally been associated with greater mechanical loading and potential for early loosening, these effects may be mitigated by younger more active patients with good bone stock (Van Praet & Mulier, 2019) and advances in implant design and surgical technique. Longer-term follow-up is warranted to determine whether such demographic differences influence survival beyond 10-years.

Despite adjustment for key covariates, including age, sex, BMI, ASA score, ethnicity, and funding source, uncontrolled confounding cannot be excluded. Other unmeasured factors, such as activity level, rehabilitation (Chojnowska et al., 2024) smoking status (Ehnert et al., 2019), bone mineral density (Daher et al., 2024), surgical approach (Fagotti et al., 2021), surgical volume (Ravi et al., 2014), and surgical experience (Ravi et al., 2014), could also influence outcomes, but were not available for analysis. While these factors limit the ability to eliminate selection bias, the consistency of results across adjusted analysis suggests that fixation type itself was not an independent determinant of 10-year implant survival.

6.4.2. Reasons for revision

Although the low revision rate supports excellent implant performance in both implant groups, the small number of events limits power to detect small to moderate differences and explore causes. Future survival studies could prioritise larger, event-driven cohorts or pooled registry analysis with longer median follow-up. However, this approach would again introduce heterogeneity in patient demographics (ethnicity, socioeconomic status, etc). These differences may obscure true fixation related effects and complicate interpretation. This bias could be mitigated by adjusting for clustering by centre or surgeon to preserve internal validity while benefiting from greater precision.

6.4.3. Other indicators of primary total hip arthroplasty success

Success in THA extends beyond implant survival. Radiographic stability, absence of complications, and sustained improvements in pain, function, and quality of life reflected through patient-reported outcomes (PROMs) provide a more comprehensive measure of outcome (Pearce, Butcher, et al., 2025). Extended survival in presence of pain, dysfunction, and poor quality of life is indicative of poor patient outcome (Golinelli et al., 2022; Okafor & Chen, 2019). Low Māori observations in both THA cohorts indicates low uptake comparative to population norms, indicating possible systemic barriers (referral patterns, geographic access, financial constraints, limited culturally safe care) (Rahiri et al., 2018) and may present later with advanced disease state than non-Māori, despite a comparable burden of disease (Gleeson, 2023). Addressing inequality through culturally safe pathways, improved primary-specialist coordination and equitable rehabilitation access is critical to ensure functional benefits of THA are realised equitably across populations.

6.4.4. Decline in cemented total hip arthroplasty

Survival was comparable between the cemented and hybrid implant combinations examined in this population. Such a large shift away from cemented THA is puzzling, with cemented THA dropping to less than 5% of all THAs in NZ (McKie et al., 2024) since 2021 considering its excellent survival and affordability (Pennington et al., 2015). Possibilities may be heavy promotion within the market of cementless as “next generation”, perceived to offer easier revision and better long-term bone integration (Matthias et al., 2021), which seems to be driven largely by perception (Karuppall, 2016) and training patterns (Ryan et al., 2022). No peer-reviewed study that reliably quantifies the difficulty of revision (e.g., operative time, bone loss or

complication rate) by fixation type was identified. Several systematic reviews (Abdulkarim et al., 2013; Pearce, Butcher, et al., 2025; Van Praet & Mulier, 2019) acknowledged the preference for uncemented acetabulum fixation were unexplained by superior survival. However, one of the most clinically significant advantages of cementless acetabular systems is their modularity. Uncemented shells, including the Trident system used in the present study, accept a wide range of interchangeable polyethylene, ceramic, and dual mobility liners across multiple head sizes and offset configurations, affording the surgeon considerable intraoperative flexibility to optimise head-cup diameter ratios, bearing material, and stability characteristics for the individual patient (Bozic et al., 2009). The breadth of bearing options available with modular cementless systems has expanded substantially with the advent of HXLPE, dual mobility constructs, and large-diameter ceramic heads, making the cementless platform increasingly versatile for a wide range of patient profiles and activity demands. This modularity enables the surgeon to respond to intraoperative findings, acetabular size, bone quality, range of motion, and soft tissue tension, in a way that the all-polyethylene cemented cup, which is a fixed construct with limited intraoperative adjustability, does not allow.

Ryan et al (2022) noted only 37% of orthopaedic graduate candidates perceived their training in cementing techniques to be comprehensive, with 17% reporting non-existent training in cementing. A thorough understanding of cementation techniques is crucial to ensure a favourable outcome with a uniformly thick cement mantle; incorrect cementing can lead to the premature failure of the endoprosthesis (Faris et al., 2006). A further practical consideration cited in literature as contributing to the preference for uncemented acetabular fixation is operative efficiency: cementing the acetabular component requires a second cement mix and an additional 10–15 minutes of curing time compared to press-fit insertion of a cementless cup, with implications for theatre throughput in high-volume units. However, this has not been formally quantified in studies directly comparing acetabular fixation modes within a hybrid THA construct where the femoral stem is cemented in both groups. Surgical team familiarity with a specific implant system represents a further practical determinant of prosthesis selection. Retrospective analyses across arthroplasty procedures have demonstrated that both cumulative team operative experience and surgeon-scrub nurse familiarity are independently associated with significant reductions in operative time and complication rates, effects that extend beyond the individual surgeon to include the full theatre team (Parker et al., 2020).

Cost effectiveness and affordability may drive the decision to defer to one over the other, but a review (Veldman et al., 2021) identified cemented and hybrid THAs were both cost effective. Pennington (2015) surmised that quality of life after total hip arthroplasty was the main driver of cost effectiveness, rather than risk of revision. PROMs comparison between the same two implant combinations may reveal more detailed insights into which provides greater patient perceived value, complimenting survival data in guiding implant selection.

6.5. Conclusion

These results indicate that any difference in revision risk up to 10 years between fixation types, if present, is likely modest and remains uncertain within the constraints of available event numbers. PROMs evaluation of the population may provide valuable insight as an indicator of successful THA. The reduction of cemented THA use in the Bay of Plenty, NZ is not explained by inferior PROMs, however, longer follow up is required as differences may be observed beyond 10 years.

6.6. Limitations

Observational studies cannot support causal influences. While overall survival success is an important outcome, it is acknowledged that it is not the sole indicator of success in THA. Patient characteristics are also not the only predictors of outcomes. As over 90% of surgeries in this study were performed by the same surgeons, within the same hospitals, the possibility of additional surgical confounders has been mitigated in some respects. Lack of statistical significance where small sample sizes are evident warrant cautious interpretation. A standard group-to-group survival comparison requires a minimum of 66 events to reliably detect a large clinical difference (Hazard Ratio = 2.0) and 191 events to detect a moderate difference (Hazard Ratio = 1.5) therefore these results must be interpreted with caution due to the small incidence of events in this population.

Femoral head material and size were not evaluated as covariates in the survival analysis, and the distribution of both varied between the cemented and hybrid cohorts. Cobalt-chromium was the predominant head material in both cohorts; however, the proportion of ceramic heads differed, accounting for 15% of cases in the hybrid cohort compared with 5% in the cemented cohort. This difference introduces a potential confounding variable. As neither head material nor head size was adjusted for in the present analysis, residual confounding from these variables cannot be excluded, and any difference in revision rate or patient-reported outcome between the cemented and hybrid cohorts should be interpreted with this in mind.

A potential source of bias relates to the asymmetry in revision options available for the two fixation modes following dislocation. In the cementless cohort, a well-fixed but malpositioned or unstable shell can often be managed with a comparatively minor procedure; isolated liner or head exchange without removal of the osseointegrated shell; whereas no equivalent minor revision option exists for a cemented cup, where management of recurrent dislocation typically requires either non-operative measures or full cup revision with cement removal. This asymmetry may have introduced a surgeon-level threshold bias, whereby dislocation in the cemented cohort was more likely to be managed conservatively rather than surgically, potentially underestimating the true revision rate for dislocation in this group relative to the cementless cohort.

Chapter 7. Ten-year comparison of patient-reported outcome measures in hybrid and cemented primary total hip arthroplasty implants: A New Zealand regional study

Prelude: The preceding chapter examined implant survival between the Trident hybrid THA and fully cemented Rimfit THA. While crude analyses suggested superior survival in the modern cemented THA up to 10 years, this association was attenuated after adjustment for case-mix imbalance using propensity weighting, indicating that the unadjusted findings were likely confounded by baseline patient characteristics rather than reflecting true implant-level differences. Given the absence of robust survival differences after adjustment, the next step was to determine whether PROMs differed between the modern hybrid and cemented THA. Implant survival alone does not capture the full patient experience, particularly in the presence of systematic differences in patient characteristics between implant groups.

Accordingly, this study aimed to compare PROMs between the hybrid and cemented THA in the region over 10 years, incorporating patient characteristics and funding resource type as potential influential factors. This approach allows assessment of whether differences in PROMs exist independent of survival, and whether specific patient subgroups experience differential outcomes across implant constructs.

7.1. Introduction

Total hip arthroplasty (THA) is one of the most successful and frequently performed orthopaedic procedures worldwide (Evans et al., 2019), delivering substantial improvements in pain, mobility, and overall health-related quality of life for individuals with end-stage hip osteoarthritis (Vergari et al., 2024). As populations age and expectations for functional longevity continue to rise, long-term outcomes following THA have become increasingly important to patients, clinicians, and health systems (Patel et al., 2023). New Zealand (NZ), like many countries, is experiencing sustained growth in THA demand, accompanied by pressure on public health resources and heightened scrutiny of implant value, longevity, and equity of outcomes across demographic groups (Stilwell et al., 2025).

What constitutes the “optimal” method of implant fixation remains a topic of ongoing debate in THA practice. Options include cemented, uncemented, hybrid, and reverse hybrid constructs, each with differing theoretical advantages. Fully cemented fixation, particularly of the femoral component, has an established history of long-term success in primary THA for OA (Pearce, Joshi, et al., 2025a; Perticarini et al., 2024; Van Praet & Mulier, 2019). More recently, hybrid fixation, combining an uncemented acetabular component with a cemented femoral stem, has gained popularity. By 2023 in NZ, hybrid implant THA combinations had increased to ten times that of cemented combinations (McKie et al., 2024) despite minimal evidence to support this shift. Advocates of hybrid constructs cite improved biological fixation of the cup (González Della Valle et al., 2016), reduced challenges related to cementing of the acetabulum (Van Praet & Mulier, 2019), and reliable stability of the cemented stem (González Della Valle et al., 2016). Opposingly, advocates for cemented implant combinations cite excellent long-term survival (Pearce, Joshi, et al., 2025a), reduced periprosthetic fracture rates (Sassoon et al., 2024), and improved cost effectiveness (Veldman et al., 2021). Despite these differing philosophies, evidence comparing long-term patient-reported outcome measures (PROMs) between fixation types remains limited (Pearce, Butcher, et al., 2025; Van Praet & Mulier, 2019), and clinical practice may reflect surgeon training or preference rather than strong comparative data (Ryan et al., 2022). Existing literature comparing cemented and hybrid constructs has largely focused on implant survival and revision rates rather than patient-reported outcome measures. Only three studies available on this topic focussed exclusively on PROMs in cemented and hybrid implant comparison in osteoarthritis (Nilsdotter & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994), evaluated THAs performed between 1988 and 1998, and none of these studies extended PROM comparisons beyond 3.6 years follow-up (Pearce, Butcher, et al., 2025). All three studies showed very low certainty of evidence when evaluated, compared heterogeneous populations, used assorted PROMs tools and were limited in their analysis of influential patient factors on PROMs (Pearce, Butcher, et al., 2025). The studies reported improvements in PROMs for hybrid and cemented THA at their chosen follow-up periods of one (Norman-Taylor & Villar, 1997), two (Onsten & Carlsson, 1994), and three-and-a-half years (Nilsdotter & Lohmander, 2003) yet no significant differences in outcomes between the two constructs.

Long-term PROMs are increasingly recognised as critical to understanding the true durability of THA benefit (Baumhauer & Bozic, 2016; Lavalley et al., 2016; Quiceno et al., 2024; Yamate et al., 2023). Survivorship alone does not reflect the lived experience of pain, function, and quality of life a decade after surgery. A 10-year horizon allows assessment of sustained benefit, late decline, or divergence between implant combinations that may not be apparent in early follow-up. Patient factors that may influence these PROMs have direct implications for patient-specific implant selection, surgeon training, procurement decisions, and value-based care strategies within health systems. Broad comparison of various fixation methods has also been criticised as limited, identifying generalised trends, but lacking in detail needed to guide surgeon choice and it has been recommended that more detailed implant specific analysis be performed (Boyle et al., 2023; Boyle et al., 2022).

The Exeter® V40 cemented femoral stem is one of the most used and extensively studied stems internationally, with long-term reliability, low revision rate and high-level functional performances (Mahon et al., 2020; Mancino et al., 2023; Perticarini et al., 2024). When paired with the Exeter Rimfit™ (Rimfit) cemented acetabular component, this implant combination represents a fully cemented construct. In this region of interest, the Bay of Plenty in NZ, this combination shows equitable survival outcomes to the “gold standard” early generation Exeter Contemporary flanged™ cup (ECF) (Lamberton et al., 2023; Maggs et al., 2016; Pearce, Joshi, et al., 2025a). It is the most used cemented implant combination in NZ after the ECF cup (McKie et al., 2024), which is no longer in use. In the Bay of Plenty, the Exeter Trident hybrid combination (Trident) – pairing the Exeter V40 femoral stem with the Trident™ uncemented Series 1 acetabular cup – is a popular hybrid implant combination (McKie et al., 2024). Because both constructs share the same femoral stem and differ only in acetabular fixation, they provide a uniquely controlled opportunity to compare the PROMs of two fixation strategies while minimising implant design confounding. Thus, the aim of this study was to firstly compare 10-year PROMs following primary THA for osteoarthritis using the Trident (hybrid) and Rimfit (cemented) constructs, using a large and detailed regional dataset and secondly determine influential patient factors such as sex, age, body mass index (BMI), comorbidity status, ethnicity, and funding pathway (public or private).

7.2. Methods

7.2.1. Data source and collection

Anonymised, prospectively collected PROM data were obtained for primary THAs performed between 1 January 2003 and 30 June 2023 for osteoarthritis, with either an Exeter X3 Rimfit (cemented) (Rimfit) or an Exeter Trident series 1 acetabular cup (uncemented) (Trident) and a cemented Exeter V40 stem (Stryker, Mahwah, NJ) in the Bay of Plenty region of NZ. Patient data were extracted from the Tauranga Orthopaedic Research (TOR) regional registry when presenting with at least one PROM at any of the timepoints of interest. TOR is a non-profit organisation that independently maintains a comprehensive registry of all THA procedures performed in the region, separate from the NZJR. With patient consent, data are prospectively entered into SOCRATES software (version 3.5.8.26 10150). PROMs are routinely collected preoperatively and at 1-year, 5-years and subsequently at 5-year intervals. These PROMs include the Oxford Hip score (OHS), Western Ontario

and McMasters university Osteoarthritis index (WOMAC), and Veterans RAND 12-item Health Survey (VR-12) physical and mental component scores. The University of Waikato Human Research Ethics Committee (HREC2023#12) granted ethical approval for this study. This study was conducted and reported in accordance with the STROBE guidelines (von Elm et al., 2007).

7.2.2. Patient-reported outcome measures

Preoperative PROMs consisted of scores collected before surgery. Follow-up intervals were defined as 1-year (10-14 months postoperatively), 5 years (4-6 years postoperatively), and 10 years (9-11 years postoperatively). To facilitate clinical interpretation between implants cohorts and their patient subgroups (sex, age, body mass index [BMI], American Society of Anaesthesiologists [ASA] rating, funding source, and ethnicity), minimal clinically important difference (MCID) thresholds were calculated using a distribution-based approach. Each MCID was set at 0.5 times the standard deviation of the preoperative score for each cohort (Molino et al., 2022). Although intended to describe within-patient change (Deckey et al., 2023), MCID was applied here to aid interpretation of between-group differences to assess their potential clinical relevance. Score differences exceeding the threshold were considered clinically meaningful (Beard et al., 2015).

7.2.3. Patient characteristics

Collected demographic and clinical categorical parameters included sex (male, female), ASA grade (1-4), funding source (public, private), and ethnicity (NZ European, Māori, Other). Age and BMI were treated as continuous variables. The “Other” ethnicity represented a small heterogeneous group (Rimfit $n = 5$, Trident $n = 26$) and was excluded when examining the influence of ethnicity on PROMs. Due to low frequency, patients classified as ASA 4 were reclassified as ASA 3 (Rimfit $n = 7$, Trident $n = 12$) to allow for sufficient representation in statistical models. Funding source (public, private) was used as a proxy indicator of socioeconomic status.

7.2.4. Statistical analysis

All analyses were conducted in RStudio (Vienna, Austria) (Posit, 2023), with methodological oversight from a specialist in public health statistics and biostatistics. Missing data were handled using pairwise (available case) deletion, meaning that all available observations were used for each analysis without requiring complete data across all variables. Missing data may be due to incomplete questionnaires, non-returned questionnaires, or study withdrawal. Baseline distribution of categorical variables (sex, ASA rating, funding source, and ethnicity) and continuous variables (age, BMI) were summarised for each implant type, along with mean OHS, WOMAC, and VR-12 scores obtained preoperatively and at 1, 5 and 10 years postoperatively. Missing data resulting from incomplete or unreturned questionnaires or study withdrawal were handled using pairwise deletions, ensuring that all available data were retained for analysis. Comparisons of categorical variables between implants were conducted using Chi-squared or Fisher’s exact tests, as appropriate. Continuous variables (age, BMI, and PROMs) were compared using independent students t -tests or Welch’s t -tests, as appropriate. Normality was assessed using visual inspection of histograms and Q–Q plots. Due to the incomplete pairing of preoperative and postoperative data, independent t -tests were used for temporal comparisons. Variations in PROM scores

between successive follow-up intervals within each cohort were assessed using analysis of variance (ANOVA) with post-hoc Tukey testing. Postoperative OHS values below 27 were classified as “poor” and associated patient characteristics were descriptively analysed separately. Multiple linear regression was used to determine patient characteristics independently associated with preoperative and postoperative PROMs within each cohort. Model diagnostics included assessment of residual plots (normality of residuals was assessed visually using Q-Q plots), influence statistics, variance inflation factors, and the Durbin-Watson statistic. Preoperative scores were included as covariates in postoperative models, and variables significantly associated with preoperative outcomes were excluded from postoperative models to minimise confounding. Minor deviations from normality were observed in untransformed postoperative OHS and WOMAC scores in both cohorts. However, given the large sample size and the exploratory nature of the analysis, these deviations were not expected to bias parameter estimates. Statistical significance was defined as $p < 0.05$ and all results were reported with corresponding 95% confidence intervals [lower, upper].

7.3. Results

We identified 2331 (Trident $n = 1229$, 52.7% of total), Rimfit $n = 1102$, 47.3% of total) THAs with at least one PROM. In the Trident cohort, there was a significantly higher proportion of males ($p < 0.001$, 11.3% greater), publicly funded ($p < 0.001$, 21.9% greater), Māori ethnicity ($p < 0.001$, 5.5% greater), and “Other” ethnicity ($p < 0.001$, 1.6% greater). We noted a significantly higher proportion of NZ Europeans ($p = 0.02$, 4.8% greater), higher mean age ($p < 0.001$, 2.6 years older) and lower BMI ($p < 0.001$, 1.21 kg.m² lower) in the Rimfit cohort (Table 30). Cobalt-chromium was the predominant head material in both groups, accounting for 95% of heads in the cemented cohort and 85% in the hybrid cohort, with the remaining 15% of hybrid heads being ceramic; no ceramic heads were used in the cemented cohort. Femoral head size distribution also differed: in the cemented Rimfit cohort, 56% of heads were 32 mm and 38% were 28 mm, whereas in the hybrid Trident cohort, 83% of heads were 32 mm, with 28 mm and 36 mm heads each accounting for 8%.

Table 30. Comparison of implant patient characteristics between a hybrid and cemented primary total hip arthroplasty for osteoarthritis

	Both Implants	Trident	Proportion	Rimfit	Proportion	p- value
Total	2331	1229	52.72%‡	1102	47.3%‡	-
Age (mean ± SD)	-	68.78 ± 9.58		71.39 ± 8.52		<0.001*
BMI (mean ± SD)	-	29.21 ± 5.70		28.00 ± 4.93		<0.001*
Sex, n ¶						
Male	1055	632	51.42%	423	38.38%	<0.001*
Female	1276	597	48.58%	679	61.62%	<0.001*
Funding, n ¶						
Public	1329	828	67.37%	501	45.46%	<0.001*
Private	999	401	32.63%	598	54.26%	<0.001*
Missing †	3	0	0.00%	3	0.27%	-
ASA, n ¶						
1	314	168	13.67%	146	13.25%	0.813
2	1430	770	62.65%	660	59.89%	0.185
3 and 4	550	272	22.13%	278	25.23%	0.090
Missing †	37	19	1.55%	18	1.63%	-
Ethnicity, n ¶						
NZEU	2090	1074	87.39%	1016	92.20%	0.020*
Māori	184	129	10.50%	55	4.99%	<0.001*
Other	31	26	2.12%	5	0.45%	<0.001*
Missing†	26	0	0.00%	26	2.36%	-

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, Body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup.

† Missing values have not been included in proportion difference calculations

‡ Percentage represents proportion of total sample

¶ Percentage represents proportion within specific implant type

* Significance set at $p < 0.05$

7.3.1. Patient-reported outcomes measures

PROMs comparisons between and within cohorts can be found in Table 31. Significant differences were noted in all preoperative PROMs, with Trident showing significantly poorer preoperative scores across tools ($p < 0.001$). No significant differences were noted at 1, 5, and 10 years postoperatively between the implants, except for the Trident 1-year VR-12 physical score being significantly better than the Rimfit ($p < 0.033$), and its 10-year VR-12 mental score being significantly worse than the Rimfit ($p = 0.047$). For each implant, ANOVA testing revealed a significant difference between preoperative and 1-year scores across tools ($p < 0.001$). In the Rimfit, no significant difference between 1-year, 5-year, and 10-year scores was noted. In the Trident, no significant difference between 1-year and 5 years was noted, but a significant drop in VR-12 physical scores was noted between 5-year (44.12 ± 11.14) and 10-year (41.20 ± 10.74 , $p = 0.031$), yet the drop in score (2.9) is still well below the MCID of 4.11.

7.3.2. Poor postoperative patient-reported outcome measures

A total of 106 OHS scores <27 were identified (Rimfit n = 53, 4.3%; Trident n = 53, 4.8%. (Supplementary Table 4). The two implant cohorts were similar in age (71.6 ± 8.3 y; 68.1 ± 9.96 y), with no significant differences in any of the examined patient characteristics between the cemented and the hybrid implants.

7.3.3. Linear regression: Preoperative patient-reported outcome measures

Funding source and ASA grade significantly influenced all preoperative PROMs (Table 32 and Table 33). Public patients and those with ASA 3 grade had significantly poorer scores than private patients and those with lower ASA grades. For every PROM, public funding was associated with worse preoperative scores that exceeded the MCID. PROMs of patients with ASA 3 grade also exceeded the MCID for VR-12 physical scores in both implant groups, and for VR-12 mental scores in the Rimfit cohort. Increased BMI was a negative predictor of OHS, while female sex was associated with poorer WOMAC, VR-12 physical, and VR-12 mental scores. Māori ethnicity was additionally associated with poorer VR-12 mental scores in both implant groups and exceeded the MCID in the Rimfit cohort. The R^2 values ranged from 0.12 to 0.31 across regression analyses.

7.3.4. Linear regression: Postoperative patient-reported outcome measures

Preoperative scores and age at surgery were consistent significant predictors of postoperative scores in all PROMs in both cohorts, except in the VR-12 mental postoperative scores in the cemented Rimfit cohort (Table 34 and Table 35). BMI was a significant predictor of WOMAC and VR-12 physical postoperative scores in the Trident cohort and the VR-12 mental postop scores in the Rimfit. In the Rimfit cohort, Māori ethnicity was identified as an additional significant predictor of poorer postoperative PROMs compared to non- Māori, with poorer OHS by ~5 points, WOMAC by ~6 points, and VR-12 physical by ~8 points. However, the small number of Māori patients (n = 36) with postoperative scores requires cautious interpretation. The R^2 values ranged from 0.08 to 0.14 across regression analyses.

Table 31. Comparison of preoperative and postoperative patient-reported outcome measures between a hybrid and cemented primary total hip arthroplasty for osteoarthritis

	Rimfit					Within Rimfit ANOVA ¶	Trident					Within Trident ANOVA ¶	Between implant t- test	
	n	Mean	SD	Diff [95% CI] †	MCID ‡	p-value	n	Mean	SD	Diff [95% CI] †	MCID ‡	p-value	p-value	Diff [95% CI]
Oxford (0-48)														
Preop	837	18.23	±8.96		4.48		861	15.36	±8.36		4.18		<0.001	2.87 [2.04, 3.70]
1-year postop	842	41.29	±7.42	23.06 [22.25, 23.82]		<0.001*	953	41.80	±7.92	26.44 [25.47, 27.41]		<0.001*	0.159	0.51 [0.20, 1.22]
5-year postop	490	42.88	±6.85			0.002*	521	42.54	±7.50			0.336	0.451	0.34 [-0.54, 1.22]
10-year postop	124	41.64	±8.67			0.409	133	42.27	±6.56			0.989	0.517	0.63 [-1.26, 2.52]
WOMAC Total (0-96)														
Preop	827	54.23	±18.51		9.26		850	60.70	±18.37		9.19		<0.001	6.47 [4.69, 8.25]
1-year postop	810	14.12	±14.09	40.15 [38.60, 41.71]		<0.001*	935	13.71	±15.50	46.99 [44.92, 49.07]		<0.001*	0.550	0.41 [-0.94, 1.76]
5-year postop	483	12.41	±14.29			0.259	505	13.87	±16.63			0.998	0.131	1.46 [-0.44, 3.36]
10-year postop	124	15.38	±17.23			0.256	129	14.88	±14.06			0.944	0.801	0.50 [-3.38, 4.38]
VR-12 Physical ($\bar{x}$ = 50)														
Preop	836	27.61	±8.21		4.11		857	25.97	±7.66		3.83		<0.001*	1.64 [0.88, 2.40]
1-year postop	840	44.01	±10.57	17.05 [16.12, 17.97]		<0.001*	946	45.09	±10.73	19.12 [17.91, 20.33]		<0.001*	<0.033	1.08 [0.09, 2.07]
5-year postop	487	44.43	± 10.37			0.876	514	44.12	±11.14			0.301	0.649	0.31 [-1.02, 1.64]
10-year postop	125	42.23	± 11.34			0.111	130	41.20	±10.74			0.031*	0.458	1.03 [-1.70, 3.76]
VR-12 Mental ($\bar{x}$ = 50)														
Preop	836	46.36	±12.76		6.38		857	42.58	±13.37		6.69		<0.001*	3.78 [2.53, 5.03]
1-year postop	840	53.31	± 9.40	6.49 [5.49, 7.48]		<0.001*	946	52.76	±9.70	10.19 [8.82, 11.55]		<0.001*	0.224	0.55 [-0.34, 1.44]
5-year postop	487	53.97	± 10.00			0.711	514	52.78	±9.50			1	0.054	0.19 [-0.02, 2.40]
10-year postop	125	55.16	± 8.86			0.691	130	52.80	±10.01			1	0.047*	2.36 [0.03, 4.69]

Abbreviations: CI, confidence interval; Diff, difference; MCID, Minimal clinically important difference (distribution-based); Preop, preoperative; Postop, postoperative; Rimfit, Exeter X3 Rimfit cup; SD, standard deviation; Trident, Exeter Trident Series 1; VR-12,

Veterans Rand 12-item health survey; WOMAC, Western Ontario and McMaster Universities Index.

† Difference calculated between the mean preoperative score and the mean 1-year postoperative score

‡ MCID calculated using the distribution method of 0.5 x SD of the preoperative score

¶ with post hoc Tukey

* Significance level set at $p < 0.05$

Table 32. Preoperative patient-reported outcome measure linear regression for the Exeter Trident (hybrid) implant in primary total hip arthroplasty for osteoarthritis

Predictor	Sample (n)	R ²	F-Statistic	DF	Trident				Interpretation
					Estimate	STD Error	t-value	p-value	
Oxford preop (0-48)	774	0.30	46.98	7, 740				<0.001*	
(intercept)					26.85	1.42	18.89	<0.001*	Baseline: Private funding, ASA 1
Funding (Public)					-9.00	0.56	16.12	<0.001*	Public patients score 10 points worse than private patients
ASA 2					-1.30	0.80	-1.62	0.107	
ASA 3					-3.48	0.94	-3.72	<0.001*	ASA 3 patients score ~3.5 points worse than ASA 1 patients
BMI					-0.12	0.05	-2.71	0.007*	
WOMAC total preop (0-96)	812	0.25	68.53	4, 807				<0.001*	
(intercept)					46.04	1.85	24.91	<0.001*	Baseline: Female, private funding, ASA 1
Funding (Public)					18.01	1.24	14.58	<0.001*	Public patients score 18 points worse than private patients
ASA 2					3.30	1.73	1.90	0.057	
ASA 3					7.61	1.99	3.83	<0.001*	ASA 3 patients score ~8 points worse than ASA 1 patients
Sex (Male)					-3.43	1.12	-3.05	0.002*	Females score ~ 3.5 points worse than males
VR12 physical preop ($\bar{x}$ = 50)	819	0.15	36.01	4, 814				<0.001*	
(intercept)					30.91	0.81	38.24	<0.001*	Baseline: Female, private funding, ASA 1
Funding (Public)					-5.30	0.55	-9.67	<0.001*	Public funding ~5 points worse physical health to private
ASA 2					-1.48	0.76	-1.95	0.051	
ASA 3					-3.78	0.87	-4.34	<0.001*	ASA 3 patients score ~4 points worse than ASA 1 patients
Sex (Male)					1.14	0.50	2.29	0.022*	Males score ~1 point better physical health than females
VR12 Mental preop ($\bar{x}$ = 50)	819	0.12	21.85	5, 813				<0.001*	
(intercept)					49.90	1.45	34.53	<0.001*	Baseline: Female, private funding, ASA 1, NZ European
Funding (Public)					-8.03	0.99	-8.13	<0.001*	Public funding ~8 points worse mental health to private
ASA 2					-2.05	1.36	-1.51	0.133	
ASA 3					-3.61	1.57	-2.30	0.022*	ASA 3 patients score ~3.5 points worse than ASA 1 patients
Sex (Men)					1.83	0.89	2.05	0.040*	Males score ~2 points better mental health than females
Ethnicity (Māori)					-4.48	1.44	-3.11	0.002*	Māori score ~4.5 points worse than NZ European patients

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, F-statistic; HRQOL, health-related quality of life; Preop, preoperative; Std, standard; WOMAC, Western Ontario and McMaster Universities; Arthritis Index; VR-12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$

Table 33. Preoperative patient-reported outcome measure linear regression for the X3 Rimfit (cemented) implant in primary total hip arthroplasty for osteoarthritis

Exeter X3 Rimfit									
Predictor	Sample (n)	R ²	F-Statistic	DF	Estimate (β)	STD Error	t-value	p-value	Interpretation
Oxford preop (0-48)	767	0.31	67.07	5, 762				<0.001*	
(intercept)					30.91	1.61	19.23	<0.001*	Baseline: Female, private funding, ASA I
BMI					-0.27	0.06	-4.73	<0.001*	↑ BMI → ↓ Oxford score
Sex (Male)					1.98	0.57	3.53	<0.001*	Males score ~ 2 points better than females
Funding (Public)					-8.25	0.58	-14.28	<0.001*	Public patients score ~ 8 pts worse than private
ASA (2)					-2.10	0.80	-2.64	0.009*	ASA 2 score ~ 2 points worse than ASA 1
ASA (3)					-3.50	0.94	-3.70	<0.001*	ASA 3 score ~ 3.5 points worse than ASA 1
WOMAC total preop (0-96)	758	0.29	60.45	5, 753				<0.001*	
(intercept)					28.71	3.38	8.47	<0.001*	Baseline: Female, private funding, ASA (1)
BMI					0.52	0.12	4.36	<0.001*	↑ BMI → ↑ (worse) WOMAC
Sex (Male)					-3.98	1.18	-3.37	<0.001*	Females score ~ 4 points worse than males
Funding (Public)					16.25	1.22	13.35	<0.001*	Public patients score ~ 16 points worse than private
ASA (2)					5.10	1.66	3.06	0.002*	~ 5 points worse than ASA (1)
ASA (3)					7.85	1.99	3.96	<0.001*	~ 8 points worse than ASA (1)
VR-12 physical preop (x̄ = 50)	763	0.20	38.37	5, 764				<0.001*	
(intercept)					38.08	1.60	23.74	<0.001*	Baseline: Female, private funding, ASA (1)
BMI					-0.20	0.06	-3.64	<0.001*	↑ BMI → ↓ physical HRQOL
Sex (Male)					2.05	0.56	3.64	<0.001*	Males score 2 points better physical HRQOL than female
Funding (Public)					-5.56	0.58	-9.64	<0.001*	Public funding ~5.5 points worse physical HRQOL to private
ASA (2)					-3.56	0.79	-4.50	<0.001*	~3.5 points worse physical HRQOL than ASA (1)
ASA (3)					-4.21	0.94	-4.47	<0.001*	~4 points worse physical HRQOL than ASA (1)
VR-12 mental preop (x̄ = 50)	824	0.15	29.16	5, 819				<0.001*	
(intercept)					52.28	1.11	47.00	<0.001*	Baseline: Female, private funding, non-Māori, ASA (1)
Sex (Male)					2.79	0.86	3.25	0.001*	Males score ~ 3 points better mental HRQOL than females
Funding (Public)					-6.80	0.88	-7.76	<0.001*	Public funding ~7 points poorer mental HRQOL to private
ASA (2)					-3.30	1.22	-2.70	0.007*	~ 3 points worse mental HRQOL than ASA (1)
ASA (3)					-6.48	1.42	-4.56	<0.001*	~ 6.5 points worse mental HRQOL than ASA (1)
Ethnicity (Māori)					-6.25	1.82	-3.44	<0.001*	Māori score ~ 6 points worse mental HRQOL

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, F-statistic; HRQOL, health-related quality of life; Preop, preoperative; Std, standard; WOMAC, Western Ontario and McMaster Universities; Arthritis Index; VR-12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$

Table 34. Postoperative patient-reported outcome measure linear regression for the Exeter Trident (hybrid) implant in primary total hip arthroplasty for osteoarthritis

Predictor	Sample (n)	R ²	F statistic	DF	Trident				Interpretation
					Estimate	STD Error	t-value	P-value	
Oxford postop (0-48)	559	0.08	12.15	2, 556				<0.001*	
(intercept)					42.86	2.66	16.11	<0.001*	Baseline
Oxford preop					0.24	0.04	6.14	<0.001*	Each 1-point ↑ preop → 0.24-point ↑ postop → better postop
Age at surgery					-0.07	0.04	-2	0.046*	Each 1-point ↑ BMI → 0.07-point ↓ postop → worse postop
WOMAC postop (0-96)	482	0.10	17.64	3, 478				<0.001*	
(intercept)					-25.36	6.96	-3.65	<0.001*	Baseline
WOMAC preop					0.20	0.04	5.49	<0.001*	Each 1-point ↑ preop → 0.20-point ↑ postop → poorer postop
BMI					0.35	0.12	2.96	0.003*	Each 1-point ↑ BMI → 0.35-point ↑ postop → worse postop
Age at surgery					0.24	0.08	3.19	0.002*	Each 1 year ↑ age at surgery → 0.24-point ↑ postop → worse postop
VR12 physical postop ($\bar{x}$ = 50)	496	0.14	26.85	3, 492				<0.001*	
(intercept)					61.67	5.05	12.21	<0.001*	Baseline
VR12 physical preop					0.34	0.06	5.97	<0.001*	↑ preop physical scores ↑ postop → better postop
BMI					-0.32	0.08	-3.95	<0.001*	Each 1-point ↑ BMI → 0.32-point ↓ postop → worse postop
Age at surgery					-0.24	0.05	-4.74	<0.001*	Each year ↑ is a 0.24 ↓ in postop → worse postop
VR12 mental postop ($\bar{x}$ = 50)	558	0.13	39.57	2, 55				<0.001*	
(intercept)					50.46	3.19	15.84	<0.001*	Baseline
VR12 mental preop					0.25	0.03	8.31	<0.001*	higher preop mental health scores predict better postop
Age at surgery					-0.12	0.04	-2.99	0.003*	Each year ↑ is a 0.12 ↓ in postop → worse postop

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, F-statistic; Preop, preoperative; Postop, postoperative; PROMs, patient-reported outcome measures; Std, standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$.

Table 35. Postoperative patient-reported outcome measure linear regression for the Exeter X3 Rimfit (cemented) implant in primary total hip arthroplasty for osteoarthritis

Exeter X3 Rimfit cup									
Predictor	Sample (n)	R ²	F statistic	DF	Estimate (β)	STD Error	t-value	P-value	Interpretation
Oxford postop (0-48)	607	0.08	18.55	3, 604				<0.001 *	
Intercept					44.77	2.671	16.76	<0.001*	Baseline: Ethnicity (NZEU)
Oxford preop					0.181	0.034	5.36	<0.001*	↑ preop score → higher postop Oxford → better postop
Age at surgery					-0.093	0.035	-2.63	0.009*	↑ age → lower postop Oxford → worse postop
Ethnicity (NZ Māori)					-4.925	1.441	-3.42	<0.001*	NZ Māori score ~5 points lower → worse postop
WOMAC postop (0-96)	585	0.08	18	3, 582				<0.001 *	
Intercept					-13.14	5.032	-2.61	0.009*	Baseline: Ethnicity (NZEU)
WOMAC preop					0.18	0.03	5.63	<0.001*	↑ Preop WOMAC → ↑ postop WOMAC → worse postop
Age at surgery					0.24	0.07	3.52	<0.001*	Each 1 year ↑ is a 0.24 ↑ postop WOMAC → worse postop
Ethnicity (NZ Māori)					5.83	2.69	2.17	0.031*	NZ Māori score ~ 6 points higher → worse postop
VR-12 physical postop (x̄ = 50)	612	0.11	27.14	3, 609				<0.001 *	
Intercept					58.06	3.85	15.07	< 0.001 *	Baseline: Ethnicity (NZEU)
VR-12 physical preop					0.23	0.05	4.75	< 0.001 *	↑ Preop VR12 Physical → ↑ postop VR12 Physical → better postop
Age at surgery					-0.27	0.05	-5.65	< 0.001 *	Each 1-year ↑ is a 0.27 ↓ in postop → worse postop
Ethnicity (Māori)					-7.56	1.88	-4.03	< 0.001 *	Māori associated with ~8 point lower postop → worse postop
VR-12 mental postop (x̄ = 50)	563	0.14	45.76	2, 561				<0.001 *	
Intercept					46.54	2.77	16.83	< 0.001 *	Baseline
VR12 mental preop					0.26	0.03	8.73	< 0.001 *	Each 1-point ↑ preop → 0.26-point ↑ postop → better postop
BMI					-0.19	0.08	-2.48	0.014*	↓ BMI → 0.19 point ↑ postop → better postop

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, body mass index; DF, degrees of freedom; F-Stat, f-statistic; Preop, preoperative; Postop, postoperative; PROMs, patient-reported outcome measures; Std, standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR- 12, Veterans Rand 12-item health survey.

* Significance set at $p < 0.05$.

7.4. Discussion

PROMs following cemented Rimfit and hybrid Trident THA were examined using one of NZ's most comprehensive regional arthroplasty datasets, incorporating PROMs captured preoperatively and at 1, 5, and 10 years. The TOR regional database used in this study provides detailed and longitudinal PROMs, surgical data, and demographic characteristics across a diverse population. This richness of data supports rigorous long-term comparative analysis between implant types while accounting for demographic and service-delivery differences. Across all analyses, several consistent themes emerged that collectively highlight the complexity of interpreting outcomes and the importance of contextualised regional data.

The results demonstrate that fixation type does not meaningfully influence postoperative PROMs up to 10 years. Instead, the strongest and most consistent predictors of postoperative PROMs were the preoperative scores themselves. Patients who entered surgery with poorer physical or mental health almost universally achieved lower postoperative PROMs, independent of fixation or surgical factors. The linear regression findings corroborate literature demonstrating that preoperative PROMs are the most powerful predictors of postoperative functional results after hip arthroplasty (Grits et al., 2023; O'Connor et al., 2022; Pearce, Joshi, et al., 2025b; Ren et al., 2023; Zhang et al., 2022). Factors such as public funding, higher ASA classification, female sex, older age, and higher BMI have been associated with poorer preoperative status, which in turn can lead to less favourable outcomes (Golinelli et al., 2022; Pearce, Joshi, et al., 2025b). Importantly, the observed decline in VR-12 physical component score at long-term follow-up may reflect the compounding influence of patient age and comorbidity burden, as well as elevated BMI rather than any deterioration in the function of the operated hip itself (Cole et al., 2025). Thus, age and BMI serve as key variables linking patient-level health trends to generic physical health measures, a phenomenon not captured by joint specific PROMs. These findings highlight that within this region disparities are established well before surgery and that clinical improvement after THA is heavily influenced by where patients start. Poorer postoperative outcomes in Māori in the cemented Rimfit cohort need to be interpreted with caution due to the low numbers of Māori postoperative scores but demonstrates the low uptake of THA in Māori. Bourke et al. (2023) identified competing responsibility, disrupted mana (feeling disempowered), and systemic abdication as a probable contributing factor to healthcare accessibility for Māori (Bourke et al., 2023). Socioeconomic inequities may also contribute to inequity in THA uptake (Cohen-Levy et al., 2022; Loring, 2022). Further in-depth research into why Māori are not accessing THA services in this region would be beneficial and would assist to further develop strategies to promote higher uptake of THA services when needed, which improves quality of life, reduces pain, and dysfunction.

Both implant combinations demonstrated significant improvements in the mean OHS, WOMAC, and VR-12 physical and mental scores from preoperative to 1-year postoperatively. OHS, WOMAC, and VR-12 mental component scores also remained stable between 1, 5, and 10-year follow-up indicating sustained joint-specific and mental health outcome over the long-term. However, a statistically significant decline in the VR-12 physical

score of 2.92 points (less than the MCID of 3.83) was noted in the Trident between 5 and 10 years postoperatively ($p < 0.033$). Similarly, there was a decline of 2.1 points (less than the MCID of 4.11) in the Rimfit cohort which did not reach statistical significance. Unlike OHS and WOMAC, which exclusively evaluate hip specific pain, function, and stiffness (Pulik et al., 2020); the VR-12 physical component captures broader aspects of physical health and mobility, encompassing the impact of comorbidities and age-related decline in overall physical functioning (Selim et al., 2019). As such, a reduction in VR-12 physical score over time may reflect deterioration in patient general health or the onset of new medical conditions unrelated to the hip arthroplasty (Cole et al., 2025), while the preserved joint specific scores indicate the hip function itself remained well maintained (Pulik et al., 2020). The stability of the VR-12 mental scores supports this interpretation, suggesting that psychological wellbeing did not account for the observed change in physical health status (Benyamini et al., 2025; Lynch et al., 2021). These findings highlight the importance of interpreting generic and joint-specific PROMs in tandem to distinguish between prosthesis related outcomes and broader health trajectories as patients age following hip replacement (Cole et al., 2025; Golinelli et al., 2022). Patients receiving the Trident implant demonstrated significantly greater change scores from preoperative to 1-year in all tools compared to those receiving the Rimfit. However, despite significantly poorer baseline PROMs in the hybrid cohort, postoperative PROM scores were comparable between fixation groups, indicating convergence of patient-reported outcomes at long-term follow-up.

Finally, although factors such as funding pathway, ASA classification, and BMI consistently influenced PROMs, the explanatory power of the models remained modest (R^2 0.08–0.31). This low power highlights an important limitation of conventional comorbidity classification systems: They are too broad to capture specific conditions that meaningfully influence pain, function, and mental health. More granular comorbidity data, particularly related to chronic pain disorders, mental health conditions, metabolic disease, and social determinants, are needed to advance PROMs research and improve equity-driven, patient-centred care.

A distinctive strength of this research lies in the use of a rich regional registry. Unlike national joint registries, which often dilute local variation through aggregation, regional datasets provide a nuanced understanding of population-specific strengths and inequities. In this context, the ability to track PROMs longitudinally within a defined region allowed clearer identification of local disparities, cultural influences, and system-level factors relevant to Māori and publicly funded patients. Such information would be obscured in nationwide analyses.

7.5. Conclusion

This study demonstrates that implant choice is unlikely the driver of outcome variation in this population. Rather, preoperative health status and sociodemographic context shape postoperative recovery. Regional PROM-rich registries are essential for revealing these patterns, which may be diluted in large registry data analysis, and can guide more equitable and targeted improvements in arthroplasty care across NZ and serve as a model internationally.

7.6. Limitations

Several limitations should be acknowledged. External generalisability may be constrained, as findings reflect a specific regional cohort. Heterogeneity between implant groups may have influenced comparisons, and potential ceiling effects of the PROMs may have reduced sensitivity to detect clinical meaningful differences. Residual and unmeasured confounding, including factors like surgical approach and rehabilitation adherence, cannot be excluded. The broad comorbidity classification may not have fully captured disease severity, and the modest explanatory power of the models suggest additional unmeasured factors likely contributed to outcomes. As an observational study, casual inferences cannot be made.

Femoral head material and size were not evaluated as covariates in the survival analysis, and the distribution of both varied between the cemented and hybrid cohorts. Cobalt-chromium was the predominant head material in both cohorts; however, the proportion of ceramic heads differed, accounting for 15% of cases in the hybrid cohort compared with 5% in the cemented cohort. This difference introduces a potential confounding variable, as ceramic heads have been reported to produce modestly lower linear wear rates on cross-linked polyethylene compared with cobalt-chromium heads, although this has not been shown to translate into a significant difference in revision rate or functional outcome.

Chapter 8. Summary and recommendations

Prelude: The preceding chapter demonstrated that differences in PROMs between hybrid and fully cemented THA for OA in the region were most apparent in the preoperative period, with consistent patient-level factors predisposing certain groups to poorer baseline scores. Across implants, preoperative PROMs were the strongest predictor of postoperative PROMs, reinforcing the central importance of patient characteristics and preoperative status in shaping recovery trajectories.

This Discussion chapter synthesises the findings of the Thesis, returning to the original research questions and situating the results within the context of modern THA. It considers what was initially sought, what was ultimately found, and how these findings refine current understanding of implant performance, patient-reported outcomes, and survival beyond implant-level comparisons alone. The implications of these findings are discussed in relation to patients, clinicians, and health systems, including policy makers and joint registries, with particular attention to patient selection, expectation management, and interpretation of registry-reported outcomes. The strengths and limitations of the Thesis are critically appraised, and key considerations for future research are identified, particularly in relation to equity, preoperative optimisation, and the role of PROMs in evaluating long-term success after THA in the Bay of Plenty region of NZ.

8.1. General summary

This thesis aimed to evaluate long-term survival and PROMs following THA for OA, with a particular focus on the performance of specific cemented and hybrid implant constructs and the influence of patient characteristics and funding source on outcomes. Using national registry data and regional longitudinal PROM data, this work sought to move beyond broad fixation categories and revision-based definitions of success, towards a more implant-specific and patient-centred assessment of implant performance.

The systematic review (Part 1, Chapter 2) demonstrated that while THA for OA is widely regarded as a cost-effective and successful intervention, there is moderate-to-high bias and very low overall certainty in evidence of superior outcomes for cemented over hybrid THA due to few high-quality studies and the presence of methodological heterogeneity (Pearce, Butcher, et al., 2025). Specifically, five studies addressed survival outcomes (Bloemheuvel et al., 2022; Jämsen et al., 2014; Kandala et al., 2015; Mäkelä et al., 2008; Pedersen et al., 2014) and three studies reported PROMs (Nilsson & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994) for hybrid and cemented. Substantial heterogeneity existed between studies in implant constructs, patient characteristics (particularly age), PROM tools, follow-up duration, and analytical methods. Across the eight included studies, patient characteristics were rarely incorporated into analyses of implant survival or PROM outcomes beyond restricted age-bands and sex in some cases. No difference in 10-year survival between the two THA implants was identified, however, long-term studies of 15 and 16 years indicated superior cemented survival outcomes. Included studies indicated no difference in short- to medium-term PROMs with follow up of 1, 2, and 3.6 years at most (Nilsson & Lohmander, 2003; Norman-Taylor & Villar, 1997; Onsten & Carlsson, 1994). There was a notable absence of long-term PROM data. All identified studies were derived from European cohorts spanning several decades, limiting relevance to modern practice and to health systems outside Europe. The limited adjustment for patient-level characteristics and the frequent use of age-restricted cohorts highlight an important gap in the existing literature. This limitation is particularly relevant given growing evidence that baseline patient factors strongly influence postoperative PROMs (Grits et al., 2023; Harris et al., 2022; Pearce, Joshi, et al., 2025b; Robins et al., 2026), underscoring the need for analyses using broader, more representative cohorts with comprehensive covariate adjustment. Overall, the identified gaps highlighted the need for modern, implant-specific analyses using standardised methodology and extended PROM follow-up, particularly outside of Europe with the inclusion of patient characteristics as possible predictors of survival and PROMs. In this context, NZ joint registry and TOR data provided a unique opportunity to examine survival and PROM outcomes within a defined healthcare system, while accounting for patient and funding factors relevant to regional and national decision-making.

In the first section of Part 2, Chapter 3 used NZJR data to compare survival outcomes of an earlier generation and modern cemented THA for OA to determine whether the successor implant was a suitable replacement given not all implants perform equally (Wyatt et al., 2021). Both cemented THAs used identical cemented stems but were implanted within different eras (2003 to 2013 and 2010 to 2023, respectively). There was no

significant difference in 10-year survival outcomes between the predecessor and its successor cemented implant despite temporal separation in their periods of use (Pearce, Joshi, et al., 2025a), substantiating it as a suitable replacement for its predecessor. Both the predecessor and successor cemented THAs demonstrated survival rates that exceeded 95% at 10 years, indicating durable outcomes consistent with 10-year performance of NZ and international cemented THAs (Bissias et al., 2021; Clar et al., 2024; Kunutsor, Barrett, et al., 2019; Kunutsor, Beswick, et al., 2019; Mäkelä et al., 2014; McKie et al., 2024). Survival outcomes were not affected by age, sex, BMI, ethnicity, ASA rating, or funding source. These findings suggest that both the predecessor and successor cemented THAs in the Bay of Plenty region of NZ provide robust survival outcomes across different eras of surgical practice and patient cohorts over time. Both implants also demonstrated no 10-year difference in reasons for revisions, with low dislocation (0.8%), infection (0.61%), and aseptic loosening (0.24%) rates comparative to reported revision rates elsewhere (Kandala et al., 2015). The findings suggest that implant type did not substantially influence underlying mechanisms of failure. From a clinical perspective, no significant difference in survival indicates both designs are comparable in terms of stability and fixation durability.

In the second section of Part 2 (Chapter 4), long-term PROMs of the earlier generation cemented THA implanted for OA from TOR registry data were examined over 15 years to establish a benchmark for comparison use in Chapter 5 and Chapter 7, with particular emphasis on patient-level predictors of poorer outcomes. OHS scores (0-48) identify hip specific pain and function outcomes higher values indicating positive outcomes. WOMAC score (0-96) identifies more detailed function, stiffness and pain for osteoarthritis with an aim for lower scores. VR-12 scores indicate health related quality of life in both physical and mental health domains with population standardised score of $50 \pm 1SD$ for each. This analysis confirmed excellent PROMs (OHS >41) in this earlier generation cemented THA up to 10 years and very good PROMs (OHS >34) up to 15 years based on OHS thresholds (Kalairajah et al., 2005). The findings from Chapter 4 indicate long-term, consistent, and positive PROM outcomes from the earlier generation cemented THA (Pearce, Joshi, et al., 2025b). Sex and funding source significantly influenced all preoperative scores (OHS, WOMAC, VR-12 physical, VR-12 mental), with BMI also influencing preoperative OHS and WOMAC scores. Females, public funding, and greater BMI were significant predictors of poorer preoperative PROMs. Preoperative PROMs were identified as the most influential predictor of all postoperative scores. Older age at surgery and higher ASA rating also significantly contributed to poorer postoperative physical function (WOMAC, VR-12). These findings reinforce the importance of not only considering the effect of implant type on outcomes, but also the effect of patient characteristics and funding source on preoperative scores, which significantly influence postoperative scores (Appiah et al., 2023; Orr et al., 2022). Ethnicity was not identified as a predictor of PROMs; however, only 3.5% and 4.5% of THA patients identified as Māori or of 'Other' ethnicity in the registry, reducing statistical power and robust inferences. Considering Māori represents 29% of the Bay of Plenty region, and 17% of the NZ population, uptake of surgery by Māori is relatively poor (*Māori Population estimates: At 30 June 2022*). Patients with poorer preoperative PROMs may require additional preoperative support, encompassing both functional and mental health strategies to improve postoperative outcomes. Patients presenting with older age

at surgery and/or higher ASA ratings may require additional postoperative support. Further investigation into mechanism for additional support in these identified groups are needed for this region of NZ.

In the third section of Part 2, Chapter 5 extended this work by using TOR registry data to compare 10-year THA PROMs of the modern cemented THA with those of the early generation cemented THA, hence comparing the successor cemented THA to its predecessor. Only one study has previously directly compared outcomes of these two cemented THA for osteoarthritis up to 5 years postoperatively, but with both THAs using a rim cutter device. No significant differences in OHS and Harris hip scores between the two were noted (vanWinterswijk et al., 2017). This identified a gap in long-term PROMs comparison of the modern cemented THA and its early generation predecessor. Rather than a 15-year observation, it was only possible to assess up to 10 years due to the successor implant's reduced time in circulation. Within each THA cohort, there were no significant difference between 1, 5, and 10-year postoperative PROM scores, indicating stability of outcomes over 10 years for both implants. Both THAs demonstrated excellent OHS PROMs based on established thresholds (Kalairajah et al., 2005), and no significant difference in physical PROMs (OHS, WOMAC, and VR-12 physical) between implants up to 10 years. This finding indicates positive physical outcomes for both cemented THAs that are sustained over a 10-year period, despite differing implantation eras. Significantly poorer mental quality of life (VR-12 mental) preoperatively and at 1 and 5 years in the earlier generation cemented THA was noted. This result may reflect differences in baseline psychological profiles or early postoperative experiences between groups (Aspari & Lakshman, 2018). However, at 10 years, there was no longer any significant difference in mental quality of life scores. In line with findings from Chapter 3, poorer baseline PROMs were again identified as a significant predictor of poorer postoperative PROMs in both THA groups. The same patient and funding factors identified in the 15-year predecessor study (female sex, public funding, and greater BMI) were also associated with poorer outcomes in the successor implant. In addition, ASA 3 rating was identified as a significant preoperative predictor of poorer baseline PROMs, suggesting that comorbidity burden may significantly impact outcomes. The concordance across implants strengthens the evidence that patient factors, in addition to implant design, play a central role in determining long-term outcomes following THA. With both survival and PROMs of the earlier generation and modern cemented implants showing no significant differences in long-term outcomes, the Thesis progressed to comparing the survival outcomes of the modern cemented THA with a modern hybrid THA.

The first section of Part 3 (Chapter 6) analysed NZJR data to compare 10-year survival of the modern cemented and hybrid THAs, expecting that hybrids would demonstrate superior outcomes given it now represents a substantial proportion (45%) of THAs in NZ (McKie et al., 2024). Significant differences in patient characteristics were observed at baseline between the cemented and hybrid THA groups, with the hybrid group exhibiting a younger mean age at surgery, a greater BMI, and a higher proportion of male, Māori, and publicly funded patients. While crude Kaplan-Meier analyses suggested superior survival in cemented (97.0%) than hybrid (95.9%) reaching statistical significance, this difference was no longer significant after propensity-weighted Cox regression was applied to account for the differences in patient characteristics. These findings challenge

assumptions that hybrid fixation results in better survival outcomes. There were no significant patient or funding predictors of survival outcomes. Having explored survival outcomes between the modern cemented and hybrid THAs, the Thesis moved to comparing PROMs between the implants as complementary indicators of success in THA for OA.

The second section of Part 3 (Chapter 7) therefore evaluated PROMs up to 10 years for the modern cemented and hybrid THAs from the TOR registry. Similar to the NZJR analysis, significant differences in patient characteristics between the cohorts were identified. Hybrid patients were more likely to be funded publicly and exhibited a younger mean age at surgery, greater mean BMI, and higher proportion of males and Māori compared to the cemented THA patients. Hybrid THAs reported significantly poorer baseline PROMs across tools, likely reflecting differences in underlying patient case-mix rather than implant-related factors. Hybrid fixation was more frequently used in patients with higher BMI and in Māori, male, and younger patients. Postoperatively, no significant differences in PROMs were noted between the cemented and hybrid cohorts at 1, 5, and 10 years, except where the hybrid VR-12 physical score at 1-year was significantly better than the cemented, and the 10-year cemented VR-12 mental score was significantly better than the hybrid. The lack of significant differences between implants over time may partly reflect ceiling effects of the PROM instruments used, whereby postoperative scores approach the upper limits of the scale, limiting the ability to detect further improvement or between-group differences. Nevertheless, the convergence of postoperative scores also suggests that both the cemented and hybrid THA were effective in improving PROMs, even among patients with poorer baseline PROM scores and health status. These findings reinforce the importance of considering both baseline PROMs and change scores when interpreting postoperative outcomes in observational cohorts. Regression analysis identified the same factors as significant predictors of baseline PROMs (funding, sex, and ASA rating), with the addition of ethnicity for VR-12 mental preoperative PROMs. Public funding, female sex, ASA 3 rating, and Māori were significant predictors of poorer preoperative PROMs, and poorer preoperative PROMs, increased age at surgery, and greater BMI were significant predictors of poorer postoperative PROMs. This Chapter, consistent with Chapters 4 and 5, demonstrated that postoperative outcomes in THA are influenced predominantly by preoperative scores, health status, and funding source rather than fixation type. The key findings from Part 2 and Part 3 that relied on the TOR and NZJR data are summarised in Table 36.

Table 36. Summary of key findings per Thesis chapter

Thesis	Aims	Findings
Part 2, Chapter 3		
Ten-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis (NZJR)	1. Compare survival outcomes of an earlier generation and modern cemented THA. 2. Identify if patient characteristics, funding source and/or implant type were predictors of survival outcomes.	• No significant difference in survival between modern (97.9% [95.9, 98.2]) and early generation (95.6% [93.4, 97.9]) cemented THA for OA. • Both cemented THAs demonstrated superior survival than broad category cemented implants in NZ (94.8%) recorded by NZJR. • No patient characteristics or funding factors investigated significantly predicted survival outcome. • No significant difference in reasons for revision between cemented THA implants. • Despite different eras, both cemented THAs provide lower revision risk than the recommended benchmark of <5% at 10 y.
Part 2, Chapter 4		
PROM outcomes up to 15 years of an early generation cemented THA (TOR)	1. Determine a benchmark for long-term cemented PROMs. 2. Identify if patient characteristics and funding source were predictors of long-term PROMs.	• Significant improvements in baseline PROMs noted 1-year postop, maintained at 5, 10, and 15y. • Provided excellent PROMs (OHS >41) up to 10 years and very good scores (OHS >35) up to 15 y. • Significant predictors of poor baseline PROMs were public funding, female sex, and greater BMI. • Poorer baseline PROMs, higher ASA rating, and greater age at surgery were significant predictors of poorer postoperative PROMs. • Low R² values indicated additional factors may influence PROMs.
Part 2, Chapter 5		
PROM outcomes up to 10 years of early-generation and modern cemented THAs (TOR)	1. Compare PROMs of the modern cemented THA with its predecessor to determine if it represents a suitable replacement. 2. Identify if patient characteristics and funding	• Significant improvement in baseline PROMs noted at 1y in modern cemented THA that were maintained at 5 and 10 y. • No significant difference in physical function PROMs between cemented THAs at any time point. • Modern cemented THA cohort exhibited superior mental health PROMs preop and at 1 and 5 y postop, but no difference to early generation at 10y. • Predictors of poorer preop PROMS were consistent in both cemented THAs, with the addition of ASA 3 rating in the modern cemented THA.

source were predictors of long-term PROMs

- Predictors of poorer postop PROMs were consistent in the two cemented THAs. Preop PROMs are the most influential predictor of postop PROMs.
- In the modern cemented THA, Māori ethnicity was identified as an additional significant predictor of poorer post PROMs.

Part 3, Chapter 6

Survival outcomes up to 10 years of modern cemented and hybrid THAs (NZJR)

1. Compare survival outcomes of an earlier generation and modern cemented THA.
2. Identify if patient characteristics, funding source and/or implant type were predictors of survival outcomes.

- Hybrid THA survival (95.9% [94.7, 97.0]) was similar to the NZJR mean hybrid (95.11%) survival rate at 10 y.
- Crude analysis indicated significant survival differences, with superior survival in hybrid than cemented THA.
- After propensity weighting, no significant difference in survival between hybrid and cemented was noted.
- No significant patient characteristics or funding source predicted survival in either the modern cemented or hybrid THA.

Part 3, Chapter 7

PROM outcomes up to 10 years of modern cemented and hybrid THAs (TOR)

1. Compare PROMs between a modern cemented and hybrid THA.
2. Identify if patient characteristics and funding source were predictors of long-term PROMs

- Significant improvements in baseline PROMs were noted at 1y and maintained to 10y postoperatively.
- Baseline PROMs in the hybrid cohort were significantly poorer than the modern cemented THA.
- Physical HRQOL score was better in the hybrid cohort at 1 y
- Mental HRQOL scores were significantly better preoperatively and at 10 y in the cemented THA.
- Predictors of poorer preoperative PROMs were consistent in both THA cohorts, with the inclusion of ethnicity in mental preop scores in the hybrid THA.
- Predictors of postoperative PROMs included baseline scores as the most influential predictor, followed by greater age at surgery, and with the addition of ethnicity in the hybrid THA.

Numbers in brackets represent 95% confidence intervals [95% CI]

Abbreviations: HRQOL, health-related quality of life; NZJR, New Zealand Joint Registry; OHS, Oxford Hip score; postop, postoperatively; PROMs, patient-reported outcome measures; preop, preoperatively; THA, total hip arthroplasty; TOR, Tauranga Orthopaedic Research Inc; y, years

8.2. Synthesis

We hypothesised that hybrid THA would demonstrate superior implant survival and PROM outcomes compared with cemented fixation, given it has become the predominant mode of THA in NZ, accounting for approximately 45% of procedures, compared with fewer than 5% using fully cemented fixation (McKie et al., 2024). Several important observations were identified throughout this Thesis.

8.2.1. Early generation and modern cemented outcomes

Comparing the early generation and modern cemented THA revealed no significant difference in 10-year survival, with both implants exceeding the accepted 95% benchmark (Kandala et al., 2015). These findings extend prior 5-year comparative outcomes (vanWinterswijk et al., 2017), which reported radiographic and PROM results but did not evaluate survivorship, by demonstrating maintained performance at 10 years. To my knowledge, this represents the only identified direct long-term survival comparison of these two cemented implants in primary THA for OA.

The documentation of 15-year PROMs for the early generation cemented THA represents one of the first long-term PROMs evaluations of this cemented implant, establishing a benchmark (Pearce, Joshi, et al., 2025b). This implant demonstrated sustained excellent outcomes up to 10 years and very good outcomes up to 15 years based on established OHS thresholds (Kalairajah et al., 2005). PROMs were stable across early, mid-, and long-term follow-up, and predictors of both preoperative and postoperative scores were identified over time. Furthermore, comparison with the modern cemented THA demonstrated no significant difference in 10-year PROMs, with consistent predictors of outcome observed, supporting no functional difference between implant generations. While derived from a single regional population, this study draws on a large cohort of over 1,600 patients treated within a consistent healthcare system, enhancing internal validity and supporting the relevance of these findings to comparable settings.

8.2.2. Modern cemented and hybrid outcome comparison

Significant differences in baseline characteristics were observed between the hybrid and modern cemented cohorts in the survival and PROMs analyses. These differences likely reflect both patient and system level factors. The following section considers potential explanations for these disparities and their implications for implant survival and long-term PROMs.

The composition of the hybrid cohort may in part reflect differences in surgeon decision-making and practice patterns, which can influence both patient and implant selection. Such variation within orthopaedic practice represents a recognised source of selection bias in observational cohort studies, as individual surgeons' preferences and thresholds for operating may shape cohort composition beyond clinical indication alone (Keding et al., 2019). For example, if one surgeon practices predominantly in the private sector and preferentially uses cemented fixation, while others perform hybrid procedures primarily in public practices, the

resulting cohorts may differ systematically according to surgeon practice rather than true differences in patient characteristics.

In a UK national survey of 101 surgeons, 60% of surgeons surveyed would choose hybrid, 31% uncemented, and 9% cemented THA implants. For patients 70 years or older, 55% of surgeons surveyed would choose hybrid, 11% uncemented, 33% cemented, and 1% reverse hybrid. The most influential patient characteristics involved in surgeon preference were patient age and activity level (Baji et al., 2025). The preferential use of hybrid fixation in younger and male patients, as found in this Thesis, is commonly justified by assumptions regarding superior bone stock, perceived biological advantages of osseointegration, and easier revision (Lindgren et al., 2018). However, these rationales are largely based on biological constructs and surgical convention rather than robust comparative evidence and have rarely been formally evaluated in long-term outcomes studies (Howard et al., 2011; Lindgren et al., 2018). Clement et al. (2019) identified no significant evidence to support the claim that younger patients benefitted from improved fixation using uncemented acetabular cups.

Although the cohorts differed in baseline characteristics, no significant differences in implant survival or postoperative PROMs were identified after adjusting for these differences using propensity weighting between the hybrid and cemented cohorts in the Bay of Plenty region of NZ. The only significant difference was poorer preoperative PROMs among patients receiving hybrid THAs, a finding that may be explained by the greater representation of publicly funded patients in this cohort, who typically present with worse baseline PROMs (Tynkkynen & Vrangbaek, 2018).

8.2.3. Survival outcomes

Although crude survival analysis identified differences between the hybrid and cemented THA cohorts, the significance of this difference was no longer evident after propensity weighting. In weighted analysis, fixation type did not drive meaningful differences in survival outcomes with both THAs demonstrating no significant difference in long-term performance after accounting for patient characteristics and funding source. Despite their proven durability, the use of fully cemented THA has declined to less than 5% in NZ (McKie et al., 2024), Australia, UK, and USA (Paxton et al., 2019; Zhang, 2017). As differences between fixation types may emerge beyond the first decade, examining outcomes beyond 10 years remains important to inform long-term implant selection (Fowler et al., 2019; Pedersen et al., 2014).

Although uncemented acetabular fixation is often perceived to be easier to revise than cemented fixation, largely because it does not require cement removal, there is limited empirical evidence directly comparing the revision complexity between fixation methods (Fowler et al., 2019; Van Praet & Mulier, 2019). Cemented cups are frequently described as technically demanding to revise when the cement mantle is well interlocked, with removal potentially time-consuming and associated with additional bone loss (Stevens et al., 2018). Retained cement fragments may complicate reaming and reconstruction, particularly when interdigitated with host

bone. These factors contribute to a perception that cemented acetabular components may pose greater technical challenges at revision. Conversely, others argue that cemented components may offer certain advantages at revision. The cement-bone interface can be visualised and “debonded” facilitating controlled removal (Maggs & Wilson, 2017). In cases where loosening has already occurred, polyethylene cemented cups may occasionally be removed with the cement mantle, potentially limiting further bone loss (Judas et al., 2015). In contrast, while some surgeons report that uncemented implants can be removed with minimal collateral damage using appropriate techniques (Goplen & Munro, 2024), deep osseointegration, porous coatings, and screw fixation may be associated with increased risk of bone loss (Goplen & Munro, 2024; Judas et al., 2011).

In clinical practice, perceived revision difficulty appears to depend more on contextual factors than fixation method alone, including bone quality, extent of osseointegration, prior surgical technique, and surgeon experience (Chung et al., 2025; Zhang, 2017). Importantly, much of the available literature reflects surgeon-reported experience rather than controlled comparative trials. Without robust evidence demonstrating superior revision outcomes for either fixation type, shifts in utilisation patterns should not be driven solely by perceptions of revision complexity.

8.2.4. Patient-reported outcomes

Extended survival, although an essential outcome, is not the only determinant of THA success. PROMs are an important consideration in the overall success of THA. Poor quality of life, pain, and impaired function are also indicators of poorer outcomes (Golinelli et al., 2022). Although observational studies are limited in their ability to define causation, they can identify associations between risk factors and a response variable. This Thesis identified significant improvements in PROMs at 1-year post surgery, and excellent scores based on OHS thresholds (Kalairajah et al., 2005) consistent across the early generation, modern cemented, and hybrid THA cohorts. These positive outcomes were maintained up to 10 years, reinforcing the value of these THA options in Bay of Plenty OA populations. When comparing the modern constructs, preoperative PROMs were significantly poorer in the hybrid compared to the modern cemented THA, yet postoperative PROMs in general were not significantly different. As such, the improvement in PROM outcomes postoperatively can appear superior if relying only on the change in scores from preoperative, but doing so may be misleading as does not account for baseline differences and the ceiling effects inherent to PROM instruments (Harris et al., 2016).

8.2.4.1. Preoperative patient-reported outcomes

This Thesis identified that patient-specific factors and funding source influenced preoperative status. Public funding, female sex, greater BMI, and higher ASA rating negatively influenced baseline PROM scores, consistent with previous research (Onggo et al., 2020; Seddigh et al., 2021). These factors do not necessarily change the revision risk or implant survival, but they set the trajectory for improvement by influencing where patients start (Boyer et al., 2019). This finding recognises that disparities in PROMs begin before surgery, and not necessarily after.

Female sex was associated with poorer baseline functional and mental health scores, which may predispose them to postoperative dissatisfaction (Jüni et al., 2010). Studies show that females are less likely to be referred to a specialist, more likely to oppose surgery due to competing responsibility, and generally need more information before deciding on surgery (Jüni et al., 2010). Females are also likely to have higher rates of depression, lower back pain, and comorbidities than males (Clement et al., 2020; Patel et al., 2020). Consistent with our observations, Greene et al. (2021) identified that patients using public funding pathways for THA report poorer PROMs than those in private settings. This observation may be due to increased wait times; however, evidence is inconsistent (Hirvonen et al., 2009). Public patients may also be overweight with higher comorbidity status (Tynkkynen & Vrangbaek, 2018). In NZ, Māori are more likely to be public patients (Reid et al., 2022). Competing responsibility (prioritising work and family), disrupted *mana*³, and systemic abdication may explain their under-representation as THA patients (Bourke et al., 2023). Socioeconomic deprivation may also represent potential sources of health inequity for Māori (Loring, 2022).

While indices such as ASA may be predictors of THA outcomes, they provide limited guidance for individualised treatment as specific conditions influence recovery differently (Podmore et al., 2018). Several studies highlight the value of documenting comorbidities in greater detail (Jämsen et al., 2013; Podmore et al., 2018; Reisinger et al., 2025). Hazard ratios are also affected by cardiac, endocrine, oncological, and mental health conditions in both univariate and multivariate analysis (Jämsen et al., 2013). It may be beneficial for joint registries to record more detailed comorbidity data and pursue future comorbidity data analysis to determine which specific comorbidities may predict the poorest outcomes.

8.2.4.2. Postoperative patient-reported outcomes

In both cemented and hybrid THA cohorts across the Chapters of this Thesis, preoperative PROMs were the single strongest predictor of postoperative PROMs, consistent with prior literature (Harris et al., 2022; Huber et al., 2019; Kim et al., 2017). This finding holds for both physical (OHS, WOMAC, VR-12 physical) and VR-12 mental health scores and is consistent across the timepoints of 1, 5, and 10 years. This Thesis further demonstrates that age at surgery and ethnicity are independent predictors of postoperative PROMs, with older age and NZ Māori associated with lower postoperative scores. Collectively, these findings indicate that patient-level factors, rather than implant characteristics alone, meaningfully shape patient outcomes following THA. For clinical practice, this finding supports the use of preoperative PROMs and demographic factors to identify patients at higher risk of poorer outcomes, enabling a more realistic expectation setting, culturally responsive care, and targeted preoperative support. From a systems perspective, these results reinforce the need to include quality improvement efforts before THA, such as optimisation of mental health, addressing comorbidity burden, and considering social context prior to surgery (Rogers et al., 2022).

³ Mana- Power, authority, or prestige; *spec.* (in Polynesian and Melanesian religions) an impersonal supernatural power which can be associated with people or objects, and which can be transmitted or inherited.

8.2.5. Equity

In this Thesis, equity emerged as a central consideration in evaluating outcomes following THA. Female sex, public funding, and Māori ethnicity were independently associated with poorer PROMs, identifying groups at risk of less favourable PROMs. Although THA is regarded as an effective procedure, women, publicly funded, and non-white patients are more likely to present with greater comorbidity burden, higher rates of periprosthetic joint infection, and increased revision risk (Tucker & Mont, 2023). Importantly, disparities in outcomes persist even within insured or managed care populations, indicating that differences in sex and ethnicity are not fully explained by socioeconomic status (Okike et al., 2022). Sex, funding, and ethnicity-based inequities in healthcare utilisation therefore have wide-reaching implications for both individual patients and health systems (Stone et al., 2019).

Public funding status reflects broader systemic inequalities within the NZ health system. Publicly funded patients experience poorer pain, function, and quality of life outcomes compared with private patients (Pearce, Joshi, et al., 2025b; Snell et al., 2019). Despite increasing procedure volumes, publicly funded THA rates have not kept pace with population growth (Harcombe et al., 2016), potentially exacerbating existing inequities in access and outcomes. Māori patients demonstrated lower uptake of THA in this region, consistent with national data and patterns in knee arthroplasty (Gleeson, 2023; McKie et al., 2024). A large NZ registry study (2019, using 2005–2017 data on >53,000 hip replacements) found Māori had the highest age-standardised rate of hip replacements, followed by European/others and Pacific, with Asian having the lowest rate (Lao et al., 2019). Despite the same risk of being diagnosed with osteoarthritis, Māori are less likely to undergo THA and TKA (Gleeson, 2023). Evidence suggests that providing support to address transport and financial barriers, including home-based rehabilitation programmes, can promote equitable outcomes for Māori (Cate et al., 2023). Māori patients also frequently present with poorer preoperative general health (Singleton et al., 2013), likely to influence postoperative PROMs. A recent scoping review highlighted the need for Māori led research into surgical disease, care pathways, and preoperative experiences for Māori (Rahiri et al., 2025).

While area-level deprivation indices have been associated with increased healthcare utilisation following THA (Grits et al., 2022), geographic or deprivation-based measures were not included in this Thesis. This decision was made to prioritise individual-level characteristics and funding pathway variables. Funding source was included as a marker of healthcare access pathway. While funding source may be associated with socioeconomic factors, it does not capture the multidimensional nature of socioeconomic status and was not interpreted as a direct surrogate for socioeconomic status. Nonetheless, deprivation, funding status and ethnicity are interrelated and future analysis incorporating validated deprivation indices may further clarify the structural drivers of inequity. Systematic collection of baseline PROMs provides an opportunity to identify inequities early and support equitable models of care. Expanding routine PROMs collection to include

preoperative baseline PROMs within the NZJR would enable more equitable risk stratification, targeted intervention, and evaluation of efforts to reduce disparity of THA outcomes.

8.2.6. Patient-reported outcome model variance

Although patient characteristics and funding sources significantly influenced PROMs, the models explained only a modest portion (between 7 and 34%) of the variance. There are many factors affecting long-term pain, function, and satisfaction that were not quantified in this Thesis, such as smoking status (Ehnert et al., 2019; Matharu et al., 2019; Yue et al., 2022), activity level (Reine et al., 2022), medication use (Nguyen et al., 2016), postoperative rehabilitation, social determinants of health (Stisen et al., 2024), and deprivation index (Dubin et al., 2024; Gordon et al., 2025).

Smokers are reported to exhibit lower preoperative scores compared to non-smokers (Khan et al., 2009; Matharu et al., 2019), show a greater decline in PROMs (Hesseling et al., 2019) particularly between 6 months and 1-year (Yue et al., 2022), and exhibit an increased postoperative use of painkillers and anti-inflammatories (Khan et al., 2009). Patients who use narcotics prior to THA may be more likely to suffer from opioid-induced hyperalgesia after surgery and have worse clinical outcomes. When possible, efforts should be made to use other modes of analgesia or wean patients from their use prior to THA (Pivec et al., 2014). Patients with a history of chronic opioid use who successfully decreased their use of opioids before surgery had substantially improved clinical outcomes that were comparable to patients who did not use opioids at all (Nguyen et al., 2016). Reine et al. (2022) noted both active and mildly active patients preoperatively achieved better absolute outcomes following THA than non-active patients. Tailoring exercise rehabilitation for patients (Stisen et al., 2024) and early rehabilitation lead to improvements in THA outcomes (Chojnowska et al., 2024). Education in the perioperative period promotes guidance to perform rehabilitation exercises, improves hospitalisation experience, increases participation in rehabilitation, allows early mobilisation, and increases functional potential, altogether enabling faster reintegration into society (Nicolau et al., 2022). These preoperative factors are important to document, as they influence both short- and long-term outcomes in THA. Collecting this information allows for risk stratification, personalised rehabilitation and pain management, and more accurate interpretation of baseline PROMs. PROMs are essential, not optional, for understanding outcomes.

8.2.7. Cost effectiveness

The lack of significant differences in survival and postoperative PROM outcomes raises questions about the relative value of hybrid components in the context of cost effectiveness. Indeed, the absence of demonstrable survival or PROM advantage for hybrid over cemented fixation has economic and policy implications, particularly cost implications. Cemented prostheses often have the lowest upfront cost (Pennington, Grieve, Sekhon, et al., 2013) and are less expensive than hybrid ones (Van Praet & Mulier, 2019). Many models show lower lifetime costs for cemented THA when revision and utility outcomes are considered, although hybrid implants may be more cost-effective in some age groups if they deliver superior quality-adjusted life years

(Pennington et al., 2015). Implant survival alone is an incomplete measure of success, as patients may experience persistent pain or functional limitation for years without undergoing revision, generating real but often unmeasured costs to patients and health systems. In this context, higher implant cost cannot be justified without corresponding improvements in patient-centred outcomes or reductions in downstream healthcare utilisation. The widespread adoption of hybrid fixation appears to have preceded the availability of robust long-term PROM data, highlighting how surgical practice may evolve in response to training norms (Ryan et al., 2022), perceived innovations (Sharkey et al., 1999; Wasterlain et al., 2017), and market forces/vendors (Burns et al., 2009) rather than outcome-based evidence. The Thesis findings support a more critical appraisal of implant value and underscore the importance of integrating PROMs alongside survival when evaluating fixation strategies at a population level.

Cemented THA is a highly mature technology with excellent long-term survival, leaving limited scope for further measurable gains in pain, function, or quality of life. Any theoretical biological or biomechanical advantages of hybrid constructs may therefore be insufficient to translate into meaningful patient-perceived benefit, particularly given the ceiling effects observed in commonly used PROMs (Harris et al., 2016). In addition, hybrid fixation was preferentially used in younger patients with poorer baseline PROMs in this Thesis, creating the appearance of greater postoperative improvement despite similar end-state outcomes. Once baseline status was accounted for using weighted analytic approaches, outcome trajectories converged, reinforcing the conclusion that fixation method did not materially influence patient-reported recovery. The results of the three PROMs studies (Chapter 4, 5, and 7) underscore the critical value of regional PROMs-rich registries in identifying predictors of poorer PROMs to support more equitable, contextually informed arthroplasty care. Collectively, these findings suggest that when specific implant constructs are examined and patient characteristics appropriately accounted for, both cemented and hybrid THAs can deliver excellent long-term survival and PROMs. Differences in outcomes appear more strongly driven by patient-level factors than by fixation strategy alone.

Although this Thesis cannot conclude that cemented THA is superior to hybrid, the findings challenge the assumption that modern hybrid THAs confer improved survival or PROMs compared with well-performing cemented constructs. It is acknowledged that this Thesis did not test “cemented versus hybrid” as broad categories but tested specific modern implant constructs. Furthermore, the population examined has distinct patient selection, funding, and demographic patterns. Rather than limiting generalisability, the distinct characteristics of the NZ population provide an opportunity to examine implant performance in patient groups often under-represented in clinical trials.

8.3. Implications

8.3.1. Patients and communities

For patients, the findings from this Thesis are important as revision surgery represents only one dimension of success following THA. Many patients may live for years with persistent pain, functional limitation, or reduced quality of life without undergoing revision (Cheng et al., 2025). Outcomes are invisible when implant survival is the sole measure of success. No significant survival differences between implants does not necessarily equate to equivalent patient experience. This work matters to patients because it focuses on outcomes that reflect lived experience rather than technical success alone. Patients care about how they *feel*, not what implant they have. Patients do not experience “hybrid fixation” or “cemented fixation”. They experience pain, mobility, and ability to work, parent, sleep, and participate in life. More expensive and more commonly used implants do not necessarily make patients feel better. Many patients may be labelled as “success” despite ongoing pain, stiffness, or poor mental wellbeing when revision is the only outcome considered.

Implant choice can affect access and equity. Healthcare budgets are finite. If money is spent on more expensive implants without clear benefit, it is not spent on reducing waiting times, rehabilitation, or support for high-risk patients. Patients are often reassured with claims that “this is a better implant”, however, their sex, ethnicity, baseline pain and function, comorbidities, mental health, and social context matter more than fixation strategy. True informed consent requires honest discussion of likely outcomes based on evidence, not marketing narratives. Patient characteristics, including baseline function, exert a greater influence on postoperative experience than fixation strategy, underscoring the need for personalised decision-making and equitable allocation of healthcare resources. Patients deserve treatments that improve how they live, not just how long an implant lasts. The promotion of early engagement and education about OA management and surgical pathways to reduce late presentation with more advanced disability may improve uptake (Nicolau et al., 2022). Expanding culturally appropriate preoperative optimisation (both physical and mental) (Rahiri et al., 2022) and shared decision-making resources (Rahiri et al., 2025), especially targeted to publicly funded, female, and Māori patients, may begin to address the inequity seen in this Thesis.

8.3.2. Clinicians

For surgeons, survival is not the only outcome to determine success of primary THA for OA. Systematically incorporating preoperative PROMs into clinical consultations may guide realistic expectations and assist in tailoring prehabilitation (van Koningsveld-Couperus et al., 2025). Using preoperative PROMs to triage patients and personalise care pathways (e.g., enhanced rehabilitation or psychosocial support for low baseline scores) may address modifiable needs without compromising timely access to surgery (Kim et al., 2017). Although informative, the reporting rate of PROMs within the NZJR is not powerful enough in terms of total THA population representation to perform comprehensive subgroup or regional comparisons. Baseline PROMs are currently not recorded in the registry, although the 2024 report mentions introducing their capture in the future (McKie et al., 2024). Given that this Thesis demonstrates baseline PROMs predict postoperative PROMs,

and that poor PROMs at 1 and 2 years are associated with increased revision risk (Ackerman et al., 2024; Eneqvist et al., 2018), baseline PROM collection should be introduced to the NZJR as a matter of urgency. Patient factors are important to consider when providing primary THA for OA. While no significant differences in postoperative PROMs were identified between the hybrid and cemented THA cohorts in general, patient characteristics and funding models are reported to influence timing of surgery, not captured in this Thesis. Public patients (Pilc et al., 2025), females (Mannion et al., 2015), and individuals with greater BMI (Mukka et al., 2020) and higher ASA present later, wait longer, and begin at worse baseline function (Golinelli et al., 2022). These aspects contribute to prolonged pain and disability, reduced work participation, greater psychosocial burden, and higher preoperative risk. The complexity and risk associated with THA surgeries increase with higher BMI and ASA ratings, being associated with longer operative times, higher complication risks (Bonney-Mazure et al., 2025; Matar et al., 2020), and increased resource use, physiotherapy needs, and readmissions (Girardi et al., 2019) postoperatively.

Higher BMI and comorbidity burden influence surgical complexity, affecting case planning, implant selection, and preoperative optimisation strategies (Bonney-Mazure et al., 2025). Funding and service delivery models may also shape the extent to which preoperative optimisation is feasible, including weight management or pharmacological modification. Although THA is clinically effective across diverse patient groups, access to timely surgery is not always equitable. Implant selection alone cannot compensate for structural inequities in access. When surgery is delayed, patients from disadvantaged groups may experience further functional decline, increased pain, and worsening comorbidity before receiving treatment. While these challenges reflect broader system-level factors, surgeons remain key stakeholders within this landscape, as their decision-making, advocacy, and engagement with optimisation pathways influence outcomes of equity of care.

8.3.3. Health systems and policy makers

The Thesis findings that higher BMI, greater comorbidity burden, public funding status, and female sex predict poorer preoperative PROMs has implications beyond individual patient outcomes. Firstly, these variables reflect differences in baseline disease burden at the point of surgery, which in turn influence service complexity, resource utilisation, and funding adequacy (Blashinsky et al., 2025; Orr et al., 2025). Patients entering surgery with greater functional impairment may require more intensive preoperative support (Bills et al., 2024), longer theatre time, more complex anaesthetic management, increased allied health input (Bonney-Mazure et al., 2025), and extended hospital stay (Hirani et al., 2025). Even where survival and revision rates are not significantly different, the pathway to achieving these outcomes may be more resource intensive. Hospitals serving higher proportions of these patients may therefore deliver comparable technical outcomes at greater operational cost.

Secondly, the association between public funding status and poorer baseline function suggests structural rather than biological drivers. This finding has policy relevance. If funding allocations are tied primarily to procedural

volume or revision rates alone, they may fail to account for variation in baseline burden. Services treating populations with higher preoperative disability risk being under-resourced relative to case complexity. Thirdly, sex-based differences in baseline PROMs raise questions about symptom recognition, referral pathways, and prioritisation processes. Female patients consistently presenting with poorer functional status at surgery may reflect systemic differences in access and referral pathways (Borkhoff et al.; Chi et al., 2024), biological differences (Call et al., 2025), or the threshold for decision making (Borkhoff et al.). These are relevant considerations, as they point to upstream behaviour and understanding rather than implant performance. For policy makers, the implication is that performance frameworks should consider incorporating baseline PROM severity into benchmarking and funding models. Adjusting for preoperative burden may allow more accurate assessment of service performance and fairer allocation of resources. Without this moderation, hospitals serving higher-risk populations and communities may appear equivalent on paper while absorbing greater hidden complexity. In summary baseline PROM disparity is not simply a clinical observation, it has implications for funding equity, workforce planning, service design, and how health systems define and measure fairness.

Another central finding of this Thesis is that preoperative PROMs are the strongest predictor of postoperative PROMs. Baseline functional status is therefore not simply a descriptive characteristic; it is a determinant of outcome trajectory. Patients who enter surgery with greater pain, disability, and functional limitation are less likely to achieve equivalent postoperative scores, even when implant survival is comparable. If baseline PROM severity drives postoperative PROM outcomes, then disparities present before surgery are likely to persist after surgery. Incorporating PROM informed prioritisation, baseline adjusted performance metrics, and risk-adjusted funding models may better align service planning with patient need. In this context, equity cannot be defined solely by revision rates or implant longevity, it must also consider who reaches surgery, in what condition, and how baseline status shapes achievable outcomes.

Some recommendations for improving disparity include developing integrated preoperative optimisation clinics (multidisciplinary: physiotherapy, exercise physiology, weight and comorbidity management, mental health, social work) prioritised by PROMs risk; as well as using regional PROMs dashboards within the NZJR to allow hospitals and health boards to monitor equity and outcomes. This prioritisation may in turn inform service planning, resource allocation, and consider funding models that incentivise outcome improvement (PROMs-informed quality metrics) rather than procedure volume alone.

8.4. Recommendations

To improve THA equitably, emphasis should move toward a deeper understanding of the patient's preoperative context. This understanding requires support for enhanced data linkage between the NZJR and primary care, mental health, pharmaceutical, and social service datasets to identify upstream drivers of outcome variations and evaluate targeted interventions. Investment in population-level OA prevention and chronic disease management is also needed to reduce inequities entering surgical pathways. Regional PROM-rich registries are

uniquely positioned to support this shift by identifying local inequities, informing targeted care pathways, and measuring the impact of upstream changes over time. However, translating registry insight into meaningful action will require data enrichment, including greater comorbidity granularity, capture of social determinants of health, and pain phenotype characterisation. It is also recommended to embed PROMs-triggered pathways within clinical decision-making and funding systems.

The below proposed recommendations to the NZJR may address the key limitations identified in this research:

1. Sociodemographic, regional and access factors may meaningfully shape baseline status, but are not routinely collected. Include baseline collection of PROMs as a standard.
2. Broad comorbidity categories obscure condition-specific influences on PROMs. Classify comorbidity into specific categories, including but not limited to, cardiac, endocrine, neurological, mental health,
3. Mental health and socioeconomic factors can affect PROMs trajectories yet remain unmeasured. Include NZ Individual Index of Deprivation as a marker of socioeconomic status.
4. Routine collection of additional predictors other than patient characteristics that may affect THA outcomes to determine significance of these predictors to poorer outcomes, such as smoking, activity level, and rehabilitation access/completion.

Together, these additions may substantially enhance the registry's ability to interpret outcomes, identify inequities, support regionally targeted interventions, and inform national policy. See appendix R for detailed joint registry recommendations.

8.5. Strengths and limitations

Strengths and limitations have been addressed within each chapter of this Thesis; however, their implications are best considered collectively in interpreting the findings. Table 37 provides a chapter-by-chapter summary, highlighting how methodological decisions, data sources, and analytical approaches shaped the overall interpretation of findings across the Thesis.

A major strength of this study is its population-based cohort design, capturing real-world regional data that enhances external validity and relevance to community and health service planning. The inclusion of both PROMs and survival outcomes within a single study provides comprehensive evaluation of THA from both patient-centred and clinical perspectives. Statistical analyses were conducted with oversight from an experienced biostatistician, enhancing methodological rigour and analytical transparency. Importantly, the research was co-designed in partnership with the University of Waikato, the TOR group, and undertaken by an interdisciplinary team comprising orthopaedic surgeons, allied health professionals (including a physiotherapist and clinical exercise physiologist), statisticians, and academic researchers. This collaborative approach strengthens clinical relevance, methodological robustness, and translational potential.

For the specific implants investigated in this Thesis, over a 20-year period, ~83% of patients within the TOR registry reported at least one PROM score in each of the three PROMs tools, reflecting high data integrity and minimising response bias. The richness of the dataset enabled robust multivariable modelling and subgroup analyses, including the exploration of equity-related differences. Comprehensive regional registry data offer unique explanatory power in a PROMs context. A key thread of this Thesis is the importance of regional context. Regional PROMs datasets give more meaningful interpretation of population disparities. National registries often smooth over these nuances. Surgeons value hyper-local information that reflect their actual patient mix.

This study was conducted using national registry data from the Bay of Plenty region of New Zealand, and findings may not be directly generalisable to other healthcare systems or populations with different patient characteristics, surgical indications, funding structures, or access to revision surgery. Differences in age distribution, comorbidity burden, socioeconomic factors, and thresholds for revision may influence both survival and PROMs internationally. The patterns observed in this study should be considered hypothesis-generating rather than definitive for other settings.

Limitations include residual confounding, era effects, and ceiling effects in PROMs. Survival analysis is limited due to the small number of events. Surgeons determine whether patients are suitable for surgery, which introduces selection bias. Peer-reviewed evidence indicates that surgeons differ substantially in their decision-making and practice patterns, leading to variation in which patients are selected for surgery and the types of procedures performed (Keding et al., 2019).

A further limitation relates to potential surgeon-level decision bias in the choice of revision construct. Surgeons may have preferentially selected cemented or cementless components for revision based on perceived case complexity, bone stock quality, or familiarity with a given fixation method, rather than this choice being randomly distributed across patients. This introduces the possibility that apparent differences, or lack thereof, in revision outcomes between fixation types partly reflect surgeon preference and case selection rather than a true effect of the implant itself. Relatedly, this study is limited by reliance on revision surgery as a proxy for treatment failure. Not all complications meeting clinical or radiographic criteria for "failure" result in revision: dislocations managed successfully with closed reduction alone, and periprosthetic fractures treated with fixation rather than component exchange, would not appear in our revision-based outcome data. As a result, our reported rates of dislocation and periprosthetic fracture likely underestimate the true incidence of these complications, and the denominator used to calculate revision rates may not capture the full burden of fixation-related morbidity in this cohort.

A potential source of bias relates to the asymmetry in revision options available for the two fixation modes following dislocation. In the cementless cohort, a well-fixed but malpositioned or unstable shell can often be managed with a comparatively minor procedure; isolated liner or head exchange without removal of the

osseointegrated shell; whereas no equivalent minor revision option exists for a cemented cup, where management of recurrent dislocation typically requires either non-operative measures or full cup revision with cement removal. This asymmetry may have introduced a surgeon-level threshold bias, whereby dislocation in the cemented cohort was more likely to be managed conservatively rather than surgically, potentially underestimating the true revision rate for dislocation in this group relative to the cementless cohort.

Preoperative and postoperative PROMs values as categorical variables were not included as predictors of implant survival meant categorising subgroups for comparison reducing degrees of freedom, increasing possibility of overfitting, and reduction of the event to predictor ratio, thus increasing Type II error probability. Only OHS scores have published thresholds for categorisation; thus, further research is needed to establish categorisation thresholds for other PROMs. Future research and the conclusion of this Thesis follow the final table of strengths and limitations (Table 37).

Femoral head material and size were not evaluated as covariates in the survival analysis, and the distribution of both varied between the cemented and hybrid cohorts. Cobalt-chromium was the predominant head material in both hybrid and modern cemented cohorts; however, the proportion of ceramic heads differed, accounting for 15% of cases in the hybrid cohort compared with 5% in the cemented cohort. This difference introduces a potential confounding variable, as ceramic heads have been reported to produce modestly lower linear wear rates on cross-linked polyethylene compared with cobalt-chromium heads, although this has not been shown to translate into a significant difference in revision rate or functional outcome. The predominant head sizes were 28 and 32 mm.

Table 37. Chapter and Thesis strengths and limitations

Thesis	Strengths	Limitations
Part 1, Chapter 2		
Outcomes of cemented and hybrid primary total hip arthroplasty for osteoarthritis: A systematic review with narrative synthesis.	- Adhered to the structure and reporting guidelines of PRISMA - Comprehensive systematic review of peer-reviewed literature for hybrid and cemented THA for OA outcome comparison - Identified evidence gaps in outcome comparison between hybrid and cemented THA for OA	- Quality is constrained by included studies. Heterogeneity limited the interpretability - Studies with null or negative findings may be unpublished - Evidence is dated and may not reflect current practice - Cannot account for residual confounding or selection bias. Excluding non-English studies or grey literature may introduce bias
Part 2, Chapter 3		
Ten-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis (NZJR)	93% of both cohorts' surgeries were performed by the same surgeon limiting select confounding factors - Entire population analysed rather than a subsample - First study of survival comparison between the predecessor and its successor implant outside of a design centre	- Observational nature of the study precludes causal inferences - Low number of revision events - Potential confounders were not fully accounted for, such as surgical approach, intraoperative technique - Relatively small sample sizes made subgroup analyses less powerful for Māori, other ethnicities, patients <55years, and individuals with greater BMI - Femoral head size and material were not included as covariates - Surgeon decision making may bias decision to revise

Part 2, Chapter 4

Fifteen-year patient-reported outcomes of a cemented flanged cup and stem combination in primary total hip arthroplasty for osteoarthritis (TOR)

- 90% of surgeries performed by one surgeon performed in the same three hospitals limiting select confounders
 - Population-based cohort (n = 263)
 - High PROMs completeness and data richness (73%)
 - Explored four WOMAC subcategories
 - First extended study of this implant outside of a design centre
 - Observational nature of the study precludes causal inferences
 - Relatively small sample size due to extended time period to 15 years, with smaller subgroups
 - Residual and unmeasured confounding (surgical approach, rehabilitation adherence)
 - Modest explanatory power of models
 - Broad comorbidity classification may not accurately reflect disease severity
 - Missing funding and BMI data at the start of registry establishment
-

Part 2, Chapter 5		
Ten-year patient-reported outcome measure comparison of two cemented primary total hip arthroplasty implant combinations for osteoarthritis (TOR)	- Population-based cohort rather than a sample (n = 1365) - High PROMs completeness and data richness (>80%) - Real-world regional data, relevance to community and health service planning - Consistency of surgical practice, 90% THAs by the same surgeons in three hospitals limiting select confounders - Contemporary cohort, same implant era, same surgical factors - Size of the dataset allowed exploration of some subgroups	- Observational nature of the study precludes causal inferences - Low number of revision events - Residual and unmeasured confounding (surgical approach, rehabilitation adherence) - Modest explanatory power of models - Broad comorbidity classification may not accurately reflect disease severity - Femoral head size and material were not included as covariates
Part 3, Chapter 6		
Ten-year survival comparison of a modern cemented and hybrid primary total hip arthroplasty for osteoarthritis (NZJR)	- Population-based cohort (n = 2823) - Consistency of surgical practice, 90% THAs by the same surgeons in three hospitals limiting select confounders - First study of survival comparison between the predecessor and its successor implant outside of a design centre	- Observational nature of the study precludes causal inferences - Potential confounders were not fully accounted for (surgical approach, intraoperative technique) - Small subgroup sizes and event numbers limit power (Māori and other, <55 years, >40 BMI) - Femoral head size and material were not included as covariates - Surgeon decision making may bias decision to revise

Part 3, Chapter 7		
Ten-year patient-reported outcomes comparison of a modern cemented and hybrid primary total hip arthroplasty (TOR)	• Population-based cohort (n = 2331) • High PROMs completeness and data richness (>83%) • Real-world regional data, relevance to community and health service planning • Consistency of surgical practice, 90% THAs by the same surgeons in three hospitals • Contemporary cohort, same implant era, same surgical factors • Size of the dataset allowed exploration of subgroups	• Heterogeneity between implant groups • Potential ceiling effects of PROMs • Residual and unmeasured confounding (surgical approach, rehabilitation adherence) • Broad comorbidity classification may not accurately reflect disease severity • Modest explanatory power of models, other factors of influence • Femoral head size and material were not included as covariates

Overall Thesis		
Outcomes of cemented and hybrid primary total hip arthroplasty for osteoarthritis: A New Zealand regional study	• Population-based cohort • Consideration of PROM and survival outcomes in one study • High PROMs completeness and data richness (>83%) • Real-world regional data, relevance to community and health service planning • Consistency of surgical practice • Contemporary cohorts • Ability to examine equity and explore subgroups • Statistician oversight of analyses • Co-design of research with TOR • Interdisciplinary team (orthopaedic surgeons, allied health professionals i.e. physiotherapist and clinical exercise physiologist, statisticians, researchers)	• Observational nature of the study precludes causal inferences • Heterogeneity between implant groups • Potential ceiling effects of PROMs • Residual and unmeasured confounding (surgical approach, rehabilitation adherence) • Broad comorbidity classification may not accurately reflect disease severity • Modest explanatory power of models, other factors of influence • Era differences • Missing patient involvement in the co-design of the research • Femoral head size and material were not included as covariates • Surgeon decision making regarding revision options may be biased

Abbreviations: BMI, body mass index; NZJR, New Zealand Joint Registry; OA, osteoarthritis; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PROMs, patient-reported outcome measures; THA, total hip arthroplasty; TOR, Tauranga Orthopaedic Research Inc; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

8.6. Future research

Future research should expand upon this work by comparing commonly used uncemented THA implants with hybrid and cemented constructs, incorporating both long-term survival and PROMs. Additional patient-level predictors such as smoking status, physical activity and additional comorbidity detail should be included to understand additional factors that may influence THA outcomes. Investigation of time from diagnosis to surgery and disparity among publicly funded patients is warranted to clarify the impact of delayed access on recovery, functional outcomes, and health equity. Dedicated research addressing lower utilisation among Māori as well as gender-related differences in access and outcomes is needed to identify structural and cultural barriers to care. Finally, future studies should move beyond revision as the sole indicator of success or failure, incorporating broader surgical endpoints and patient-centred outcomes to more fully capture meaningful failure following THA. Future studies would benefit from capturing all-cause complication data including non-operatively managed dislocations and fracture fixations not requiring component exchange, rather than relying solely on revision as the outcome of interest, in order to more accurately characterise the true burden of fixation-related morbidity and reduce the influence of surgeon-level treatment selection on reported outcomes.

8.7. Conclusion

This thesis evaluated implant survival and PROMs following a modern cemented and hybrid THA within a regional NZ population. Across the two THA types studied, no significant difference was observed in survival or PROMs. These findings challenge the assumption that hybrid constructs confer superior patient-centred benefit and suggest that, within this context, fixation strategy does not independently determine functional recovery of implant longevity. Importantly, while implant survival was not significantly different between the modern cemented and hybrid THA and between patient subgroups, baseline PROMs consistently shaped postoperative PROM trajectories. Preoperative PROMs were the strongest predictor of postoperative PROMs, and higher BMI, greater comorbidity burden, female sex, and public funding status were associated with poorer baseline PROMs. These findings indicate that functional outcomes after THA in this cohort, are influenced more strongly by patient factors than by THA type.

The absence of survival or PROM advantage of the hybrid over the modern cemented THA, despite higher utilisation and cost in many systems, raises questions about value-based decision making in arthroplasty. The widespread adoption of hybrid THAs may reflect historical practice patterns, perceived technological advantages, and selection effects rather than demonstrable superiority in patient-centred outcomes. In a high performing cemented environment, the potential for measurable incremental benefit may also be limited. This Thesis therefore demonstrates that, within this regional cohort, the modern cemented or hybrid THA did not independently drive survival or PROMs, and that patient characteristics exerted a more substantial influence on perceived recovery. Future work should prioritise national level baseline PROMs collection and

interpretation, long-term PROM surveillance over 10 years, equity informed service planning and investigation of possible additional outcome predictors.

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Supplementary tables

Supplementary Table 1. Detailed revision reasons and type of revision for the ECF (n = 17) in primary total hip arthroplasty for osteoarthritis

Time period	Revisions	Revision reason	(n) of each	Revision type performed
0-1 year	3	Dislocation	2	Change of femoral head
		Loosening Acetabulum (low grade infection)	1	Change of acetabulum
1-5 years	4	Periprosthetic fracture	2	Change of femoral stem
		Dislocation	1	Change of acetabulum
		Pain	1	Change of acetabulum and head
5-10 years	6	Dislocation	3	Change of acetabulum and head
				Change of head
		Infection	2	Change of femur and acetabulum
				Change of all
		Pain	1	Change of all
10-15 years	4	Aseptic loosening- Acetabulum	2	Change of acetabulum and head
		Aseptic loosening- Acetabulum and stem	1	Change of all
		Periprosthetic fracture	1	Change of femur and head

Supplementary Table 2. Descriptive statistics of preoperative patient characteristics for all observations of ECF primary total hip arthroplasty for osteoarthritis

Variable	Sample n= 388	Sex		Funding Pathway		Ethnicity		
		Men n = 170 (44%)	Women n = 218 (56%)	Public n= 133 (34%)	Private n = 255 (66%)	NZEU n = 350 (90%)	Māori n = 16 (4%)	Other n = 22 (6%)
Age (years) mean ± SD	71.30 ± 8.50	70.53 ± 8.09	71.91 ± 8.79	71.58 ± 8.54	71.16 ± 8.51	71.65 ± 8.33	67.06 ± 8.87	68.05 ± 10.25
BMI (kg/m ²) mean ± SD	28.09 ± 4.78	28.21 ± 3.46	28.00 ± 5.61	28.59 ± 4.21	27.91 ± 4.97	28.03 ± 4.89	30.72 ± 2.24	27.69 ± 3.55
ASA Grade †								
I	59(15%)	25 (15%)	34 (16%)	14 (11%)	45 (17%)	54(16%)	2 (13%)	3 (14%)
II	199 (51%)	82 (48%)	117 (54%)	57 (43%)	142 (56%)	183 (52%)	6 (37%)	10 (45%)
III	52 (14%)	26 (15%)	26 (12%)	27 (20%)	25 (10%)	46 (13%)	5 (31%)	1 (5%)
IV	1 (0%)	-	1 (0%)	1 (0%)	-	1 (0%)	-	-
Not recorded	77 (20%)	37 (22%)	40 (18%)	34 (26%)	43 (17%)	66 (19%)	3 (19%)	8(36%)

† Values are given as the number of patients, with percentage (number of patients divided by the total) in parentheses. Due to missing values, some categories do not equal the total number of patients for each column.
Abbreviations : ASA, American Society of Anesthesiologists Physical Status classification; BMI, Body Mass Index; NZEU, New Zealand European; SD, standard deviation.

Supplementary Table 3. Poor Oxford Hip score (<27) Rimfit versus ECF in primary total hip arthroplasty for osteoarthritis

	Rimfit	ECF	<i>p</i> - value
Total	53	7	0.134
Age (years) mean ± SD	71.6 ± 8.3	74.9 ± 10.1	0.566
BMI (kg/m ²) mean ± SD	29.3 ± 4.7	26.6 ± 3.6	0.106
Sex, n			
Male	20	3	1.00
Female	33	4	
ASA, n			
1	3	1	0.217
2	26	2	
3 & 4	15	4	
Missing†	9		
Funding, n			
Public	29	4	0.686
Private	14	3	
Ethnicity, n			
NZEU	44	7	0.580
Māori	9	0	

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; NZEU, New Zealand European; SD, standard deviation

† Missing values have not been included in proportion difference calculations

* Significance set at *p* < 0.05

Supplementary Table 4. Poor Oxford hip scores (<27) Rimfit versus Trident in primary total hip arthroplasty for osteoarthritis

	Rimfit	Trident	<i>p</i> - value
Total	53	53	1
Age (years) mean ± SD	71.6 ± 8.3	68.09 ± 9.96	0.052
BMI (kg/m ²) mean ± SD	29.3 ± 4.7	29.44 ± 5.84	0.892
Sex, n			
Male	20	24	1
Female	33	29	
ASA, n			
1	3	4	
2	26	28	0.825
3 & 4	15	21	
Missing†	9	-	
Funding, n			
Public	29	30	
Private	14	5	0.037*
Missing†	-	18	
Ethnicity, n			
NZEU	44	41	0.649
Māori	9	12	

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; NZEU, New Zealand European; SD, standard deviation

† Missing values have not been included in proportion difference calculations

* Significance set at *p* < 0.05

Appendix A. Systematic review publication

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REVIEW



Outcomes of cemented and hybrid primary total hip arthroplasty for osteoarthritis: A systematic review with narrative synthesis

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Abstract

Purpose To compare primary (implant survival and periprosthetic fracture rates, PPF) and secondary (patient reported outcome measures, PROMs) outcomes of cemented and hybrid primary total hip arthroplasty (THA) for osteoarthritis.

Methods Four databases (PubMed®, EBSCO, ScienceDirect®, and Scopus®) were searched (1 October 2023 and 15 November 2024) for original studies comparing cemented and hybrid primary THA for osteoarthritis. survival, PPF rates, and PROMs. Included studies were assessed for risk of bias using the Quality in Prognostic Studies or RoB 2.0 tool, critically appraised for strength of evidence using GRADE, and underwent a narrative synthesis. PROSPERO registration number CRD42023462884.

Results Eight studies met criteria for review ($n=357,748$). Risk of bias was high for two, moderate for three, and low for three studies. Quality of evidence was very low for both primary and secondary outcomes. Five studies met the criteria for the primary outcome (survival) ($n=257,756$), two PPF rates ($n=29,581$), and three PROMs ($n=382$). Three of five studies reported hybrid survival as not significantly different to cemented, and two identified cemented as superior. The three PROMs studies reported no difference between cemented and hybrid THA. A lack of studies and comparative data made it unfeasible to determine PPF outcomes.

Conclusion Few high-quality studies and methodological heterogeneity led to moderate to high bias and very low overall evidence certainty. Eligible studies indicated no difference in short to medium term PROMs or 10-year survival between the two fixations. Long-term studies indicated superior cemented survival outcomes. A substantial gap in long-term PROMs and PPF rates is noted.

Keywords Hip replacement · Quality of life · Survival · Revision · Periprosthetic fracture

Introduction

Total hip arthroplasty (THA) is recommended for severe primary osteoarthritis of the hip and is one of the most frequent surgeries worldwide. Wang et al. [1] reported 606.5 million global osteoarthritis cases by 2021, highlighting it as a major public health challenge due to its disability

burden. As joint replacement surgeries increase, identifying the most effective and durable treatment approach is essential to ensuring quality of life. THA for osteoarthritis can be performed with cemented (both femoral stem and acetabular cup cemented), cementless (both stem and cup are cementless), hybrid (cemented femoral stem and cementless cup), or reverse hybrid (cementless femoral stem and cemented cup) implants. Controversy over fixation methods for THA has been ongoing for decades, and there seems to be no consensus on which fixation method provides optimal survival and patient reported outcomes (PROMs) despite several systematic reviews and meta-analyses on the topic [2–8]. Most of the reviews in this area exclusively focus on survival and revision rates [9–14], whereas it is recognised that PROMs are an important consideration in establishing THA success and promotion of patient-centred care [15, 16]. In addition, certain of these reviews present methodological

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concerns where data from the same registry reported in different studies [4], systematic reviews or meta-analyses [4, 6, 8], and registry reports [4] alongside original research were included in the analysis, biasing findings by duplicating data analysed. Making inferences on the superiority of fixation methods for THA outcomes specifically for osteoarthritis is further challenged considering how several of these reviews included additional hip pathologies as criteria for surgery (e.g., lupus, systemic sclerosis, rheumatoid arthritis) [2, 3, 5]; involved hemi-arthroplasty in addition to full THA [3]; limited their review to restricted age groups [5]; or failed to specify whether stems were cemented or uncemented, focusing only on acetabular fixation [2, 7, 8]. We identified four reviews that included PROM comparisons as a secondary outcome to implant survival [2–4, 6], but only one of these exclusively targeted osteoarthritis [4].

The use of cemented THA implants was first described in 1891 and became more common from the 1950s [17]. Cemented THA has been identified as the most affordable fixation method [2, 4, 18] and is often considered the “gold standard” [4], setting the bar that newer implants need to surpass for widespread adoption. At the other end of the spectrum, cementless THA is considered the most costly fixation method [19] and is typically associated with poorer outcomes [9, 10, 13] and higher revision and periprosthetic fracture rates [20] than cemented. Hybrid THA, despite costing more than cemented, may offer superior postoperative quality of life [21] and function [22]. Consequently, hybrid THA has been identified as the most cost-effective replacement surgery [4] in all age groups and both sexes [18], and hybrids with conventional polyethylene show a survival advantage over cemented THA [23]. Consideration of both surgical and patient-related measures in quantifying success of THA, regardless of fixation method, is needed to shift the focus from surgeon to patient-centred models of care [24].

Given the identified gaps in the existing reviews comparing THA outcomes between fixation methods, this systematic review with narrative synthesis aimed to compare both primary (revision and periprosthetic fracture rates) and secondary (PROMs) outcomes between cemented and hybrid primary THA for severe endpoint osteoarthritis. We hypothesised hybrid THA would demonstrate potentially superior primary and secondary outcomes to cemented THA for patients with end stage osteoarthritis.

Methods

This systematic review with narrative synthesis forms part of independent research supported by a PhD scholarship award jointly funded by Tauranga Orthopaedic Research

and The University of Waikato. This review was designed to meet the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) reporting guidelines [25] and was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO identifier: CRD42023462884).

Review methods and inclusion criteria were specified in advance. The primary outcomes of interest were survival and/or revision rate and periprosthetic fracture (PPF) rate, and secondary outcomes of interest included any physical criteria PROMs, including but not limited to, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford hip score, Harris hip score, Forgotten hip score, as well as any mental health or lifestyle related PROMs (HRQOL), such as Hospital Anxiety and Depression Scale, Short Form-36 item health survey (SF-36), and Veterans Rand 12 item health survey (VR-12). Original, peer-reviewed research articles published in English were included, and spanned observational studies (prospective and retrospective) and randomised control trials. We further limited our inclusion criteria to studies evaluating outcomes over a period of at least 1 year. Where multiple studies reported on the same/similar patient cohort, the study with the longest follow-up was included to avoid duplication of data. Study population included adult patients with end stage hip osteoarthritis who had been assigned a fully cemented (cemented femoral stem and acetabular cup) or hybrid (cemented femoral stem and cementless acetabular cup) THA. Revision risk, hazard, mortality, and economic evaluations; editorials; systematic reviews; meta-analyses; joint registry reports; letters to the editor; and conference abstracts were excluded. Studies including any condition other than end stage osteoarthritis of the hip, revision outcomes, hip resurfacing (hemi-arthroplasty) or bilateral THA surgeries only were excluded. Studies that included fully cementless (cementless femoral and cementless acetabular cup) or reverse hybrid (cementless femoral stem and cemented acetabular cup) procedures were included when comparisons were made between fully cemented and hybrid THA within the study. A strength of our inclusion criteria ensured that the same dataset was not featured multiple times in different studies thereby inflating results.

Four electronic databases (PubMed®, EBSCO, ScienceDirect®, and Scopus®) were initially searched on 1 October 2023, with the search updated on 15 November 2024. The search included articles from journal inception up to and including the date of search. Broad syntax terms included “primary hip replacement”, “primary hip arthroplasty”, “osteoarthritis”, “cement*”, “hybrid” and “outcome”. Detailed descriptions of the syntax used for each database is provided as supplementary material (Supplementary 1). The database search was complemented by searching reference

lists, orthopaedic joint registries, and hip arthroplasty manufacturer websites for relevant articles. All records identified via the database search (AP) were imported to the review software Rayyan [26] and duplicates removed. Two reviewers applied eligibility criteria independently (AP, AB), and then met to discuss conflicts. There was one unresolved conflict that required input from a third reviewer (KHL). The initial screening for eligibility was performed on titles/abstracts, and the process repeated for full-text articles by the same two independent reviewers. A customised data collection form was developed for this review (Supplementary 2) and data collated in Microsoft Excel (v2501, Microsoft Corp., Redmond, WA, USA). Information extracted from each study included study type, fixation method, country of study, sample size, mean follow-up period, primary endpoint, statistical methods for survival calculation, predictors of interest, and results. Missing data were identified, and corresponding authors of these studies were contacted. If there was no response from the authors, data were reported as “missing”. Data were summarised in table format to facilitate narrative synthesis and interpretation (Supplementary 2). Studies were assessed for risk of bias and critically appraised. Two reviewers assessed each study independently (AP, AB), with a third (KHL) available for conflict resolution, but not required. Observational studies were assessed for risk of bias using the Quality in Prognostic Studies (QUIPS) tool [27] and randomised control trials with the Cochrane RoB version 2.0 [28]. The QUIPS is considered a useful and reliable tool for systematically assessing the risk of bias in prognosis research across six key domains (study participation, attrition, factor measurement, confounding, outcome measurement and analysis/reporting). The RoB 2.0 provides a structured framework to evaluate potential bias across five domains relevant to randomised controlled trials (randomisation, deviations from intended intervention, missing outcome, measure of the outcome, selection of the reported result) [28].

Although a meta-analysis was planned to provide a quantitative synthesis of the findings from aggregate data, the decision to perform a narrative synthesis was motivated by six factors: data availability and homogeneity, type of data, study design, purpose of the synthesis, study quality and reporting, and flexibility. As five or more studies using similar statistical methods and reporting the same outcomes from similar populations are needed to achieve reasonable power from a random effect model meta-analysis [29], data extracted as part of this review were deemed insufficient for meta-analysis of primary and secondary outcomes. A narrative synthesis systematically synthesises evidence to generate new insights by analysing and interpreting findings from included studies. The process involves three steps: developing a preliminary synthesis, exploring data relationships,

and assessing the robustness of the synthesis [30]. These steps were followed when undertaking our synthesis. The overall quality of evidence for each gradable outcome was assessed by one reviewer (AP) using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) working group system [31], and verified by a second (KHL). This structured approach has four levels or certainty of evidence ratings (very low, low, moderate, and high) used to assess risk of bias, imprecision, inconsistency, indirectness, and publication bias. Gradable outcomes were survival/revision rate, PPF rate, and PROMs. Study design, risk of bias assessment, and quality of evidence ratings did not constitute study exclusion. Results were organised based on primary and secondary outcomes. Comparison and synthesis of results for each of these categories of outcome were summarised and categorised as conclusive (either “there is difference” or “there is no difference”) or inconclusive [32] based on heterogeneity, statistical uncertainty, inconsistency in treatment effects, and/or incomplete information.

This review focused specifically on studies reporting survival percentages and revision rates (absolute outcomes), rather than those which modelled the risk of revision over time. We were interested in how many hips had been revised or remained unrevised at a specific timepoint rather than the statistical likelihood of revision. This focus on absolute outcomes allows for clarity and accessibility of easily interpretable data with concrete outcomes [33], relevant for decision making, such as benchmarking (national registry reports use survival percentage at 5, 10 or 15 years to compare models) [11] and clinical planning (surgeons want information on likelihood of a revision, not just the relative risk). This approach also aligns with real-world clinical goals, such as identifying implants that consistently exceed revision benchmarks [11].

Results

The initial search identified 1095 studies, with 9 studies identified from citation searches. After duplicate removal, 1027 studies were excluded at title and abstract screening (Fig. 1). Ultimately, 8 studies met inclusion. Five of these reported on the primary outcome (all observational), and three these addressed the secondary outcome (two randomised control trials and one observational). We attempted to contact three authors [34–36] for further information, but no replies were received.

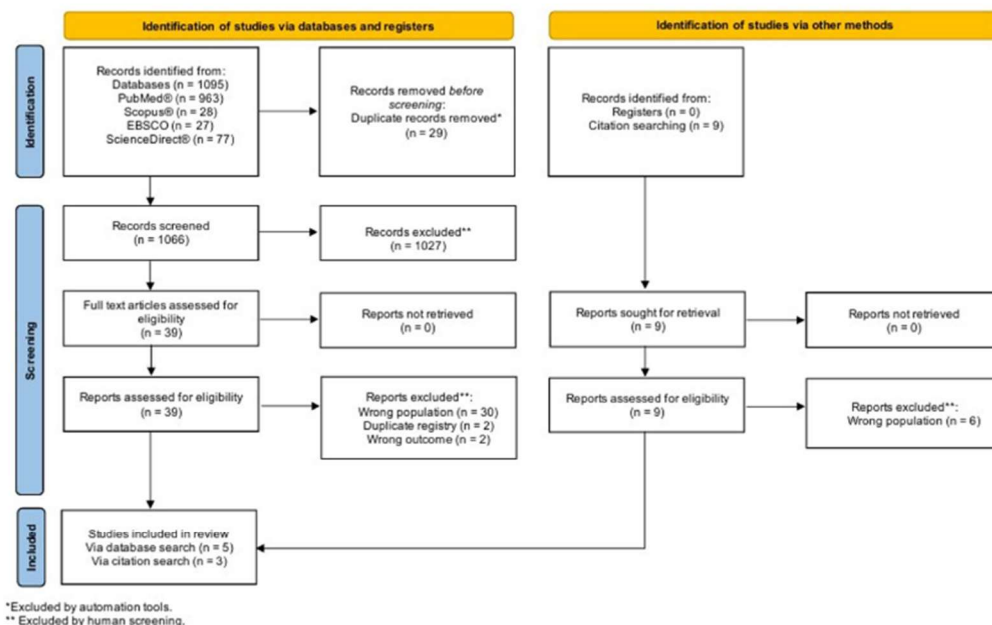


Fig. 1 PRISMA flow chart of the search strategy and study selection process

Table 1 Risk of bias assessment

Primary outcome (survival)						Secondary outcomes (PROMs/HRQOL)			
	Bloem- heuvel et al. (2022) [9]	Jansen et al. (2014) [10]	Kan- dala et al. (2015) [11]	Makela et al. (2008) [12]	Ped- ersen et al. (2014) [13]	Nilsson- dot- ter et al. (2003) [34]	Norman- Taylor et al. (1997) [35]	Onsten et al. (1994) [36]	
QUIPS*							ROB 2**		
Study participation	+	+	+	+	+	+	Randomisation process	x	+
Study attrition	!	+	+	+	+	!	Deviations from the intended intervention	+	+
Prognostic factor measurement	!	+	+	+	!	!	Missing outcome data	+	+
Outcome measurement	+	+	+	+	+	!	measure of the outcome	+	!
Study confounding	x	+	+	+	!	!	Selection of the reported result	+	+
Statistical analysis and reporting	+	+	+	+	+	+	Overall	!	!

Primary outcome: survival and PPF

Risk of bias

The five studies identified were assessed for risk of bias. Direct comparison of sex ratios and mean age were possible in one of five studies, which indicated no difference in proportion of male to female observations ($p=0.610$) or mean age ($p=0.464$) [10]. All other studies reported adjusting for age and sex within their statistical models to avoid

confounding [9, 11–13]. Three observational studies had independent low risk of bias [10–12], and one indicated moderate risk in prognostic factor measurement and study confounding [13]. One study displayed a high-risk of bias related to confounding and moderate bias in both study attrition and prognostic factor measurement [9]. Detailed results of the individual bias assessments can be found in Table 1.

Overall quality of evidence

Due to the heterogenous nature of the observational survival studies, both survival and PPF evidence was determined to be of low quality and certainty. Four studies collected data from participants of different age group categories. Data were collected across multiple timepoints, spanning several years, with studies capturing survival outcomes over 1–5 years, 5–10 years, or 10–16 years, making it difficult to determine a summary of primary outcomes. Only age and fixation type consistently appeared as moderating factors. GRADE quality of evidence for the outcome of survival and PPF was low, with moderate-to-high risk of bias, serious indirectness, serious imprecision, and suspected publication bias (Table 2).

Study characteristics

The five observational studies included in the analysis [9–14] represented 244,032 cemented and 39,068 hybrid THA observations (Table 1). All studies reported on European national joint registry data (four Nordic studies, one England and Wales), and included cemented, hybrid, and cementless survival comparisons, with two studies also examining reverse hybrid THA [9, 13]. There was notable

clinical heterogeneity in the age groups studied, with age ranging from 18 to 102 years in the studies that reported age. Two studies focused specifically on patients aged over 80 years [9, 10], one study included individuals aged 55 years and older [12], another targeted patients between 35 and 55 years [13], and one study did not specify the age or age range of participants [11]. Two studies reported overall male and female observations combined for all THA categories within the study [9, 13], while two others provided separate implant observations by sex [10, 12]. One study did not specify or report male and female observations [11]. Study observation periods spanned from 1980 to 2019 with follow-up durations ranging from 1 to 16 years. Survival outcomes were reported at different follow-up periods. Two studies reported survival at 1, 3, and 5 years [9, 10], and one study at 2 years [13]. Four studies reported survival at 10 years [10–13] and one at 16 years [13]. Three studies [9–11] employed a competing-risk Kaplan-Meier approach, while two used standard unadjusted Kaplan-Meier survival analysis [12, 13], reflecting methodological heterogeneity. Two studies reported PPF rates [9, 10]. Detailed characteristics can be found in Table 3.

Table 2 Certainty of evidence GRADE* for primary and secondary outcomes

Certainty assessment							Summary of findings		
Outcome	Studies (n)	Study design	Risk of bias	Indirectness	Imprecision	Publication bias	Included in narrative synthesis	Results	Quality of evidence (GRADE)
Survival	5	Observational studies ^a	moderate-high	serious ^f	serious ^h	suspected ^l	Hybrid: 39,068 Cemented: 204,964	No difference in survival rates heterogeneity in population/samples	+ - - -
PROMs	3	2 Randomised Control trials ^{b,c} ; 1 Observational study ^d	moderate-high	serious ^{g,h}	serious ⁱ	suspected ^m	Hybrid: 138 Cemented: 247	No significant difference between hybrid and cemented PROMs. Old studies, poorly conducted with limited results.	+ - - -
PPF	2	Observational studies ^e	moderate-high	serious ^g	serious ^k	suspected ⁿ	Hybrid: 3,745 Cemented: 25,836	Lowest in hybrid compared to cemented. Extremely limited study number	+ - - -

*GRADE- grading of recommendation, assessment, Development and evaluation; RCT- randomised controlled trial.

^a 3/5 studies did not justify sample size, study attrition, prognostic factor measurement and study confounding; ^b One study did not identify the randomisation process and deviated from the intended intervention; ^c Studies did not effectively measure the intended outcome; ^d The only observational study did not clearly define study attrition, prognostic factor measurement, statistical analysis and reporting used a mean follow up; ^e Study designs were not specific to periprosthetic fracture rate, this was an additional outcome; ^f Differences in age categories of all studies; ^g Two studies used the same PROMs instrument but reported the results differently; ^h Different HRQOL instruments; ⁱ Time point collection for each study was different; ^j Studies had differing predictors of interest and varied between short, medium and long term net and cumulative statistical survival calculation; ^k Periprosthetic fracture rate only recorded if part of revision, not recorded if revision not required; ^l National registries represented, results may not be attributable to other populations; ^m Only two small samples represented in the RCTs, from the same country; ⁿ Only reported in 2/8 studies.

Table 3 Survival study characteristics between cemented and hybrid primary total hip arthroplasty for osteoarthritis

Author and year	Study period and country	Study design	Sample size* (cemented; hybrid)	Age group (years)	Mean follow up, collection time points (years), collection end	Outcomes	Predictors of interest	Key findings
Bloemhewer et al. 2022 [9]†	2007–2019 Netherlands ¹	Observational. Cemented, hybrid, cementless, reverse hybrid	n=43,053 (22,025; 3,243)	≥80	Mean: 4.2 (0–13) Times: 1, 3, 5 End: Revision	Competing risk Kaplan Meier; Revision rate (%)	Age, sex, ASA, fixation, head size, approach	No difference in survival at either 1, 3 or 5 years. PPF rates cemented 6%, and hybrid 3%.
Jämsen et al. 2014 [10]†	1998–2009 Finland ²	Observational. Cemented, hybrid, cementless.	n=4,777 (3,811; 502)	≥80	Mean: 4 (1–13) Times: 1, 3, 5, 10 End: Revision	Competing risk Kaplan Meier % survival.	Age, sex, facility, year, comorbidity type, popularity of implant	No difference in survival at 1, 3, 5 or 10 years. PPF 11% in cemented, 18% cemented women vs. 0% hybrid.
Kandala et al. 2015 [11]	2003–2012 England and Wales ³	Observational. 2 cemented, 2 cementless and 1 hybrid.	n=239,089 (137,990; 28,471)	Not reported	Mean: not reported Times: 1, 5, 10 End: Revision	Competing risk Kaplan Meier; Bath-tub, Weibull, Loglogistic, Flexible Revision rate (%) ‡	Age, sex, fixation, bearing type	Conclusive. Reported new 5% benchmark for revision. Revision rate of 1.88–2.11% in cemented and 2.42% in hybrid.
Makela et al. 2008 [12]	1980–2004 Finland ²	Observational. 2 cementless, 1 cemented and 1 hybrid.	n=50,968 (34,296; 3,784)	55–64, 65–74, >75	Mean: 4.5–9.2 Times: 10, 15, 20 End: Revision	Kaplan Meier standard % Survival	Implant groups, age, sex	No difference. All age groups in both hybrid and cemented groups had a survival of >90% at 10 years.
Pedersen et al. 2014 [13]	1995–2011 Sweden, Denmark, Finland, Norway ⁴	Observational. Cemented, cementless, hybrid and reverse hybrid.	n=29,558 (6,842; 3,068)	35–45 & 46–55	Mean: not reported Times: 2, 10, 16 End: Revision	Unadjusted Kaplan Meier % survival at 2, 10 and 16 years	Age, sex, fixation technique and calendar year	Conclusive. Cemented indicated higher survival percentage at 2, 10 and 16 years for any revision reason, revision for aseptic loosening and revision for any other cause.

ASA- American anesthesiologist physical status rating; PPF-Periprosthetic fracture rate.

All studies included cementless/uncemented and/or reverse hybrid fixation or more than one cemented/hybrid component for comparison.

*Total sample size includes all hip fixation methods within the study, including cementless and reverse hybrid, where applicable.

** Specified a loaded-taper or composite beam stem.

† These studies included periprosthetic fracture rates.

‡ Actual revision rates at 5 years and estimated 10-year rates for 70-year-old males and females only.

¶ No data at 15 or 20 years for hybrid fixation. The fixation technique did not fulfil the proportional hazards assumption for Cox proportional hazards calculation; therefore, the population was split into subgroups (1995–1999, 2000–2003, 2004–2007, 2008–2011).

¹ Dutch arthroplasty register; ² Finnish Arthroplasty Registry; ³ National registry for England and Wales; ⁴ Nordic arthroplasty registry.

Narrative synthesis

Three survival studies with the lowest risk of bias [10–12] identified no significant difference in survival between cemented and hybrid THA at 1, 3, 5, and 10 years. All three studies presented mean survival for each fixation method, which ranged between 98.6 and 98.8% at 1 year, 98.1 to 98.3% at 3 years, 97.8 to 98.1% at 5 years, and 83 to 96% at 10 years. Due to heterogeneous methodologies, these survival percentages were not directly comparable. In an England and Wales 10-year follow up study [11], after completing

five different Kaplan-Meier model analyses, the cemented prostheses with metal-on-polyethylene bearing surface had the highest estimated mean survival rate of 98.02% at 10 years, with cemented ceramic-on-polyethylene survival second with 97.5%, and hybrid metal-on-polyethylene third with 97.32%. With similar 10-year estimates between prostheses and a revision percentage below 5%, the authors recommended the 10-year benchmark revision rate for all THA in England and Wales be lowered from 10 to 5% [11]. No difference in survival between hybrid and cemented THA was reported, although not assessed for statistical

significance. Makela [12] identified that at 10 years, all age groups in both hybrid and cemented THAs exceeded a survival of 90% with no significant difference between the two fixation categories across age groups ($p=0.22$ to 0.80). A moderate risk of bias study [13] reported survival comparison at 10 and 16 years for both cemented and hybrid THA using three endpoints: revision for any reason, revision for aseptic loosening, and revision for other causes. Cemented THA was reported to show superior survival to hybrid THA at 10 years when the endpoint was revision for any reason ($90.2 \pm 0.43\%$ versus $86.6\% \pm 0.69$), for aseptic loosening ($92.8\% \pm 0.38$ versus $91.4\% \pm 0.59$) and for other reasons other than aseptic loosening ($97.3\% \pm 0.23$ versus $94.8\% \pm 0.44$). The same pattern was reported at 16 years, with cemented exhibiting higher survival than hybrid. Statistical significance results were not reported. Synthesis of results seems to indicate that at timepoints up to 10 years, survival tends to be similar and that there is little, if any, difference in survival between cemented and hybrid implants, but that longer time frames may favour cemented THA. Two studies reported PPF rates [9, 10], with one of these studies only reporting cemented PPF rate and not the hybrid PPF rate. The low risk of bias study [10] reported a 10-year cemented PPF revision rate of 11%. The high risk of bias study [9] reported a PPF rate of 6% in cemented and 3% in hybrid THA at 5 years [10], thus it is not possible to definitively establish whether PPF rates are lower in cemented or hybrid THA. Both studies showed no difference in survival between hybrid and cemented THA [9, 10]. Detailed survival study information can be found in Table 4.

Secondary outcome: patient reported outcome measures

Risk of bias

Three studies [34–36] were identified as including PROMs and evaluated for risk of bias. The only observational study [34] was evaluated using the QUIPS tool [27], and the two remaining RCTs [35, 36] evaluated using the ROB 2 [28]. Baseline comparisons showed no age or sex differences between cemented and hybrid groups in the Swedish RCT [36] (low risk of confounding). In the UK RCT [35], the hybrid group was significantly younger than the cemented group ($p<0.001$, $d=0.97$), indicating possible age-related confounding. The Swedish observational study [34] had more females and older participants in the cemented group, suggesting imbalance in key demographic variables. While both RCTs showed comparable sex ratios ($p>0.05$) [35, 36], the observational study did not [34]. These differences lower confidence in the observational findings due to risk of confounding and contribute to downgrading the certainty of

evidence. The observational study [34] indicated a moderate risk of bias in study attrition, prognostic factor and outcome measurement, and study confounding, with all other factors indicating a low risk of bias. Both RCTs scored moderate risk of bias overall [35, 36]. Individual high-risk of bias was identified in the randomisation process in one of the RCTs where randomisation was not described [35]. Results can be found in Table 1.

Overall quality of evidence

The overall certainty of evidence was very low based on GRADE for secondary outcomes (PROMs) when comparing hybrid and cemented THA, with moderate-to-high risk of bias, serious indirectness, serious imprecision, and suspected publication bias (Table 2). All three studies indicated methodological heterogeneity, using assorted and inconsistently applied tools at varying follow-up points (1, 2, and 3.6 years), and across heterogeneous populations with poorly defined or non-existent subgroups. These factors severely limited the validity, comparability, and applicability of findings to clinical practice.

Study characteristics

Characteristics of individual studies can be found in Table 5. The three studies [34–36] together compared PROMs scores between 138 hybrid and 247 cemented primary THAs (186 males and 200 females) for osteoarthritis. Two RCTs ($n=80$ and $n=60$ respectively) [35, 36], and one observational study ($n=196$) [34] were performed in Europe (two in Sweden [34, 36] and one in the UK [35]) and compared specific hybrid and cemented implants rather than broad category components. Observation periods ranged from 1988 to 1998 and reported short-term (1, 2, and 3.6-year) PROMs, with two studies also reporting preoperative scores [34, 35]. Both RCTs [35, 36] used the Harris hip score measurement tool, however one RCT converted the original Harris score to Rosser Index pain and disability values [35], and reported Rosser Index quality of life results rather than Harris hip score.

The results of the Swedish RCT study [36] indicated a 2-year mean Harris pain score of 42 out of 44 for each THA group, and mean Harris hip score of 91 and 92 for hybrid and cemented respectively, with no reporting of statistical significance. In the UK RCT [35], there was no statistically significant difference between the cemented and hybrid pre-operative Rosser Index HRQOL scores ($p=0.596$); but at 1-year, hybrid THAs performed statistically significantly better than cemented THAs (0.988 ± 0.018 , 0.995 ± 0.006 respectively, $p=0.015$) with the cemented hip reporting better Rosser Index HRQOL scores. The study determined

Table 4 Survival and revision rate study outcomes

Study (Age group)	Sample size	Periprosthetic fracture rates	1-y survival %	2-y survival %	3-y survival %	5-y survival %	10-y survival %	15-y survival %	16-y survival %
Bloemheuvel et al. 2022 [9] ^{ab}	Cemented: 22,025	26/427 (6%)	Net: 98.7 (98.6–98.8) ^{ab}	-	Net: 98.2 (98.1–98.3) ^{ab}	Net: 97.8 (97.7–97.9) ^{ab}	-	-	-
≥ 80 years			CR: 98.7 (98.6–98.9) ^{ab}		CR: 98.3 [98.1–98.4] ^{ab}	CR: 98.0 (97.7–98.2) ^{ab}			
Median age: 83 (80–108) ^a M: 10,931; F: 32,073 ^a							-	-	-
			Net: 98.6 (98.4–98.8) ^{ab}	-	Net: 98.2 (98.0–98.4) ^{ab}	Net: 98.0 (97.7–98.3) ^{gh}			
Median FU: 4.2y	Hybrid: 3,243	2/61 (3%)	CR: 98.8 (98.3–99.1) ^{ab}		CR: 98.3 [97.8–98.7] ^{ab}	CR: 98.1 [97.5–98.6] ^{ab}			
Jämsen et al. 2014 [10] ^{ab}	Cemented: 3,811	5/46 (11%) 1y	CR: 98.8 (98.4–99.2) ^{ab}	-	CR: 98.1 (97.7–98.6) ^{ab}	CR: 97.8 (97.3–98.3) ^{ab}	CR: 97.4 (96.9–98) ^{ab}	-	-
≥ 80y	M: 1,143; F: 2,668 Mean age: 82y (80–102)	10/57 (18%) in F							
	Hybrid: 502	0/5 (0%) in F	CR: 98.6 (97.6–99.7) ^{ab}	-	CR: 98.1 (96.9–99.4) ^{ab}	CR: 98.1 (96.9–99.4) ^{ab}	CR: 98.1 (96.9–99.4) ^{ab}	-	-
Mean FU: 4y	M: 145; F: 357 Mean age: 82y (80–95)								
Kandala et al. 2015 [11] ^{abcd}	Cemented: 137,990	-	-	-	-	-	CeCoP: 98.12 ^f (97.89–98.03) ^j	-	-
Age not specified	M: -; F: -						CeMoP: 97.78 ^f (97.17–97.58) ^j		
Median age: 70.4y ^a									
	Hybrid: 28,471	-	-	-	-	-	HyMoP: 97.58 ^f (96.92–97.50) ^j	-	-
Mean FU: -	M: -; F: -								
							Aseptic loosening ^j 55–64y: 85 (84–86) n=2,138 65–74y: 91 (91–92) n=5,899 ≥ 75y: 95 (95–96) n=2,299	Aseptic loosening ^j 55–64y: 71 (69–73) n=1,086 65–74y: 85 (84–86) n=2,049 ≥ 75y: 93 (92–94) n=441	-

Table 4 (continued)

Study (Age group)	Sample size	Peripros- thetic frac- ture rates	1-y sur- vival %	2-y sur- vival %	3-y survival %	5-y sur- vival %	10-y survival %	15-y survival %	16-y survival %
Makela et al. 2008 [12] ^{ad}	Cemented: 34,296		-	-	-	-	All: 91 (91–91) <i>n</i> = 10,335	All: 83(82–84) <i>n</i> = 3,575	
	M: 12,004; F: 22 292	-	-	-	-	-	All reasons^j	All reasons^j	
	Mean age: 70y (55–95)	-	-	-	-	-	55–64y: 83 (82–85) <i>n</i> = 2,140	55–64: 68(66–70) <i>n</i> = 1,088	
		-	-	-	-	-	65–74y: 89 (89–90) <i>n</i> = 5,904	65–74: 82(81–83) <i>n</i> = 2,051	-
55–>75y		-	-	-	-	-	≥ 75y: 93 (93–94) <i>n</i> = 2,300	≥ 75y: 91(90–92) <i>n</i> = 441	
		-	-	-	-	-	All: 89 (89–89) <i>n</i> = 10,343	All: 80(80–81) <i>n</i> = 3,579	
		-	-	-	-	-	Aseptic loosening^j		
		-	-	-	-	-	55–64y: 90 (85–95) <i>n</i> = 77		
mean FU: 3.6–10.2y	M: 1,551; F: 1,548	-	-	-	-	-	65–74y: 93 (91–95) <i>n</i> = 194	-	-
	Mean age: 72y (55–96)	-	-	-	-	-	≥ 75y: 96 (93–100) <i>n</i> = 73		
		-	-	-	-	-	All: 93 (92–95) <i>n</i> = 343		
		-	-	-	-	-	All reasons^j		
Pedersen et al. 2014 [13] ^a		-	-	-	-	-	55–64y: 83 (76–89) <i>n</i> = 78		
		-	-	-	-	-	65–74y: 88 (86–91) <i>n</i> = 194	-	-
		-	-	-	-	-	≥ 75y: 92 (88–95) <i>n</i> = 73		
		-	-	-	-	-	All: 88 (86–90) <i>n</i> = 344		
35–55y	Cemented: 6,842	-	-	Any: 98.6 ± 0.14 ⁱ	-	-	All: 90.2 ± 0.43 ⁱ	-	All: 77.4 ± 1.13 ⁱ
		-	-	AL: 99.6 ± 0.43 ⁱ	-	-	AL: 92.8 ± 0.38 ⁱ		AL: 80.5 ± 1.13 ⁱ
		-	-	Other: 99.0 ± 0.12 ⁱ	-	-	Other: 97.3 ± 0.23 ⁱ		Other: 96.1 ± 0.39 ⁱ
		-	-	Any: 97.7 ± 0.27 ⁱ	-	-	All: 86.6 ± 0.69 ⁱ		All: 68.5 ± 2.12 ⁱ
Mean age: -		-	-		-	-			
M: 15,391 ^e		-	-		-	-			

Table 4 (continued)

Study (Age group)	Sample size	Periprosthetic fracture rates	1-y survival %	2-y survival %	3-y survival %	5-y survival %	10-y survival %	15-y survival %	16-y survival %
F: 14,167 ^a		-	-	AL: 99.3±0.15 ⁱ	-	-	AL: 91.4±0.59 ⁱ	-	AL: 75.9±2.17 ^j
Mean FU: -	Hybrid: 3,068			Other: 98.4±0.23 ⁱ			Other: 94.8±0.44 ⁱ		Other: 90.1±1.08 ⁱ

AL- Aseptic loosening; CeCoP- Cemented ceramic on polyethylene; CeMoP- Cemented metal on polyethylene; CR- Competing risk (death); F- Female; FU- Follow up; M- Male.

^a Included other hip types (cementless and/or reverse hybrid) in the comparison; ^b Only included specific makes of component; ^c Included bearing surface as a predictor of survival; ^d Bilateral THR not mentioned; ^e Of the entire sample only; ^f Crude survival rate - Competing risk survival rate with death as a competing risk; ^g Net survival rate- The estimated survival rate accounting for only those who survived long enough to require revision potentially; ^h Mean survival% [95%CI][low - high]; ⁱ Mean survival% ± standard deviation; ^j Range of survival percentages between Bathub, Weibull, Loglogistic and flexible Kaplan-Meier models.

Table 5 Characteristics of included studies comparing proms in cemented and hybrid total hip arthroplasty for osteoarthritis

Author	Study period and country	Study design	Sample size	Age group	Outcomes	Follow-up period	Collection time points	Predictors of interest	Key findings
Nilsdotter et al. (2003) [34]	1995–1998 Sweden	Observational†	n=196 C-139 H-57	NR	HRQOL: SF-36 PROM: WOMAC PreOp: Yes	3.6 y	1 and 3.6y	Age, sex, fixation, follow up time, baseline values	No difference in PROMs between cemented and hybrid THR noted. Statistically significant improvement in postoperative scores for both fixation types.
Norman-Taylor and Villar (1997) [35]	1992–1994 United Kingdom	RCT	n=80 C-40 H-40	<70	HRQOL: Rosser Index PROM: Harris Hip Score PreOp: Yes	1 y	1 y	Age, sex	Inconclusive. Harris hip score used to determine Rosser index score
Onsten et al. (1994) [36]	1988–1991 Sweden	RCT	n=60 C-30 H-30	40–70 y	HRQOL: No PROM: Harris Hip Score PreOp: No	2 y	2 y	Fixation	No difference in PROMs between cemented and hybrid THA noted.

C- Cemented; H- Hybrid; THA- Total hip arthroplasty; NR- Not reported; PROMs- Patient reported outcome measures; RCT- Randomised Control Trial; SF-36- 36 Item Short Form Survey; WOMAC- Western Ontario and McMaster Universities Arthritis Index.

† Hospital sample

a hybrid prosthesis did not impair early quality of life outcomes and although HRQOL scores increased in all 80 patients, the study identified that 60% of hybrid THA patients achieved maximal HRQOL scores after 1 year. The study, however, suggested improvement in quality of life was not dependent on prosthesis type.

The observational study [34] included preoperative, 1-year, and 3.6-year WOMAC and SF-36 scores. No difference in WOMAC scores between the cemented or hybrid groups at any timepoint was noted. The SF-36 subscales of “role physical” and “general health” showed statistically significant differences ($p<0.05$) preoperatively, and in all but one subscale (i.e., “bodily pain”) at 1-year, and two subscales (i.e., “bodily pain” and “general health”) at 3.6 years with hybrids indicating better scores. However, when the scores were adjusted for age, sex, follow-up time and

baseline values, no statistically significant differences were revealed. See Table 6 for detailed results of each study.

Narrative synthesis

With very low certainty of evidence, in three heterogeneous studies using assorted PROMs tools at inconsistent time-points, drawing secondary outcome conclusions regarding superiority is challenging. All three studies report PROM improvements in both cemented and hybrid THAs at their chosen follow-up periods, and no significant differences in PROMs between the two THA options. Despite differences in instruments and follow-up durations, the consistent direction of effect (i.e., no observed or statistically significant difference) supports the conclusion that PROMs may be similar between the two fixation types. While formal data synthesis was not feasible, our narrative synthesis suggests

Table 6 Outcomes. Of PROM studies

Article	Prosthesis type	PROM (mean±SD)			HRQOL (mean±SD)		
		Instrument	Sub level	PreOp	1 year	2 years	3.6 years
Nilsdotter et al. (2003) [34] <i>n</i> =245 Age: NR	Cemented (<i>n</i> =177) Mean age: 75 (61–92)† M: 73; F: 104	WOMAC	Pain Stiffness Function	PreOp 37.1±15.5 75.4±18.0 71.3±20.4	1 year 84.4±17.1 75.8±20.5 76.1±22.0	2 years -	3.6 years 81.0±20.1 76.1±22.0 71.3±20.4
	Hybrid (<i>n</i> =68) Mean age: 62 (50–72)† M: 39; F: 29	WOMAC	Pain Stiffness Function	PreOp 44.8±15.9 42.0±15.7 41.8±12.5	1 year 84.1±18.1 81.8±16.6 83.0±16.1	2 years -	3.6 years 84.2±21.0 80.7±22.3 81.2±20.4*
Norman-Taylor & Villar (1997) [35] <i>n</i> =80 Age: <70y	Cemented (<i>n</i> =40) Mean age: 58.22y±6.7 (40–65) M: 19; F: 21	Harris Hip†	Pain Hip	PreOp -	1 year -	2 years -	3.6 years -
	Hybrid (<i>n</i> =40) Mean age: 52.90y±6.6 (39–67) M: 22; F: 18	Harris Hip†	Pain Hip	PreOp -	1 year -	2 years -	3.6 years -
	Cemented (<i>n</i> =30)	Pain	-	-	-	42	-
	Hybrid (<i>n</i> =30)	Pain	-	-	-	-	-

Table 6 (continued)

Article	Prosthesis type	PROM (mean ± SD)		HRQOL (mean ± SD)		Instrument		
		Instrument	Sub level	PreOp	1 year	2 years	3.6 years	3.6 years

Onsten et al. (1994) [36]
 n = 60
 Age: 40–70y
 M: 16; F: 14
 Mean age: 63 ± 6†
 Hybrid (n = 30)
 M: 17; F: 13
 Mean age: 62 ± 6†

* $p < 0.05$ between hybrid and cemented mean outcome score.

BP-Bodily pain; GH-General health; HRQOL-Health related quality of life; MH-Mental health; PROM-Patient reported outcome measure; PF-Physical function; RE-Role emotional; RP-Role physical; SD-Standard deviation; SF-36-36 Item Short Form Survey; VT-Vitality; WOMAC-Western Ontario and McMaster Universities Arthritis Index.

† Actual scores not reported, used to determine Rosser index.

‡ No range provided.

¶ No standard deviation provided.

¶ The Rosser index derives scores from the Harris hip Score, the matrix allocates scores from –1.486 to 1.000. A score of 1 indicates complete normality; death is given a score of 0.000. Numbers reported are the distribution of patients within each category with A1 being the best score and DVI being the worst quality of life score.

that across different instruments and timepoints, PROMs do not appear to differ meaningfully between cemented and hybrid THA. However, due to high risk of bias and very low certainty of evidence, these findings must be interpreted with caution. The lack of observable difference may be due to study limitations and imprecision.

Discussion

This review focused on studies comparing implant survival, PPF rate, and PROMs between hybrid and cemented primary THA for end stage osteoarthritis. From the eight retrieved studies [9–13, 34–36], five observational studies [9–13] compared the primary outcomes of survival and two studies compared PPF rate [9, 10]. Two RCTs [35, 36] and one observational study [34] analysed PROMs.

Survival

While the overall number of observations in the survival studies was substantial ($n = 283,100$), lack of clinical and methodological homogeneity led to variability in findings. Three studies [9, 10, 12] found no survival difference between hybrid and cemented THA over 1, 3, and 5 years, while two [11, 13] reported marginally better 10-year cemented survival and one study [13] better 16-year cemented survival. However, neither of the latter studies confirmed whether the observed differences reached statistical significance. Survival outcomes appeared to vary by patient group, follow-up duration, and implant type. Studies examined patients from under 55 years only [13] to those over 80 years only [9, 10]. In some studies, survival seemed to be better in specific cemented subgroups (e.g., ceramic-on-polyethylene bearings) [11], suggesting that individual implant characteristics may be more important than fixation type alone.

Broad category classifications of THA fixation groups include multiple implant brands (stems and acetabular cups), designs (geometry), materials, and coatings, which can behave differently in terms of longevity, wear, and complications [37]. Examining broad categories can highlight general trends, but lacks the detail needed to guide implant selection. Research on specific implant comparison may allow more accurate assessment of variability in patient outcomes, improve implant selection for patients, provide more clinically relevant outcomes, and avoid misleading conclusions [38]. Focusing on specific implant comparisons risks reduced sample sizes and statistical power, compromising inference, but the continued use of regional or national registry data could mitigate this limitation by leveraging access to larger and more generalisable patient populations.

Only two studies reported PPF rates [9, 10], both in patients 80 years and older but at different timepoints. One study indicated higher PPF rates in cemented THA [9]. Still, this difference did not translate into poorer implant survival in cemented THA overall. The available data do not support PPFs as the most common cause of revision in either cemented or hybrid THA. More importantly, clinical failures that did not result in revision were not documented. Since some PPFs are managed without revision (e.g., with fixation), and these cases were not reported, the true incidence of PPFs may be underestimated in both fixation types. This lack of reporting lowers the proportion outcome of PPF in cemented and hybrid fixation in THA. A study analysing data from the UK National Joint Registry found that 56% of postoperative PPFs were not captured by the registry, as the cases were treated without the replacement of components [39]. Lamb et al. [39] noted PPF as the leading cause of major reoperation (but not necessarily component replacement) following THA and that the prevention and treatment of PPF requires further research. It may be prudent to include, at a minimum, PPFs requiring surgical intervention within revision registry data collection.

All survival studies [9–13] used national registry derived data for survival analysis. The lack of consistent reporting of statistical significance, follow-up periods, and patient stratification reduces the overall ability to determine meaningful inferences from findings. While national joint registries are invaluable for monitoring and improving the outcomes of joint replacement surgeries, they do have some limitations. National registries provide broad standardised data that help identify overall trends in outcomes, implant longevity, and patient demographics [40, 41]. However, they mask regional disparities by averaging data across different populations and may not capture variations, for example, between wealthier and deprived regions or populations of different ethnicities. Regional joint registries may offer more detailed insights into regional population characteristics, specific access barriers, rural versus urban areas, and variations in surgical and funding outcomes (private versus public) [42]. For surgeons, regional data analysis may be more effective at determining the most successful THA for a specific demographic of patient.

Methodological heterogeneity between the survival studies complicated comparison and inference. Standardising survival analysis models, the handling of missing data, statistical adjustments, and definition of outcomes affected the validity and comparison of results. Methodological homogeneity in registry data analysis would allow opportunity for easier comparison and evaluation of survival outcomes.

Patient reported outcome measures

Although limited, all PROMs studies [34–36] reported improvements in HRQOL following primary THA for osteoarthritis, regardless of fixation type. One RCT [35] found a statistically significant advantage for hybrid THA at 1-year using the HRQOL Rosser Index. The observational study [34] reported differences in SF-36 subscales, favouring hybrid THA at 1-year and 3.6-years, but these differences were not statistically significant after adjusting for age, sex, follow-up time, and baseline values. Overall, both hybrid and cemented PROMs improved substantially and appeared similar between groups, but due to a small number of studies and no follow-up beyond 3.6 years, no difference in PROMs between hybrid and cemented THA could be identified in the medium-term to long-term. The included studies spanned a 30-year period and dated time-frame (1988–1998) and offer valuable historical perspectives. However, their relevance to contemporary practice is limited due to outdated measurement tools, evolving surgical techniques, and shifting patient expectations. Interpretation should be cautious, particularly when comparing to modern cohorts. In all three studies [34–36] included in our systematic review, younger, likely more active patients, were selected for hybrid THA, possibly reflecting surgeon preference rather than a truly random comparison. This bias creates indirectness of evidence as outcomes may reflect patient characteristics rather than implant design.

The absence of comparable PROM data of more than 3.6 years also highlights a major evidence gap. A seven-year prospective international multicentre study observed that while patients experienced significant improvements in PROMs within the first-year post THA, certain factors like obesity and postoperative difficulties in self-care were associated with a gradual decline in outcomes over the subsequent years [43]. This study highlights the importance of continued monitoring to assess the sustainability of surgical benefits. Research also indicates that PROMs tend to plateau after 1-to-2 years post-surgery, but that attrition over time may affect study sensitivity [44]. This attrition rate could be mitigated by using prospective national or regional population PROMs data rather than smaller sample groups [45]. A longitudinal cohort study by Schwartz et al. [46] emphasised that cognitive and mental health assessment significantly influence recovery trajectories post THA and suggested that long-term PROMs are essential for identifying patients at risk of poorer outcomes and for tailoring postoperative care accordingly. Such information is vital for setting realistic patient expectations and facilitating informed decision making regarding the procedures available. Although one RCT reported statistically significant HRQOL differences at 1 year favouring hybrid THA [35],

this finding was not consistently observed across other studies or timepoints.

There is a pressing need for contemporary, high-quality research evaluating patient-centred outcomes across different fixation types using standardised PROMs. Future studies should standardise the selection, collection and reporting of PROMs ideally in alignment with internationally agreed guidelines. While the Oxford hip score is one of the most used hip-specific PROM tool for THA [47], valued for its simplicity, validation and strong correlation with patient satisfaction and outcomes, the WOMAC is considered the highest quality PROMs tool for osteoarthritis [48]. The authors propose the use of at least one of these tools as an international standard. Transparency on missing data, loss to follow-up, and selection bias is essential. Lack of studies could reflect a systematic under collecting and under-reporting of PROMs in this area contributing to uncertainty and limiting evidence-based decision making. Our recommendations would be to collect PROMs preoperatively, at 6 months to 1-year, and then at 5 yearly intervals, in line with the New Zealand Joint Registry [49].

Although RCTs are the gold standard for evaluating the efficacy and safety of medical interventions, Pakvis et al. [7] argued that RCT studies are challenging to conduct in THA and may not always reflect the complexities of real-world orthopaedic care. These authors suggested that well-designed non-randomised studies with adequate follow-up and rigorous outcome measurement could serve as a benchmark for high-quality evidence in orthopaedics [7]. These benchmark studies would involve comparing similar populations, interventions and follow-up durations, using consistent outcome tools, data collection timelines, methodologies, and standardised statistical analyses.

Both survival and PROMs studies suffered from common limitations, including clinical and methodological homogeneity and inconsistent reporting. There are key limitations in the current literature, notably few published studies; heterogeneity in study design, outcome measures, and follow up durations; and all studies conducted in European countries. The fact that all studies in our review were European, limits the international generalizability of the findings due to potential differences in healthcare systems, surgical techniques, patient demographics, and ethnic variations in hip anatomy [50,51]. Broadening the evidence base to include studies from regions such as North America, Canada, Africa, Asia and Oceania would promote more equitable and optimal patient outcomes across diverse global populations.

Bias assessments identified moderate-to-high and high risk of bias across studies, with concerns related to confounding, prognostic factor measurement, randomisation and missing outcome data. Additionally, publication bias is suspected due to the low number of eligible studies. Taken

together, the evidence comparing hybrid and cemented THA is limited by study quality, short follow-up in PROM studies, and inconsistent methodology in survival studies. While both fixation types appear to offer good early PROMs and comparable implant longevity, further research is required—particularly longer term PROMs studies and implant survival at the prosthesis level [52] rather than broad fixation categories. Standardised methods, adjusted analyses, and stratification by patient and implant characteristics are essential for informed decision making.

Conclusion

Our review of the literature identified primary survival and PPF rates and secondary PROMs outcomes between hybrid and cemented THA for patients with end stage osteoarthritis from eight available studies. The studies do not clearly demonstrate a superior fixation category between hybrid and cemented THA. Both THA options showed improvements in early PROMs, exceeding 98% survival at 1 and 2 years and at least 90% survival at 10-years. All studies identified were European and evaluated outcomes from 1980 to 2019, suggesting that earlier studies might not relate to current surgical practices. Indeed, changes in practice over time may influence the heterogeneity of this review. The included studies were also inconsistent in reporting similar patient demographics, particularly age, PROMs, study time periods, length of follow up, statistical methods, and THA implant components. European only studies are limited in their ability to reflect outcomes in non-European settings, due to regional variations in clinical practice and patient demographics. The absence of longer-term PROM data is a significant gap and likely the byproduct of short-term focus, resource, and time constraints. Future research should focus on product specific outcomes, standardized methodologies, and longer PROMs follow up to provide clearer insights. Regional joint registry data can enhance decision making by considering demographic and socioeconomic factors for more personalised treatment procedures. This review is the first to attempt to summarise literature contrasting survival, PPF, and PROM outcomes between cemented and hybrid primary THA for osteoarthritis, identifying comparable outcomes between methods when considering the few studies available.

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that met the criteria for review. All authors AP, AB and KHL approved the final manuscript for submission.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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Appendix B. Ten-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis: a New Zealand regional study

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RESEARCH



10-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis: a New Zealand regional study

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Abstract

Introduction Compare 10-year survival of the cemented highly crosslinked polyethylene Exeter® Rimfit™ (Rimfit) Cup and its predecessor, the ultra-high molecular weight polyethylene Exeter® Contemporary Flanged Cup™ (ECF), both with an Exeter® V40™ stem, in primary total hip arthroplasty (THA) for osteoarthritis in the Bay of Plenty region of NZ.

Method We extracted national registry data for THA surgeries in the region between 1 January 2003 and 30 June 2023 and report the 10-year survival and reasons for revision of the two fully cemented implants ($n=495$). We compared standard Kaplan-Meier estimates using the log-rank test. Cox proportional hazard models investigated the potential influence of six patient variables on the survival of each implant: sex, age, body mass index (BMI), ethnicity, American Society of Anesthesiologists (ASA) rating, and funding source (public/private).

Results No statistically significant difference in 10-year survival rate between the implants ($p=0.334$) (ECF 95.6% [93.4, 97.9], Rimfit 97.0% [95.9, 98.2]) or statistically significant difference in revision reasons between the implants ($p=0.09$) was noted. Cox regression revealed no statistically significant influence of any of the six patient variables on the 10-year survival of the ECF ($p=0.584$) or Rimfit ($p=0.611$).

Conclusion Both implants exceeded 95% survival at 10-years, which is favourable compared to the corresponding 94.8% national survivorship of cemented implants in NZ. There is no statistically significant difference in the 10-year survival rate or reasons for revision of the two cemented implants compared in this region. The Rimfit appears a suitable alternative to the ECF, from a survival and revision perspective.

Keywords Total hip replacement · Fixation · Revision · Hybrid · Polyethylene

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Introduction

In 1962 Sir John Charnley pioneered the first fully cemented, low friction total hip arthroplasty (THA) using a cemented stainless-steel stem, cemented polyethylene cup (PE) and polymethylmethacrylate bone cement [1]. Since then designers have introduced substantial improvements such as flanged cups to improve cement pressurisation [2] and improved cement formulations [3]. The Exeter® Contemporary Flanged Cup™ (Stryker Orthopaedics, Mahwah, NJ, USA) (ECF), developed in 1998 reports excellent survival outcomes up to 15 years [4, 5] with extremely low dislocation [6] and aseptic loosening rates [7]. From 2010 the focus became the reduction of PE wear and improvement in cement mantle consistency [8]. New cemented components, such as the highly crosslinked polyethylene Exeter® X3® Rimfit™ (Stryker Orthopaedics, Mahwah, NJ, USA) (Rimfit) were introduced, proposed to reduce wear and lower osteolysis risk [9]. Key improvements in the Rimfit included polymethylmethacrylate spacers; a rimcutter for mantle control; a slim curved flange to match the rim; and built in radiographic marker wire [10]. Many high volume hospitals and public settings gradually discontinued use of the ECF [5] in favour of the more durable Rimfit [9]. The recommended stem for both the ECF and Rimfit is the cemented Exeter® V40™ (with a 40 mm bore diameter of the taper) with excellent survival outcomes [7, 11, 12] and a low rate of revision [7, 13]. The ECF/V40 combination is the most prominent cemented THA in NZ, representing nearly 8,000 of the 93,487 THA surgeries recorded between 1999 and 2013 [14]. The Rimfit/V40 combination is the second most prevalent cemented THA with over 3,000 surgeries from 2010 to 2022 [14].

There are few studies on survival outcomes of the ECF [4–7] or the Rimfit [15–17], and none restricted to osteoarthritis. There is no study directly comparing their survival, reasons for revision, or revision predictors of interest in osteoarthritis. In the only published comparison study [18], both displayed “similar 5-year outcomes” in radiotranslucent lines and clinical scores, but survival was not reported. Such comparison is essential to justify the transition from the ECF to the Rimfit in clinical practice.

An ideal comparison between the ECF and the Rimfit would control for fixation, stem type or approach, handling, and instrumentation. Comparing these THA components in the same region with the same group of surgeons also eliminates variations in surgical skill, experience, and preferred technique. Therefore, our analysis focused on data from a regional registry. We compared and reported patient characteristics, 10-year survival, reasons for revision, and effects of patient-specific predictors (age, sex, BMI, ethnicity, ASA rating, and funding source) on survival outcomes in the two

cemented implants for primary THA for osteoarthritis in the Bay of Plenty region of NZ to identify implant superiority in survival and revision reasons, and meaningful predictors of poorer survival.

Materials and methods

Data source and collection

Ethical approval was obtained from The University of Waikato Human Research Ethics Committee (HREC2023#12). The New Zealand Orthopaedic Association (NZOA) supplied anonymised data from the mandatory national joint registry (NZJR) for the Bay of Plenty region of NZ from 1 January 2003 up to and including 30 June 2023. All primary THAs for osteoarthritis with an Exeter V40 stem and either an Exeter Contemporary flanged Cup (Stryker Orthopaedics, Mahwah, NJ) made of ultra-high molecular weight polyethylene, or Exeter X3 Rimfit Cup (Stryker Orthopaedics, Mahwah, NJ) of highly crosslinked polyethylene, were included in analysis with follow-up to 30 June 2023 or a maximum of 10 years. We elected to report outcomes at 10 years as this represents a clinically meaningful and widely accepted benchmark in arthroplasty research. THAs were performed in three hospitals and 93% performed by four surgeons using the same modern, third generation cementing technique. Both cemented cups are widely used, intended for the same patient populations but differ in features such as flange geometry and rim configuration.

We categorised adverse events (revision) as a “1” and included censored data up until the date of death or end of the observation period or upon 10 years of follow-up and categorised as “0”. Patient-specific predictors were treated as categorical variables, and included sex, age, BMI, ethnicity, ASA rating, and funding source. Predictors and sub-categories are summarised in Table 1. Age at surgery was classified to align with the New Zealand, Australia, England-Wales, and Finland national joint registry categories. Only a small number of ≤ 55y observations (2%) in both implants were noted (ECF: $n = 8$; Rimfit: $n = 28$) and were combined with the 56–64y age group creating a < 65y category. We classified BMI at surgery into five categories as per the Centre for Disease Control [19]. ASA ratings are graded into four categories. However, eight ASA 4 observations between both implants (ECF: $n = 1$; Rimfit, $n = 7$) were recoded as ASA 3 for analysis. Ethnicities are self-reported and extracted via the National Health Index (unique identifier assigned to each person in New Zealand).

Table 1 Classification of categorical variables

<i>Sex</i>	
Male	Assigned male at birth
Female	Assigned female at birth
<i>Funding</i>	
Public	Public health system funding source
Private	Insurance or self-paid funding source
<i>Age (years)</i>	
<65	Under but not including 65 years
65–74	Including 65 and up to and including 74 years
≥75	Including and over 75 years
<i>BMI (kg/m²)</i>	
<25	Normal BMI
25–29.9	Overweight
30–34.9	Obese Class I
35–40	Obese Class II
>40	Obese Class III
<i>ASA rating</i>	
ASA 1	Patient is a completely healthy, fit patient.
ASA 2	Patient has mild systemic disease.
ASA 3	Patient has severe systemic disease that is not incapacitating.
ASA 4	Patient has incapacitating disease that is a constant threat to life.
<i>Ethnicity ‡</i>	
NZ European	New Zealanders of European descent
Māori	A person of the Māori race and includes any descendant
Other	All other ethnicities and undetermined ethnicities

ASA, American Society of Anesthesiologists Physical Status classification system; BMI, body mass index; NZ, New Zealand

‡ NZ Government Stats NZ, Tatauranga Aotearoa

Survival

We implemented a pairwise deletion approach to handle missing data so that all available data were used in statistical analysis. Revision and death were identified through the compulsory national joint registry, which captures all primary procedures, revision operations, and mortality through national data linkage. As a result, loss to follow-up was negligible. Patients who had not experienced the event of interest (revision) were right censored at the earliest of the study end date. We performed standard Kaplan-Meier analysis on the dataset using the R studio 2024.09.0 “Cranberry Hibiscus” statistical package [20]. Kaplan-Meier assumptions of independent, non-informative censoring; time-to-event data; homogeneity of survival and no influential events affecting survival were met. We considered competing risk of death analysis; however, standard Kaplan-Meier analysis was chosen as the population below 75 years where death is less likely to be a competing risk exceeded the older population

group of above 75 years. *T* tests were used to determine differences in mean age or BMI between the implant groups, and *Chi square* tests to compare proportions for each categorical predictor between implants.

Reasons for revision

Reasons for revision were categorised into dislocations, infection, periprosthetic fracture, pain, aseptic loosening of acetabulum, aseptic loosening of both components, loosening of acetabulum due to infection, fall, and broken stem. *Chi square* tests compared proportions between implants.

Regression

Uni- and multivariate Cox regressions were performed on the overall cemented sample as well as for each implant. To assess the robustness of our findings, we evaluated the proportional hazards assumption using Schoenfeld residuals and log-log survival plots. The results were consistent across methods, supporting the validity of the primary analysis. Across statistical analyses, the 95% confidence intervals [lower, upper] of estimates were extracted and significance set to $p < 0.05$. All analyses were conducted using R studio 2024.09.0.

Results

Patient variables and revisions per component are shown in Table 2. THA surgeries for OA from 1 January 2003 and 30 June 2023 ($n=1630$, age: 71.7 ± 8.5 y, BMI: 28.1 ± 5.2 kg/m²) included ECF in 363 instances (22.3%, age: 71.3 ± 8.5 y, BMI: 28.2 ± 4.8 kg/m²) and Rimfit in 1267 instances (77.7%, age: 71.7 ± 8.5 y, BMI: 28.1 ± 5.3 kg/m²), with no statistically significant difference between implant groups in mean age ($p=0.427$) or BMI ($p=0.812$) at surgery. *Chi square* tests revealed no statistically significant differences in proportion of men and women ($p=0.095$), BMI categories ($p=0.555$), or age categories ($p=0.596$) between implants. Statistically significant differences of proportion in ASA ratings ($p < 0.001$), ethnicities ($p < 0.001$) and funding pathways ($p=0.004$) between implants (Table 3) were noted. The Rimfit reported a higher proportion of Māori, ASA 3 rating, and publicly funded surgeries.

† Missing values have not been included in proportion calculations.

Survival

A total number of 1630 implants for the observation period were included in analysis, 495 in situ for 10 years (ECF:

Table 2 Patient variables and revisions per component

	Both Implants			ECF			Rimfit		
	n	%	Revisions	Revision %	n	% of Total Implants	Revisions	Revision %	% of Total implants
Total	1630		43	2.6%	363	22.3%	14	3.9%	1267
Sex									
Male	648	39.8%	19	2.9%	158	43.5%	3	0.8%	490
Female	982	60.2%	24	2.4%	205	56.5%	11	3.0%	777
Age (years)									
≤64	337	20.7%	15	4.5%	81	20.1%	4	4.9%	256
65–74	670	41.1%	16	2.4%	150	41.3%	5	3.3%	520
≥75	623	38.2%	12	1.9%	132	36.4%	5	3.8%	491
BMI (kg/m ²)									
<25	367	25.4%	7	1.9%	61	23.8%	3	4.9%	306
25–29.9	618	42.7%	15	2.4%	120	46.9%	2	1.7%	498
30–34.9	322	22.3%	10	3.1%	53	20.7%	3	5.7%	269
35–39.9	94	6.5%	4	4.3%	13	5.1%	0	0.0%	81
≥40	45	3.1%	1	2.2%	9	3.5%	0	0.0%	36
Missing†	184	NA	6	3.3%	107	NA	6	5.6%	77
ASA									
1	216	14.0%	4	1.9%	59	20.7%	1	1.7%	157
2	946	61.1%	25	2.6%	175	61.4%	6	3.4%	771
3 & 4	386	24.9%	10	2.6%	51	17.9%	3	5.9%	335
Missing†	82	NA	4	4.9%	78	NA	4	5.1%	4
Funding									
Public	566	40.5%	16	2.8%	118	33.8%	7	5.9%	448
Private	833	59.5%	24	2.9%	231	66.2%	7	3.0%	602
Missing†	231	NA	3	1.3%	14	NA	0	0.0%	217
Ethnicity									
NZEU	1455	89.3%	39	2.7%	304	83.7%	12	3.9%	1151
Maori	110	6.7%	3	2.7%	14	3.9%	1	7.1%	96
Other	65	4.0%	1	1.5%	45	12.4%	1	2.2%	20
ASA, American Society of Anesthesiologists grading; BMI, body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rim fit cup									

Table 3 Tests of proportion for each implant

Variable	Group	ECF			Rimfit			Model comparison	
		Actual	Expected	χ^2	Actual	Expected	χ^2	χ^2	p-value
Sex	Male	158	144	1.3	490	504	0.37	2.57	0.095
	Female	205	217	0.86	777	763	0.25		
Age (years)	≤ 64	81	75	0.47	256	262	0.14	1.03	0.596
	65–74	150	149.00	0	520	521	0		
	≥ 75	132	139	0.33	491	484	0.09		
BMI (kg/m ²)	< 25	61	65	0.24	306	302	0.05	3.01	0.555
	25–29.9	120	109	1.02	498	509	0.22		
	30–34.9	53	57	0.28	269	265	0.06		
	35–39.9	13	17	0.8	81	77	0.17		
	≥ 40	9	8.00	0.13	36	37.00	0.03		
ASA	1	59	40	9.3	157	176	2.1	18.4	0.0001
	2	175	174	0	771	772	0		
	3 & 4	51	71.00	5.67	335	315.00	1.28		
Funding	Public	118	141	3.81	448	425	1.27	8.16	0.004
	Private	231	208	2.59	602	625	0.86		
Ethnicity	NZEU	304	324	1.24	1151	1131	0.35	90.2	0.00001
	Māori	14	25	4.5	96	85.5	1.29		
	Other	45	15	64.4	20	50.52	18.4		

Missing values have not been included in overall proportion calculations

Abbreviations: ASA, American Society of Anesthesiologists grading; BMI, body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup

*Significance set at $p < 0.05$

$n = 245$ Rimfit; $n = 250$ Table 4) with a median follow-up of seven years. Kaplan-Meier analysis revealed a combined 10-year survival rate of 96.5% [95.5, 97.6] with log-rank revealing no statistical difference in survival between the implants (ECF: 95.6% [93.4, 97.9]; Rimfit: 97% [95.9, 98.2], $p = 0.334$) (Fig. 1). No statistically significant difference in survival between patient predictors was noted (Table 4).

Reasons for revision

Forty-three revisions (2.6%) performed over the period (ECF $n = 14$, Rimfit $n = 29$). Most revisions were due to dislocation (30%) followed by infection (23%). No statistically significant difference in proportion of dislocation ($p = 0.08$) or any other revision reason was noted (Table 5). Of the 43 revisions, 24 (56%) occurred in females and 19 (44%) in males reflecting the overall cohort distribution. By funding status, 24 (56%) were privately funded, 16 (37%) publicly funded, and 3 (7%) had missing data. Regarding ethnicity, 29 (67%) were NZ European, 3 (7%) Māori and 1 (2%) Other, with the remaining missing or uncategorised. These distributions provide context for subsequent revision patterns. Notably, 15 (35%) revisions occurred in patients under 65 years, 16 (37%) in those 65–74 years and 12 (28%) in patients ≥ 75 years. Compared with the overall cohort, patients under 65 were overrepresented (20.7% of the total sample), whereas those ≥ 75 were underrepresented (38.2%

of the total sample). However, these differences were not statistically significant in either univariate or multivariate Cox regression. BMI data were missing for 13 revision cases, limiting interpretation across categories.

Regression

Multivariate Cox regression for both implants found no statistically significant effect of any predictor on 10-year survival (Table 6). Certain subgroups (BMI 35–39.9 and ≥ 40, NZ Māori) had small sample sizes, which should be considered when interpreting these findings.

Discussion

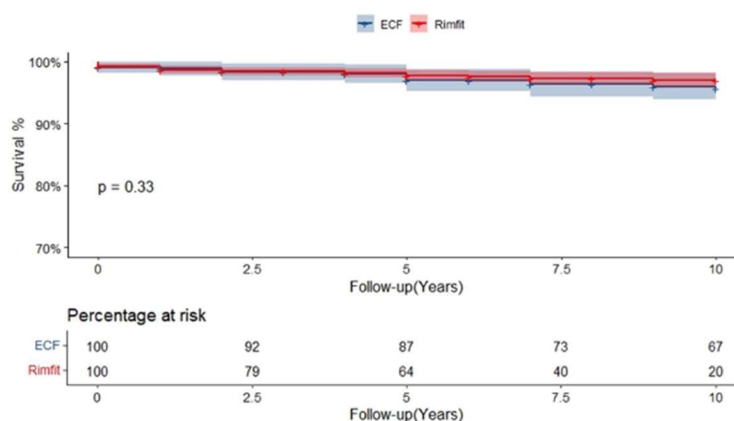
Survival

Our combined survival rates exceed 95% at 10 years, suggesting durable outcomes with both implants using the V40 stem. This benchmark outcome is consistent with the 10-year performance of broad cemented implants in NZ [14] and internationally [21–25]. For example, our 10-year 97% Rimfit survival rate aligns with the UK national joint registry and the Australian Orthopaedic association broad cemented category (97.2% and 96.6%, respectively) [22], substantiating it as a suitable replacement for the ECF. The Rimfit was introduced almost decade after the ECF, yet

Table 4 Implant survival at 10 years

Factor	Both Implants				ECF				Rimfit			
	At risk (n)	Events (n)	Survival % [95%CI]	log-rank p-value†	At risk (n)	Events (n)	Survival % [95%CI]	log-rank p-value†	At risk (n)	Events (n)	Survival % [95%CI]	log-rank p-value†
Component	495	43	96.5 [95.5, 97.6]	—	245	14	95.6 [93.4, 97.9] §	—	250	29	97.0 [95.9, 98.2] §	0.334 §
Sex												
Male	215	19	96.4 [94.8, 98.1]	0.628	105	3	98.0 [95.7, 100]	0.113	110	16	95.8 [93.6, 98.0]	0.089
Female	280	24	96.6 [95.1, 98.0]		140	11	94.0 [90.5, 97.5]		140	13	97.9 [96.8, 99.1]	
Age (years)												
<65	154	15	94.5 [91.7, 97.3]	0.172	71	4	94.8 [90.0, 99.9]	0.854	83	11	94.7 [91.6, 97.9]	0.103
65–74	229	16	97.1 [95.7, 98.5]		120	5	96.3 [93.2, 99.5]		109	11	97.5 [96.0, 99.0]	
≥75	112	12	97.7 [96.3, 99.0]		54	5	95.9 [92.4, 99.2]		58	7	98.3 [96.9, 99.6]	
Ethnicity												
NZEU	417	39	96.5 [95.4, 97.7]	0.748	201	12	95.6 [93.2, 98.1]	0.696	216	27	96.9 [95.7, 98.1]	0.744
Māori	34	3	95.2 [89.3, 100]		11	1	90.9 [75.4, 100]		23	2	97.8 [94.8, 100]	
Other	44	1	98.3 [95.1, 100]		33	1	97.7 [93.4, 100]		11	0	100 [100, 100]	
BMI (kg/m ²)												
<25	83	7	97.2 [95.2, 99.4]	0.784	37	3	94.7 [89.1, 100]	0.487	46	4	97.7 [95.5, 100]	0.527
25–29.9	175	15	97.0 [95.4, 98.6]		79	2	98.2 [95.7, 100]		96	13	96.6 [94.6, 98.6]	
30–34.9	82	10	95.5 [92.6, 98.5]		35	3	93.3 [86.3, 100]		47	7	96.5 [93.9, 99.2]	
35–39.9	30	4	95.7 [91.6, 99.9]		10	0	100 [100, 100]		20	4	95.0 [90.3, 99.9]	
≥40	20	1	97.8 [93.6, 100]		9	0	100 [100, 100]		11	1	97.2 [92.0, 100]	
missing	184	6			107	6			77	0		
ASA												
1	85	4	97.3 [94.7, 100]	0.705	49	1	98.2 [94.6, 100]	0.336	36	3	96.5 [92.2, 100]	0.892
2	267	25	96.8 [95.5, 98.0]		114	6	96.2 [93.3, 99.3]		153	19	96.9 [95.5, 98.3]	
3 & 4	83	10	95.7 [92.6, 99.0]		22	3	89.8 [79.1, 100]		61	7	97.7 [96.1, 99.4]	
missing	82	4			78	4			4	0		
Funding												
Public	160	16	96.4 [94.3, 98.5]	0.917	65	7	92.6 [87.4, 98.1]	0.128	95	9	97.8 [96.3, 99.3]	0.314
Private	292	24	96.4 [95.5, 97.4]		170	7	96.7 [94.4, 99.2]		122	17	96.1 [94.2, 98.1]	
missing	231	3			14	0			217	3		

ASA, American Society of Anesthesiologists grading; BMI, body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup
 * p-value set at <0.05; † log rank p-value for main effect of a given predictor; § log rank p-value for survival rates of ECF and Rimfit

Fig. 1 10-year Kaplan-Meier survival for both implants**Table 5** Reasons for revision

	Both implant revisions		ECF revisions		Rimfit revisions		χ^2
	(n = 43)	% total	(n = 14)	% total	(n = 29)	% total	P-value*
Dislocations	13	0.80%	6	1.65%	7	0.55%	0.08
Infection	10	0.61%	2	0.55%	8	0.63%	1
Periprosthetic fracture	8	0.49%	2	0.55%	6	0.47%	1
Pain	5	0.31%	2	0.55%	3	0.24%	0.68
Aseptic loosening (Acetabulum)	3	0.18%	1	0.28%	2	0.16%	1
Aseptic loosening (Femur & Acetabulum)	1	0.06%	1	0.28%	—	—	—
Loosening acetabulum (infection)	1	0.06%	—	—	1	0.08%	—
Fall	1	0.06%	—	—	1	0.08%	—
Broken stem	1	0.06%	—	—	1	0.08%	—

*Chi square tests of proportion with significance set at $p < 0.05$

equivalent survival rates suggest implant design/material changes did not translate into measurable differences in long term fixation. Both designs provide robust outcomes across different eras of surgical practice and support the generalisability of our findings.

Reasons for revision

Both implants demonstrated no statistically significant difference in survival up to 10 years and low rates of dislocation, infection, and aseptic loosening. This finding suggests that implant design differences did not substantially influence the underlying mechanisms of failure. From a clinical perspective, this lack of difference indicates both designs are comparable in terms of stability, infection risk, and fixation durability, with other surgical and/or patient factors potentially influencing revision risk. Comparing revision cases with overall cohort distribution revealed that patients under 65 years were overrepresented and those over 75 years were underrepresented. This pattern suggests younger, more active patients may face a relatively higher risk of revision, consistent with registry evidence linking activity levels and

implant demand to early failure [26]. BMI comparisons were less reliable due to missing data in 13 revision cases, limiting firm conclusions.

Regression

Sex, age, BMI, ethnicity, ASA rating, and funding did not significantly influence the 10-year survival of implants individually or when combined. It is worthwhile noting that no variables significantly impacted on the time until the event of interest in either the overall cemented sample or when stratified by implant design. The variables considered did not have a meaningful association with revision in our population, indicating possible weak or non-existent relationship. A low number of Māori and Other ethnicity patients, patients with BMI categories of 35 to 39.9 kg/m² and > 40 kg/m², and those < 55 years reduced precision of survival and Cox regression analysis. Hence, the lack of significance should be interpreted with caution. Our extended analysis provide insight in a NZ context, indicating that the two implants perform well across a broad range of patients, regardless of sex, age, ethnicity, BMI, ASA rating,

Table 6 Cox multiple regression for both implants

Covariate	Both Implants				ECF				Rimfit					
	Coeff (OR)	HR	95% [CI] ‡	P-value	Coeff (OR)	HR	95%CI ‡	P-value	Coeff (OR)	HR	95%CI ‡	P-value		
ASA 2	0.48	1.62	[0.54, 4.87]	0.388	0.83	2.30	[0.25, 20.90]	0.461	0.37	1.45	[0.41, 5.16]	0.562		
ASA 3	0.59	1.8	[0.49, 6.64]	0.376	1.30	3.60	[0.31, 44.06]	0.303	0.38	1.46	[0.31, 6.72]	0.624		
Age ≥ 75	-0.83	0.43	[0.17, 1.10]	0.079	-0.64	0.53	[0.10, 2.88]	0.460	0.38	0.44	[0.14, 1.31]	0.139		
Age 65-74	-0.81	0.44	[0.19, 1.00]	0.505	-0.12	0.31	[0.05, 1.97]	0.213	-0.69	0.5	[0.20, 1.25]	0.141		
BMI ≥ 40	-0.17	<0.001	[0.00, inf]	0.997	-0.2	<0.001	[0.00, inf]	0.999	-0.17	<0.001	[0.00, inf]	0.997		
BMI 25-29.9	0.07	1.07	[0.43, 2.72]	0.877	-1.03	0.36	[0.06, 2.27]	0.276	0.44	1.56	[0.49, 4.93]	0.451		
BMI 30-34.9	0.20	1.22	[0.44, 3.42]	0.703	0.01	1.01	[0.18, 5.57]	0.987	0.30	1.35	[0.37, 5.03]	0.652		
BMI 35-39.9	0.38	1.46	[0.39, 5.49]	0.567	-19.7	<0.001	[0.00, inf]	0.999	1.01	2.73	[0.61, 12.31]	0.191		
Sex Female	-0.22	0.79	[0.39,1.59]	0.527	0.72	2.04	[0.38, 11.00]	0.404	-0.49	0.62	[0.28, 1.36]	0.228		
Ethnicity Māori	-0.46	0.63	[0.14, 2.80]	0.544	-18.3	<0.001	[0.00, inf]	0.999	-0.29	0.74	[0.16, 3.46]	0.706		
Ethnicity Other	-17.00	<0.001	[0.00, inf]	0.997	-18.1	<0.001	[0.00, inf]	0.999	-17.34	<0.001	[0.00, inf]	0.998		
Funding Public	-0.09	0.92	[0.44, 1.93]	0.821	0.39	1.48	[0.32, 6.77]	0.613	-0.27	0.77	[0.32, 1.84]	0.550		
Implant ECF	-2.14	8.08	[0.36, 1.08]	0.602										
†Log-rank test of model for both implants				p=0.645	†Log-rank test of model for ECF				p=0.658	†Log-rank test of model for Rimfit				p=0.584

Specific instruments such as the Oxford Hip Score, Western Ontario and McMaster Universities Osteoarthritis index and a health-related quality of life tool, with domains including pain, function and overall patient satisfaction could be used to complement registry-based data alongside comparison of homogenous patient populations.

Considering the predominant use of hybrid fixation (51%) over cemented (4%) [14] in NZ, we recommend a comparative survival and Cox regression analysis of high-use hybrid implants; with consistent V40 stem use and highly crosslinked PE liners; with the cemented Rimplit in this population, over the same observation period, and a closer inspection and comparison of 10-year PROMs. Such a study may identify patient subgroups more susceptible to poor THA survival but also poorer PROMs outcomes.

Conclusion

The 10-year survival of both the ECF and Rimplit in this region of NZ is positive. The favourable survival rate of the Rimplit supports its continued use and justifies it as a replacement of the ECF in this region, with 10-year survival outcomes not affected by age, sex, BMI, ethnicity, ASA rating, or funding source. Future studies should include PROMs comparison between the Rimplit and ECF to identify whether Rimplit PROMs are at a minimum consistent with the ECF. With the increased use of hybrid THA in NZ, a survival and PROMs comparison of the Rimplit with a commonly used hybrid implant; with the same V40 stem; analysing the same patient predictors, is also recommended.

Limitations

This study is observational thus causal influences cannot be made. While overall survival success is an important outcome, we acknowledge that it is not the sole indicator of a successful THA. We also acknowledge that patient characteristics are not the only predictors of outcomes. Potential confounders such as differences in surgical approach, cement brands and intraoperative technique may influence outcomes but could not be fully accounted for in this study. However, as 93% of surgeries were performed by the same surgeons the possibility of confounding is less likely. The relatively small sample sizes representing Māori and Other ethnicities, patients under 55 years, and individuals with greater BMI may lead to less reliable analyses and increases risk of error. Lack of statistical significance therefore warrants cautious interpretation. This uncertainty may not accurately reflect the true population values.

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Author contributions AP led the project and is the primary author of the manuscript. KHL contributed as second author. GC, TL, SM, and AV facilitated access to data and, together with AP and KHL, contributed to the study design, defined the research focus, and provided critical feedback and intellectual input throughout the project. CJ developed the statistical methodology and analysis in collaboration with AP. All authors reviewed and approved the final manuscript for submission.

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Data availability The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. Data are located in controlled access data storage at the University of Waikato.

Declarations

Conflict of interest One author is an Editorial board member, Journal of Hand Surgery (Asia-Pacific), and another is on the Committee Asia Pacific, Orthopaedic Association, Hand & Upper Limb Section. One author is a Council member of the NZ Orthopaedics Association. Two authors have disclosed paid presentations for Stryker in 2023. One author has a Training & Education contract for Stryker.

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Appendix C. Fifteen-year Exeter Contemporary Flanged cup patient-reported outcome measures publication

Original Research Article

HIP | HIP
International

15-year patient-reported outcomes of a cemented flanged cup and stem combination in primary total hip arthroplasty: a New Zealand study

HIP International

1–11

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Sage

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Abstract

Methods: We investigated 15-year patient-reported outcomes (PROMs) and their predictors in primary total hip arthroplasty (THA) for osteoarthritis using a cemented flanged cup and stem from a regional joint registry in New Zealand. Regional data were collected for all primary THAs with this cemented combination from 1 January 2003 to 30 June 2023 who had recorded PROMs on at least 1 occasion ($n=263$). PROMs included Oxford Hip Score, Western Ontario and McMaster Universities Arthritis Index and Veterans Rand-12, evaluated against patient age, ethnicity, sex, body mass index (BMI), funding pathway, and American Society of Anesthesiologists (ASA) rating.

Results: Significant improvements across preoperative PROMs were noted 1-year post-surgery, with a mean change above 23 in the Oxford Hip Score maintained at 5, 10, and 15 years ($p \leq 0.001$).

Conclusions: Regression analysis indicated that being female, public funding, and higher BMI were associated with worse preoperative PROMs. Poorer preoperative scores, older age and ASA 3 rating correlated with poorer postoperative outcomes.

Keywords

Oxford Hip Score, postoperative, preoperative, VR-12, WOMAC

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Introduction

Surgical success for joint replacement procedures has long been evaluated using implant survivorship models.¹ With current healthcare shifting focus to patient well-being and quality of life,² patient-reported outcome measures (PROMs) have become an important metric in quantifying surgical success. PROMs allow surgeons to quantify patients' health-related quality of life and make decisions regarding optimal patient care, shifting the focus from surgeon-centred to patient-centred models of care.

The cemented, all-polyethylene flanged cup we chose to examine in this study, the Exeter Contemporary Flanged cup (Stryker Orthopaedics, Mahwah, NJ, USA), has been in use since 1991 and was the cemented cup most used in New Zealand (NZ) between 2003 and 2013.^{3,4} Schmitz et al.⁵

reported good results for this cup in THA patients under 50 years with a component survival rate of 90% after 10 years. Furthermore, Maggs et al.⁶ identified a 97.8%

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survivorship at 12.5 years in patients 46 years and above. In environments where THAs are completed in high volumes, the polished, stainless steel, tapered, and collarless cemented stem, the Exeter V40 stem (Stryker Orthopaedics) we are examining in this study, has demonstrated excellent functional outcomes based Western Ontario and McMaster Universities Arthritis Index (WOMAC) scores and 97.8% survivorship at 10 years.^{7,8} This stem has a reported 15-year survivorship of 96.6% (confidence interval [CI] 95%, 98.3–94.8) and rare periprosthetic fracture rates of 0.6% (CI 95%, 0.3–0.9) at 15 years,⁹ although this may be underestimated in studies where periprosthetic fractures requiring alternative reoperations (such as open reduction and internal fixation, and where there is no stem exchange),^{10–12} have not been reported. In NZ, over 54,000 of these particular stems were used between 1999 and 2022 and currently represent 60% of all stems used in the UK.^{4,8} This cemented combination maintained a top 10 position of all hip combinations implanted in NZ between 2003 and 2013.

Although studies have reported survivorship of this Exeter Contemporary Flanged cup with Exeter V40 stem (Stryker Orthopaedics) combination,⁶ few have examined PROMs. A more thorough investigation of this cemented cup-and-stem combination specific to osteoarthritis that includes short-, medium- and long-term PROMs evaluated against patient characteristics, comorbidities, and funding pathways may identify specific predictors affecting PROMs and populations susceptible to poorer outcomes.

Prospectively gathered data from a regional registry were used to examine preoperative, 1-year, 5-year, 10-year, and 15-year PROMs in primary THA for osteoarthritis with this cup-and-stem cemented combination against patient characteristics age, sex, and body mass index (BMI); comorbidities based on American Society of Anesthesiologists (ASA) rating; and funding pathways. Oxford Hip,¹³ WOMAC, and health-related quality of life Veterans Rand 12-item (VR-12)¹⁴ scores were analysed. The VR-12 has been validated by cross-system comparisons.¹⁵

We aimed to report PROMs for this implant combination up to 15 years, establish a benchmark methodology for future studies of other implant combinations in this region, and determine predictors of these PROMs to guide THA management in this region of interest.

Method

Data source and collection

Tauranga Orthopaedic Research (TOR) is a non-profit organisation in the Bay of Plenty region of NZ which maintains a mandatory registry of all regional joint arthroplasty surgeries. The TOR registry is independent of the NZ National Joint Registry and includes procedures from 2 public and 1 private hospital. Data are collected with

patient consent and entered into the Standardized Orthopaedic Cartilage Repair and Treatment Evaluation Software (SOCRATES version 3.5.8.26 10150).

The TOR registry collects Oxford, WOMAC, and VR-12 as their routine standard of care for THA preoperatively, at 1 year postoperatively, at 5 years postoperatively, and every 5 years thereafter. The University of Waikato's Human Research Ethics Committee granted ethical approval to analyse the database for this study (HREC2023#12).

Anonymised prospective observational data from 1 January 2003 to 30 June 2023 were retrieved in July 2023. Data were eligible for analysis when patients underwent primary THA for osteoarthritis and received an Exeter Contemporary Flanged cup with Exeter V40 stem combination within the set observational period. Patient data needed to contain at least 1 of the PROMs at any of the timepoints of interest to meet inclusion. A pairwise deletion approach was implemented to handle missing PROM scores at any timepoint (questionnaires not returned, incomplete questionnaires or withdrawal from the study at that timepoint) so that all available data were used in statistical analysis (Figure 1).¹⁶

Outcomes

We considered preoperative PROM data as scores recorded at any point preoperatively; 1-year data as scores recorded from 10–14 months postoperatively; 5-year data as scores recorded from 4–6 years postoperatively; 10-year data as scores recorded from 9–11 years postoperatively; and 15-year data as scores recorded from 14–16 years postoperatively. Although 15-year data were available for some patients, not all measures of interest had observations. Consequently, comparison of PROMs up to 10 years postoperatively were included in subgroup analysis.

Predictors

The predictors extracted from the database included patient age, sex, BMI, ethnicity, ASA rating, and funding pathway. Age and BMI were treated as continuous variables. Other predictors were treated as categorical or rank variables, and included sex (female, male), funding pathway (public, private), ethnicity (NZ European, Māori, Other), and ASA rating (a single ASA 4 observation was recoded as ASA 3 for analysis). “Other” ethnicity included “undetermined”, “undisclosed”, and any ethnicity not recorded as Māori or NZ European.

Data analysis

Data were inspected and normality of distribution verified. Descriptive statistics were computed for all variables, including counts, means, standard deviations (SD), and

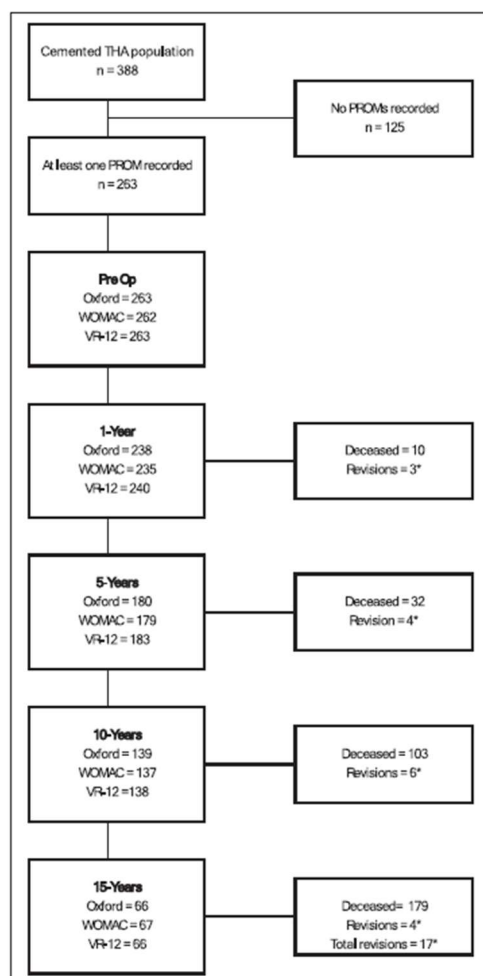


Figure 1. Flow chart depicting sample sizes, deaths and revisions at each follow-up period. All unaccounted observations were those lost to follow-up (questionnaires not returned, incomplete questionnaires or withdrawal from the study at that timepoint). *See Supplemental Table 2 for detailed reasons for revision and revision type.

ranges (minimum, maximum). Continuous numeric dependent variables were compared using 2-sample *t*-tests when normally distributed. Normal sampling mean distribution was assumed in samples ≥ 30 according to central limit theorem given parametric tests produce more accurate and precise estimates with higher statistical powers.¹⁷ Where variances were unequal, Welch 2-sample *t*-tests were performed. Analysis of variance (ANOVA) tests

were performed to compare predictors with more than 2 categories, dependent on ANOVA assumptions being met.¹⁸ The Tukey method was used in *post-hoc* testing.

Multiple linear regression analyses were performed on preoperative and postoperative PROMs to determine if any of the predictors correlated to any of the PROMs. The Bayesian Information Criterion was used to determine best model fit.¹⁹ Estimates and coefficients of determination (R^2) were extracted from the regressions to quantify the association between predictors and outcomes, as were standard errors to quantify uncertainty of estimates. Possible predictors of preoperative scores included age, ethnicity, sex, funding pathway, BMI, and ASA rating. Postoperative predictors included the same factors, but also preoperative scores as these have been identified as possible predictors of postoperative scores.²⁰ Collinearity was investigated with variance inflation factor and condition index. Significance levels were set to $p < 0.05$ and confidence intervals to 95% (lower, upper). All statistical tests were performed using RStudio 2023.09.1 build 494 "Desert Sunflower" statistical software.²¹

Results

A total of 388 THAs met inclusion for the defined period. Observations that did not have at least 1 PROM recorded were excluded, leaving 263 THAs for analysis (Table 1), with follow-up rates of 91%, 68%, 53%, and 26% at 1, 5, 10, and 15 years, respectively. Of the 263 observations with at least 1 PROM recorded, females accounted for 54.3% ($n = 143$), ASA 2 rated patients for 62% ($n = 164$) and NZ Europeans for 92.1% ($n = 242$). The mean age of patients at surgery was 71.4 years (range 46–92) and mean BMI 28.01 kg/m² (range 18.2–50.4). Five males and seven females received bilateral THAs. The standard 150-mm stem length accounted for 92.3% of all stems implanted, with 125-mm accounting for 4.6% and 205-mm at 0.7%. Stem length was not recorded in 2.4% of observations. No statistically significant differences in mean age, BMI or factor proportions between the total sample of 388 and the evaluated 263 observations were noted (Supplemental Table 1). Seventeen revisions during the observation period were noted. (Supplemental Table 2).

Patient-reported outcome measures

Descriptive statistics of PROMs, including the subscales of both WOMAC and VR-12, are reported in Table 1 for preoperative, 1-, 5-, 10-, and 15-year timepoints. 1-way ANOVA revealed statistically significant differences in mean Oxford, WOMAC, and VR-12 scores between at least 2 timepoints. *Post-hoc* testing revealed preoperative PROMs were statistically significantly different to their respective 1-, 5-, 10- and 15-year postoperative PROMs. There were no significant differences in postoperative PROMs between

Table 1. Descriptive statistics of preoperative patient characteristics for observations with at least 1 patient-reported outcome measure.

Variable	Sample n= 263	Sex		Funding pathway		Ethnicity		
		Male n= 120 (45.6%)	Female n= 143 (54.4%)	Public n= 87 (33.1%)	Private n= 176 (66.9%)	NZEU n= 242 (92.1%)	Māori n= 9 (3.4%)	Other n= 12 (4.5%)
Age ^a	71.38 ± 8.67	70.84 ± 8.35	71.83 ± 8.94	71.75 ± 8.78	71.20 ± 8.64	71.90 ± 8.40	66.00 ± 8.47	64.83 ± 10.87
BMI ^a	28.01 ± 4.75	28.14 ± 3.57	27.90 ± 5.58	28.68 ± 4.24	27.75 ± 4.92	27.95 ± 4.84	30.95 ± 2.54	27.62 ± 3.77
ASA Grade ^b								
I	49 (19%)	22 (18%)	27 (19%)	13 (15%)	36 (20.5%)	46 (19%)	2 (2.2%)	1 (8.3%)
II	164 (62%)	72 (60%)	93 (65%)	46 (52.5%)	118 (67%)	151 (62%)	3 (3.3%)	10 (83.4%)
III	46 (18%)	26 (22%)	20 (14%)	24 (28%)	22 (12.5%)	41 (17%)	4 (4.5%)	1 (8.3%)
IV	—	—	—	—	—	—	—	—
Not recorded	4 (2%)	1 (0%)	3 (2%)	4 (3.5%)	—	4 (2%)	—	—

ASA, American Society of Anesthesiologists Physical Status classification; BMI, body mass index; NZEU, New Zealand European.

^aThe values are given as the mean and the standard deviations.

^bValues are given as the number of patients, with percentage (number of patients divided by the total) in parentheses. Due to missing values, some categories do not equal the total number of patients for each column.

their respective 1-, 5-, 10-, and 15-year timepoints. Mean postoperative VR-12-physical scores for the sample were worse with scores less than the standardised T-score metric mean of 50 (Standard deviation=10) across timepoints. In contrast, mean postoperative VR-12-mental scores were better, with scores greater than the standardised score of 50.

All mean preoperative PROMs were statistically significantly poorer in females than males ($p \leq 0.041$) (Table 2). Postoperatively, WOMAC-total and function scores for females were also statistically significantly poorer 1-year and 5 years postoperatively, as were WOMAC-motion and VR-12-physical scores 1-year postoperatively. Males and females showed no statistically significant difference in postoperative Oxford, WOMAC-pain, or VR-12-mental scores at 1, 5, and 10 years postoperatively.

Publicly funded patients had statistically significantly poorer preoperative PROMs and poorer postoperative PROMs than privately funded patients across most outcomes. Mean WOMAC-pain at 10 years, VR-12-mental at 1-year, and WOMAC-motion at 1, 5, and 10 years postoperatively were still poorer in publicly funded patients, although not reaching statistical significance ($p \geq 0.053$) (Table 3).

1-way ANOVA revealed no statistically significant differences in any preoperative PROMs, postoperative WOMAC-pain, or postoperative VR-12-mental scores at any timepoint between ASA ratings. However, postoperative Oxford, WOMAC-function, WOMAC-motion, and VR-12-physical scores were typically poorer with higher ASA ratings at various timepoints. There were no statistically significant differences in any outcomes between ethnicities.

PROM predictors: preoperative

No statistically significant collinearity between predictors was identified. Regression analysis indicated preoperative

Oxford and WOMAC scores were negatively influenced when funding pathway was public, patients were females, and BMI was greater (Table 5). Preoperative scores for VR-12 were also negatively influenced when funding pathway was public, and patients were females.

PROM predictors: postoperative

As ANOVA testing of PROMs revealed no statistically significant difference in scores from 1-year to 15 years postoperatively, 1-year scores were used as the main outcome in regression analysis given the greater number of observations. As sex, funding pathway, and BMI were significant predictors of preoperative scores, they were removed as postoperative predictors. Therefore, regression models considered preoperative score, age, ethnicity, and ASA rating. Preoperative score was a statistically significant predictor of postoperative score for all PROMs (Table 6). Increased age and ASA 3 category were additional statistically significant predictors of poorer postoperative WOMAC-function and VR-12-physical scores.

Discussion

Our results indicate that primary THA with the specified cemented cup-and-stem combination for osteoarthritis improves PROMs in patients at 1-year postoperatively and that improvement is maintained in those without revision to 15 years post-surgery. Patients who were female, in the public system, and who had greater BMIs presented with poorer preoperative PROMs. Poorer preoperative PROMs negatively influenced postoperative scores across timepoints. For some outcomes, postoperative PROMs were negatively affected by higher comorbidity status (based on ASA rating) and increased age at surgery.

Table 2. Descriptive statistics of patient-reported outcomes.

PROM	Sample (n)	Mean $\pm$ SD	Range (min–max)	ANOVA (p-value)	Mean diff (95% CI)	Post hoc (p-value)
Oxford (0–48)^a						
Pre-op	263	17.75 $\pm$ 8.73	2–47	<0.001*		
1-year	238	41.30 $\pm$ 7.06	8–48		–23.38 (–25.35–21.42)	<0.001*
5-year	180	41.62 $\pm$ 7.48	12–48		–0.49 (–2.66–1.68)	0.970
10-year	139	41.30 $\pm$ 8.46	9–48		–0.13 (–2.64–2.39)	0.990
15-year	66	39.44 $\pm$ 9.58	13–48		–2.05 (–5.36–1.26)	0.440
WOMAC total (0–96)^b						
Pre-op	262	54.82 $\pm$ 19.27	0–96	<0.001*		
1-year	235	12.36 $\pm$ 12.68	0–67		42.46 (38.41–46.52)	<0.001*
5-year	179	13.18 $\pm$ 14.47	0–68		0.82 (–3.66–5.30)	0.987
10-year	137	14.66 $\pm$ 16.32	0–78		1.47 (–3.65–6.60)	0.935
15-year	67	18.91 $\pm$ 21.01	0–89		–4.25 (–10.98–2.48)	0.417
WOMAC pain (0–20)^b						
Pre-op	262	11.02 $\pm$ 4.01	0–20	<0.001*		
1-year	235	1.69 $\pm$ 2.49	0–14		9.33 (8.49–10.16)	<0.001*
5-year	180	1.87 $\pm$ 3.04	0–15		0.17 (–0.76–1.09)	0.990
10-year	139	2.45 $\pm$ 3.58	0–14		0.59 (–0.47–1.64)	0.550
15-year	67	3.15 $\pm$ 4.24	0–18		–0.70 (–2.09–0.69)	0.650
WOMAC function (0–68)^b						
Pre-op	262	39.05 $\pm$ 14.35	29–68	<0.001*		
1-year	235	9.30 $\pm$ 9.68	0–48		29.74 (26.71–32.78)	<0.001*
5-year	180	10.00 $\pm$ 11.20	0–53		0.70 (–2.64–4.05)	0.980
10-year	138	10.88 $\pm$ 12.07	0–58		0.87 (–2.95–4.69)	0.970
15-year	67	13.87 $\pm$ 15.39	0–63		–2.99 (–8.02–2.04)	0.480
WOMAC motion (0–8)^b						
Pre-op	262	4.76 $\pm$ 1.71	0–8	<0.001*		
1-year	235	1.36 $\pm$ 1.43	0–6		3.39 (3.01–3.78)	<0.001*
5-year	179	1.25 $\pm$ 1.39	0–6		–0.12 (–0.54–0.31)	0.950
10-year	137	1.35 $\pm$ 1.56	0–6		0.11 (–0.38–0.59)	0.980
15-year	67	1.90 $\pm$ 1.96	0–8		–0.55 (–1.19–0.09)	0.140
VR-12 physical ($\bar{x}$=50)^c						
Pre-op	263	26.52 $\pm$ 8.22	8.5–54.6	<0.001*		
1-year	240	43.36 $\pm$ 10.98	8.1–62.6		–16.85 (–19.34–14.35)	<0.001*
5-year	183	43.55 $\pm$ 11.76	7.6–60.3		0.18 (–2.56–2.93)	0.990
10-year	138	43.51 $\pm$ 10.49	9.9–60.7		0.03 (–3.19–3.12)	0.990
15-year	66	41.59 $\pm$ 9.46	17.8–56.4		1.92 (–2.26–6.11)	0.720
VR-12 mental ($\bar{x}$=50)^c						
Pre-op	263	43.82 $\pm$ 12.85	15.6–68.2	<0.001*		
1-year	240	51.91 $\pm$ 9.41	14.6–67.4		–8.09 (–10.61–5.57)	<0.001*
5-year	183	51.78 $\pm$ 8.31	15.7–64.7		–0.13 (–2.90–2.64)	0.990
10-year	138	53.87 $\pm$ 9.26	26.4–70.0		2.09 (–1.09–5.28)	0.376
15-year	66	54.86 $\pm$ 9.31	18.8–71.0		0.98 (–5.21–3.24)	0.970

Diff, difference; PROM, patient-reported outcome measure; CI, confidence interval; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey.

^aOxford Hip Score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

^bWOMAC minimum scores are 0 with 0 being the better score.

^cVR-12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

Note: Post hoc p-value represents the pairwise comparison of the previous timepoint to the current timepoint.

*Significance is set at $p < 0.05$.

The substantial improvement in PROMs seen post-surgery up to 15 years with this cemented cup-and-stem combination sets a benchmark against which PROMs from

other cemented or alternative implant combinations in the same or similar populations can be measured. Mean 1-, 5-, and 10-year Oxford scores were over 41, corresponding to

Table 3. Male versus female patient-reported outcomes.

PROM	Male		Female		Mean diff (95% CI)	p-value
	n	Mean $\pm$ SD	n	Mean $\pm$ SD		
Oxford (0–48)^a						
Pre-op	120	19.17 $\pm$ 8.70	143	16.55 $\pm$ 8.62	–2.62 (–4.73—0.50)	0.015*
1-year	114	41.97 $\pm$ 6.31	134	40.47 $\pm$ 7.56	–1.50 (–3.31–0.31)	0.104
5-year	83	42.77 $\pm$ 6.63	97	40.63 $\pm$ 8.02	–2.14 (–4.33–0.05)	0.055
10-year	72	42.26 $\pm$ 7.43	71	40.82 $\pm$ 8.72	–1.44 (–4.24–1.36)	0.311
WOMAC total (0–96)^b						
Pre-op	120	51.77 $\pm$ 19.20	142	57.40 $\pm$ 19.02	5.63 (0.96–10.29)	0.018*
1-year	103	10.51 $\pm$ 11.81	132	13.81 $\pm$ 13.18	3.30 (0.04–6.57)	0.047*
5-year	82	10.66 $\pm$ 13.01	97	15.32 $\pm$ 15.81	4.66 (0.34–8.98)	0.034*
10-year	63	13.63 $\pm$ 15.21	74	15.53 $\pm$ 17.27	1.72 (–3.65–7.44)	0.501
WOMAC pain (0–20)^b						
Pre-op	120	10.38 $\pm$ 3.77	142	11.56 $\pm$ 4.13	1.18 (0.21–2.15)	0.017*
1-year	103	1.46 $\pm$ 2.29	132	1.88 $\pm$ 2.62	0.42 (–0.23–1.06)	0.207
5-year	82	1.52 $\pm$ 2.69	98	2.15 $\pm$ 3.30	0.63 (–0.27–1.53)	0.168
10-year	63	2.29 $\pm$ 3.37	76	2.59 $\pm$ 3.75	0.3 (–0.90–1.51)	0.617
WOMAC function (0–68)^b						
Pre-op	120	36.92 $\pm$ 14.29	142	40.85 $\pm$ 14.21	3.93 (0.45–7.41)	0.027*
1-year	103	7.90 $\pm$ 9.02	132	10.39 $\pm$ 10.07	2.49 (–0.00–4.98)	0.050
5-year	82	7.99 $\pm$ 9.62	98	11.69 $\pm$ 12.17	3.70 (0.50–6.91)	0.023*
10-year	63	10.13 $\pm$ 11.40	75	11.51 $\pm$ 12.64	1.38 (–2.71–5.47)	0.505
WOMAC motion (0–8)^b						
Pre-op	120	4.75 $\pm$ 1.80	142	4.99 $\pm$ 1.61	0.24 (0.10–0.93)	0.015*
1-year	103	1.14 $\pm$ 1.28	132	1.54 $\pm$ 1.51	0.40 (0.03–0.77)	0.032*
5-year	82	1.15 $\pm$ 1.37	97	1.33 $\pm$ 1.40	0.18 (–0.23–0.60)	0.380
10-year	63	1.22 $\pm$ 1.46	74	1.46 $\pm$ 1.63	0.24 (–0.29–0.77)	0.376
VR-12 physical ($\bar{x}$ = 50)^c						
Pre-op†	120	28.13 $\pm$ 8.56	143	25.16 $\pm$ 7.70	–2.97 (–4.94—0.99)	0.003*
1-year	104	45.98 $\pm$ 9.75	136	41.36 $\pm$ 11.47	–4.62 (–7.39—1.87)	0.001*
5-year	82	44.97 $\pm$ 11.61	101	42.39 $\pm$ 11.83	–2.58 (–6.02–0.86)	0.141
10-year	62	43.64 $\pm$ 9.93	76	43.41 $\pm$ 10.99	–0.23 (–3.79–3.34)	0.901
VR-12 mental ($\bar{x}$ = 50)^c						
Pre-op †	120	45.59 $\pm$ 12.68	143	42.34 $\pm$ 12.86	–3.25 (–6.36—0.13)	0.041*
1-year	104	52.85 $\pm$ 7.52	136	51.20 $\pm$ 10.61	–1.65 (–3.96–0.66)	0.160
5-year	88	53.02 $\pm$ 7.67	101	50.78 $\pm$ 8.70	–2.24 (–4.66–0.19)	0.070
10-year	61	52.67 $\pm$ 8.94	76	54.85 $\pm$ 9.46	2.18 (–0.95–5.30)	0.170

Diff, difference; PROM, patient-reported outcome measure; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey.

^aOxford Hip Score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

^bWOMAC minimum scores are 0 with 0 being the better score.

^cVR-12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

*Significance is set at $p < 0.05$.

Note: Post hoc p-value represents the pairwise comparison of the previous timepoint to the current timepoint.

a Kalairajah category 1 (excellent) rating.²² Mean 15-year Oxford scores were 39.44, corresponding to a category 2 (very good) rating.²² Poor 6-month Oxford scores have been identified as a risk factor for early revision within 2 years;²³ thus, our implant combination's Oxford score suggests low early-revision risk, which needs confirmation via survivorship analysis. The mean difference in pre- and postoperative Oxford scores (>23) is substantially higher for this implant than the estimated minimally

important change value of 11,²⁴ suggestive of meaningful improvements for patients.

We identified preoperative PROMs as significantly influencing postoperative PROMs, consistent with previous studies.^{25,26} Poor preoperative scores across multiple PROMs increase likelihood of patient dissatisfaction postoperatively.²⁶ Our regression models revealed patients who are female, in the public system, and have higher BMIs were associated with poorer preoperative functional

Table 4. Public versus private patient-reported outcomes.

PROM	Public		Private		Mean diff (95% CI)	p-value
	n	Mean $\pm$ SD	n	Mean $\pm$ SD		
Oxford (0–48)^a						
Pre-op	87	10.89 $\pm$ 5.66	176	21.14 $\pm$ 7.97	10.25 (8.57–11.93)	<0.001*
1-year	73	38.60 $\pm$ 8.46	165	42.44 $\pm$ 6.05	3.84 (1.47–5.81)	0.001*
5-year	58	39.43 $\pm$ 9.11	122	42.66 $\pm$ 6.32	3.23 (0.586–5.86)	0.017*
10-year	32	37.53 $\pm$ 9.56	101	42.74 $\pm$ 7.25	5.21 (1.502–8.920)	0.006*
WOMAC total (0–96)^b						
Pre-op	86	69.72 $\pm$ 14.06	176	47.55 $\pm$ 17.19	–22.17 (–26.38—17.97)	<0.001*
1-year	70	16.69 $\pm$ 14.91	165	10.53 $\pm$ 11.14	–6.16 (–10.093—2.224)	0.002*
5-year	56	18.11 $\pm$ 17.09	123	10.94 $\pm$ 13.01	–7.17 (–12.27—2.06)	0.006*
10-year	32	21.56 $\pm$ 17.20	105	12.55 $\pm$ 15.53	–9.01 (–15.37—2.65)	0.005*
WOMAC pain (0–20)^b						
Pre-op	86	13.81 $\pm$ 3.13	176	9.66 $\pm$ 3.68	–4.151 (–5.06—3.25)	<0.001*
1-year	70	2.54 $\pm$ 3.02	165	1.34 $\pm$ 2.13	–1.20 (–1.99—0.42)	0.003*
5-year	57	2.63 $\pm$ 3.75	123	1.51 $\pm$ 2.59	–1.12 (–2.21—0.03)	0.045*
10-year	32	3.41 $\pm$ 3.61	107	2.17 $\pm$ 3.53)	–1.24 (–2.65—0.18)	0.086
WOMAC function (0–68)^b						
Pre-op	86	50.07 $\pm$ 10.43	176	33.66 $\pm$ 12.86	–16.41 (–19.34—13.48)	<0.001*
1-year	70	12.59 $\pm$ 11.15	165	7.91 $\pm$ 8.65	–4.68 (–7.64—1.72)	0.002*
5-year	57	13.61 $\pm$ 13.12	123	8.33 $\pm$ 9.81	–5.28 (–9.16—1.40)	0.008*
10-year	32	16.47 $\pm$ 12.76	107	9.19 $\pm$ 11.38	–7.28 (–11.95—2.61)	0.003*
WOMAC motion (0–8)^b						
Pre-op	86	5.84 $\pm$ 1.54	176	4.23 $\pm$ 1.54	–1.61 (–2.01—1.21)	<0.001*
1-year	70	1.56 $\pm$ 1.52	165	1.28 $\pm$ 1.38	–0.278 (–0.68—0.12)	0.173
5-year	56	1.57 $\pm$ 1.59	123	1.10 $\pm$ 1.26	–0.473 (–0.95—0.01)	0.053
10-year	32	1.69 $\pm$ 1.67	105	1.25 $\pm$ 1.51	–0.44 (–1.06—0.18)	0.162
VR-12 physical ($\bar{x}$ = 50)^c						
Pre-op	87	23.04 $\pm$ 5.74)	176	28.23 $\pm$ 8.72	5.19 (3.42–6.97)	<0.001*
1-year	74	39.92 $\pm$ 11.06	166	44.90 $\pm$ 10.62)	4.98 (2.01–7.93)	0.001*
5-year	59	38.97 $\pm$ 13.18	124	45.72 $\pm$ 10.40	6.75 (2.88–10.63)	0.001*
10-year	32	37.19 $\pm$ 10.82	106	45.43 $\pm$ 9.65	8.24 (4.28–12.20)	<0.001*
VR-12 mental ($\bar{x}$ = 50)^c						
Pre-op	87	34.64 $\pm$ 11.53	176	48.36 $\pm$ 10.92	13.72 (10.85–16.59)	<0.001*
1-year	74	50.27 $\pm$ 10.76	166	52.64 $\pm$ 8.68	2.37 (–0.44–5.18)	0.098
5-year	59	49.29 $\pm$ 10.26	124	52.97 $\pm$ 6.93	3.68 (0.74–6.60)	0.015*
10-year	32	48.94 $\pm$ 8.85	106	55.36 $\pm$ 8.90	6.42 (2.88–9.97)	<0.001*

Diff, difference; CI, confidence interval; PROM, patient-reported outcome measure; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey.

^aOxford Hip Score minimum is 0 and the maximum score is 48 with poorer scores being closer to 0.

^bWOMAC minimum scores are 0 with 0 being the better score.

^cVR-12 ideal score is ≥ 50 and acceptable is within 1 standard deviation either side.

*Significance is set at $p < 0.05$.

Note: Post hoc p -value represents the pairwise comparison of the previous timepoint to the current timepoint.

and mental scores, which may predispose them to postoperative dissatisfaction. Studies show that females are more likely opposed to surgery due to competing responsibilities, need more information before deciding, and are less likely to be sent to a specialist; therefore, females drop to a lower preoperative functional level than males.²⁷ These observations align with our findings, wherein females' preoperative scores were lower than males. Alongside poorer functional and mental preoperative scores, females

also tend to have higher rates of depression, lower back pain, and comorbidities than males.²⁸ In the TOR registry, there was a greater number of females undergoing surgery than males, consistent with national THA surgery data from NZ and other parts of the world.⁴ In the USA, not only are more females having THA surgeries,²⁵ they are also more likely to be older, have higher BMIs, and need preoperative support than males.²⁹ In a Korean study of over 1.15 million females, reproductive factors (e.g., later

Table 5. Multiple linear regression results for preoperative patient-reported outcomes.

PROM	n	Model p-value	R ²	Estimate	STD Error	p-value
Oxford pre-op	263	<0.001*	0.33			
(intercept)				26.91	2.94	<0.001*
BMI				-0.25	0.10	0.015*
Sex (Male)				3.20	0.98	0.001*
Funding (Public)				-10.46	1.10	<0.001*
WOMAC total pre-op	262	<0.001*	0.34			
(intercept)				22.55	7.80	0.004*
BMI				0.95	0.28	<0.001*
Sex (Male)				-7.80	2.45	0.002*
Funding (Public)				22.85	2.81	<0.001*
WOMAC pain pre-op	262	<0.001*	0.29			
(intercept)				5.14	1.67	0.002*
BMI				0.17	0.06	0.005*
Sex (Male)				-1.46	0.52	0.006*
Funding (Public)				4.37	0.60	<0.001*
WOMAC function pre-op	262	<0.001*	0.33			
(intercept)				14.59	5.84	0.014*
BMI				0.73	0.21	<0.001*
Sex (Male)				-5.67	1.83	0.002*
Funding (Public)				16.76	2.11	<0.001*
WOMAC motion pre-op	262	<0.001*	0.24			
(intercept)				2.92	0.77	<0.001*
BMI				0.05	0.03	0.053
Sex (Male)				-0.71	0.24	0.004*
Funding (Public)				1.79	0.28	<0.001*
VR12 physical pre-op	263	<0.001*	0.12			
(intercept)				27.30	0.88	<0.001*
Funding (Public)				-5.82	1.33	<0.001*
Sex (Male)				2.92	1.19	0.015*
VR12 Mental pre-op	263	<0.001*	0.30			
(intercept)				47.18	1.18	<0.001*
Sex (Male)				5.50	1.60	<0.001*
Funding (Public)				-14.48	1.79	<0.001*

ASA, American Society of Anesthesiologists physical status classification; PROM, patient-reported outcome measure; STD, standard; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VR-12, Veterans Rand 12-item health survey.

*Significance set at $p < 0.05$.

onset of menarche, longer time breastfeeding, hormone replacement treatment, and oral contraceptive use) were associated with higher risk for severe osteoarthritis and need for THA.³⁰ Further investigation into sex differences in THA is required to improve patient care – particularly of females – and may need to be considered in future risk-stratification models,²⁹ which should include more detailed reproductive history notetaking. Sex disparity in referral for surgery also warrants consideration.

Consistent with our observations, Greene et al.³¹ identified that patients using public funding pathways for THA report poorer preoperative and postoperative PROMs than those using private funding. Poorer public outcomes are often attributed to longer wait times; however, literature indicates the effect of increased waiting time on THA outcome is unclear or inconsistent,³² and that sex, age, and

certain modifiable risk factors (e.g., BMI, income level, and comorbidities) impact postoperative outcomes to a greater extent.³³ Higher BMI has also been identified as a risk factor for increased complications and poorer postoperative THA outcomes.³⁴ Taken together, our findings support existing literature that women, public patients, patients with higher BMI, older patients, and patients with comorbidities (i.e., higher ASA ratings) are at greater risk of poorer postoperative THA outcomes and require greater preoperative and postoperative support. Specifically, these patients may benefit from additional mental and functional prehabilitation and rehabilitation support. Recording comorbidities in more detail than relying on ASA ratings within registry data may also help discern more specifically those conditions that may increase risk of poor THA outcomes.

Table 6. Multiple linear regression results for postoperative patient-reported outcomes.

PROM	n	Model p-value	R ²	Estimate	STD Error	p-value
Oxford post-op	238	<0.001*	0.07			
(Intercept)				36.81	1.12	<0.001*
Oxford pre-op				0.22	0.05	<0.001*
WOMAC total post-op	235	<0.001*	0.15			
(Intercept)				3.29	2.74	0.232
WOMAC total pre-op				-0.70	2.08	<0.001*
ASA II				-1.11	2.04	0.586
ASA III				7.66	2.85	0.008*
WOMAC pain post-op	235	<0.001*	0.07			
(Intercept)				0.12	0.46	0.796
WOMAC pain pre-op				0.15	0.04	<0.001*
WOMAC function post-op	235	<0.001*	0.20			
(Intercept)				-10.77	5.97	0.073
WOMAC function pre-op				0.18	0.04	<0.001*
Age				0.19	0.08	0.024*
ASA II				-1.40	1.59	0.380
ASA III				5.67	2.23	0.012*
WOMAC motion post-op	235	0.005*	0.04			
(Intercept)				0.65	0.29	0.024*
WOMAC Motion pre-op				0.17	0.06	0.005*
VR12 physical post-op	240	<0.001*	0.28			
(Intercept)				58.54	6.66	<0.001*
VR12 Physical pre-op				0.53	0.08	<0.001*
Age				-0.40	0.09	<0.001*
ASA II				-0.66	1.82	0.717
ASA III				-5.56	2.52	0.029*
VR12 mental post-op	240	<0.001*	0.11			
(Intercept)				40.77	2.48	<0.001*
VR12 Mental pre-op				0.25	0.05	<0.001*

PROM, patient-reported outcome measure; VR-12, Veterans Rand 12-item health survey.

*Significance set at $p < 0.05$.

Although preoperative PROMs, ASA rating, and age were identified as significant predictors of postoperative PROMs, these factors only explained between 7 and 28% of the variance (Table 5). Hence, other factors not included in our analysis likely influence the variation in postoperative scores within our population. One such factor may be smoking status. Yue et al.³⁵ identified 4 studies where smoking negatively affected postoperative THA PROMs between 6 months and 1-year. Smokers are reported to exhibit lower postoperative Oxford³⁶ and Harris hip³⁷ scores and an increased use of painkillers and anti-inflammatories³⁶ than non-smokers and ex-smokers. In smokers, PROMs were more likely to stagnate initially, and decline over time.³⁸ It may be beneficial to record smoking status in future THA studies and registries.

Few THA patients in the TOR registry were Māori (4%), with a lower representation than the NZ joint registry at 7%.⁴ Considering Māori make up 29% of the Bay of Plenty region, 17% of the NZ population, and 16% of Māori are >55 years, uptake of surgery by Māori is

relatively poor.³⁹ Bourke et al.⁴⁰ identified competing responsibilities (prioritising work and family), disrupted *mana*¹ (feeling disempowered), and systemic abdication (inconsistent information/diagnosis) as contributing factors to healthcare accessibility for Māori, which may explain their under-representation as THA patients. Social deprivation and socio-economic inequities are potential sources of health inequity for Māori,⁴¹ which can extend to THA. Low numbers of Māori and “Other” patients made it challenging to discern differences based on ethnicity, which is further complicated due to the diversity of “Other” ethnicities.

Limitations

Observational studies are limited in their ability to define causation; however, they can identify associations between risk factors and a response variable. Additional variables, such as smoking status, physical activity, analgesic and anti-inflammatory use, rehabilitation programmes, and

specific comorbidities were not documented in the registry and therefore not analysed. Older age was identified as a predictor of poorer health scores. However, health scores also tend to deteriorate over time as age increases regardless of surgery and this was not noted most likely due to small sample sizes at 15 years. Two thirds (66%) of all surgeries within the TOR registry were privately funded, which is higher than the 2023 NZ rate of 49%.⁴ Hence, generalisation of our findings is not ensured to regions where the proportion of publicly funded surgeries is greater. Further, PROMs recorded by patients are subjective, susceptible to bias, and dependent on accurate recall.

Conclusion

The cemented combination studied demonstrated excellent PROMs out to 15 years with the association of poorer preoperative PROMs in THAs that were publicly funded, in females and those with higher BMIs, and association of poorer preoperative PROMs, older age and ASA 3 rating variables to poorer postoperative PROMs. Patients with poorer preoperative PROMs may require additional preoperative support to improve their postoperative outcomes, encompassing both functional and mental strategies. These patients, as well as those who are older and present with higher ASA ratings, may require additional postoperative support. These associated variables, sex, ethnic disparity and accessibility to surgery need further research in NZ.

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Supplemental material

Supplemental material is available online.

Note

1. Mana- Power, authority, or prestige; *spec.* (in Polynesian and Melanesian religions) an impersonal supernatural power which can be associated with people or with objects and which can be transmitted or inherited.⁴²

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Appendix D. Patient-reported outcome measures comparison of two cemented primary total hip arthroplasty implant combinations for osteoarthritis: A regional New Zealand study

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RESEARCH



Patient-reported outcome measure comparison of two cemented primary total hip arthroplasty implant combinations for osteoarthritis: a regional New Zealand study

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Abstract

Purpose Compare patient-reported outcome measures (PROMs) of two cemented implants in primary total hip arthroplasty (THA) for osteoarthritis in a New Zealand regional joint registry. Identify patient predictors of poorer PROMs.

Methods We analysed observational data from primary THA surgeries for osteoarthritis performed between 1 January 2003 and 30 June 2023, with at least one recorded PROM ($n=1365$) from a regional joint registry. We compared preoperative, 1-year, 5-year, and 10-year PROMs in the cemented, highly crosslinked polyethylene Exeter[®] V3 Rimfit cup (Rimfit) and its conventional polyethylene predecessor, the Exeter[®] Contemporary Flanged cup (ECF) with the same cemented Exeter[®] V40 stem. We investigated six patient factors and their influence on physical function, and mental and physical health PROMs.

Results No significant difference in physical function PROMs were noted between implants at any timepoint. Both implant combinations exhibited excellent (>41) mean postoperative Oxford hip scores based on published thresholds (Rimfit: mean $41.30 \pm SD 8.46$; ECF: mean $41.64 \pm SD 8.67$). Mental health was significantly better preoperatively and at 1-year and 5-year with the Rimfit based on Veterans RAND 12-Item Health Survey. Public funding was a significant and clinically meaningful predictor of poorer preoperative outcomes in all PROMs and in both cohorts, followed by comorbidity status. The strongest significant predictor of poorer postoperative PROMs was poorer preoperative PROMs, followed by Māori ethnicity.

Conclusion Both implant combinations demonstrated similar PROMs up to 10 years, but the Rimfit exhibited superior mental health. Public funding, comorbidity status, and Māori ethnicity were predictors of statistically significant and clinically meaningful poorer preoperative and postoperative PROMs.

Keywords Hip replacement · Polyethylene · Ethnicity · Health-related quality of life · Health disparity

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Introduction

Total hip arthroplasty (THA) is widely performed, highly successful, and significantly improves quality of life in patients with advanced hip osteoarthritis [1]. While literature has traditionally focused on implant survival and radiographic outcomes [2], there is a growing emphasis on patient-reported outcome measures (PROMs) as critical success indicators of hip arthroplasty [3, 4]. When new or upgraded implants are introduced, they are often assumed to perform at least as well as their predecessors, and studies rightly focus on survivorship. However, it remains to be determined whether they offer comparable patient-reported clinical benefit over time, despite survival outcomes.

The Exeter[®] Contemporary Flanged cup (ECF) was the most popular cemented cup in New Zealand (NZ) until the introduction of the Exeter[®] X3 Rimsit cup (Rimsit) in 2010, which was intended to improve wear [5] with the introduction of highly-crosslinked polyethylene. A single centre study ($n=108$) reported excellent (>41) [6] 10-year ECF Oxford hip scores, with a median OHS of 43 out of 48 [7], and a 15-year NZ regional joint registry study on the ECF ($n=263$) reported a good (34–41) [6] mean OHS score of 39.5 ± 9.58 [8] (mean $\pm$ SD). The Rimsit has also performed well in studies, exhibiting a good mean OHS [6] of 38.5 ± 7.9 ($n=178$) at 6 months and an excellent [6] score of 42.4 ± 6.2 ($n=44$) at 5 years in a NZ regional joint registry study in elderly patients [9].

Our recent study identified no evidence of significant differences in survival, or reasons for revision between these two cemented implants [10], and while van Winterswijk et al. [11] identify good-to-excellent OHS outcomes based on published thresholds [12], in both implants, comparison only compared 6 months and 5 years ($n=261$). No difference in short- and medium-term PROMs was noted, yet no predictors of outcomes or long-term outcomes were investigated. To address this gap, we compared PROMs up to 10 years between the implants using a relatively large NZ joint registry dataset ($n=1339$) and investigated the influence of six patient characteristics on PROM outcomes.

Materials and methods

Data source and collection

Anonymised, prospectively collected PROM data of all cemented primary THAs for osteoarthritis performed between 1 January 2003 and 30 June 2023 (ECF 2003–2013, Rimsit 2010–2023) in the Bay of Plenty region of NZ were retrieved in January 2024 from the Tauranga Orthopaedic Research (TOR) regional joint registry. TOR is a non-profit

organisation that maintains a registry of all Bay of Plenty joint arthroplasty surgeries separate from the NZ National Joint registry. With consent, patient data are entered into SOCRATES software (version 3.5.8.26 10150). The OHS, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and Veterans RAND 12-Item Health Survey (VR-12) physical and mental scores are routinely collected preoperatively and at 1-year, 5-year, and every 5 years thereafter. The University of Waikato's Human Research Ethics Committee (HREC2023#12) granted ethical approval for this study. All analyses were conducted in RStudio (Vienna, Austria) [13], with methodological oversight from a specialist in public health and biostatistics. Observations were eligible for analysis when at least one PROM was recorded for patients who underwent a primary THA for osteoarthritis with a cemented Exeter[®] V40 stem and either a highly crosslinked polyethylene Exeter[®] X3 Rimsit cup or an Exeter[®] Contemporary Flanged cup (Stryker Orthopaedics, Mahwah, NJ) with conventional polyethylene. Follow-up windows were necessarily broad due to the registry-based nature of PROM collection; however, given the stability of PROMs beyond 12 months following THA, variation in response timing within each window is unlikely to have materially influenced outcomes. This study was reported following the Strengthening the Reporting of Observational Studies (STROBE) guidelines [14].

Patient-reported outcome measures

Preoperative PROM data comprised scores recorded prior to surgery. Follow-up data were defined as: 1-year (10–14 months postoperatively), 5-year (4–6 years postoperatively), and 10-year (9–11 years postoperatively). To aid interpretation of differences between implant cohorts and patient subgroups (sex, age, body mass index [BMI], American Society of Anesthesiologists [ASA] rating, funding, and ethnicity), we applied minimal clinically important difference (MCID) thresholds derived from distribution-based estimates [15] using the preoperative scores from each cohort. Although anchor-based MCIDs for OHS and WOMAC have been published, MCID values are known to be population and context dependent. Given differences in population characteristics, health system structure, and baseline PROM distributions, externally derived MCIDs may not be directly applicable to the New Zealand arthroplasty population. In addition, anchor-based methods often rely on patient satisfaction measures not available in registry data. We therefore used a distribution-based approach (0.5 SD of baseline scores) to derive internally consistent MCID thresholds relevant to the study population. While MCID is primarily designed to assess within-patient changes over time [16], it

can offer contextual insight into whether observed, between-group differences are likely to be clinically meaningful [17]. A clinically meaningful difference in score was deemed one that exceeded our established MCID thresholds. For patients undergoing bilateral THA during the study period, PROMs were collected and recorded separately for each hip and corresponded to the specific surgical episode.

Patient characteristics

Patient characteristics included sex (male, female), ethnicity (NZ European, NZ Māori, Other), ASA rating (1, 2, 3, 4), and funding source (public, private) treated as categorical or rank variables, with age and BMI treated as continuous variables. "Other" ethnicity represented a small, heterogeneous subgroup ($n=5$) and was thus removed from further analysis. The small number of ASA 4 observations ($n=10$) were converted to ASA 3 for analysis. Funding source was included as a marker of healthcare access pathway. While funding source may be associated with socioeconomic factors, it does not capture the multidimensional nature of socioeconomic status and was not interpreted as a direct surrogate for socioeconomic status.

Statistical analysis

Baseline categorical (sex, ethnicity, ASA, funding) and mean continuous (age, BMI) patient characteristics, and preoperative, 1-year, 5-year, and 10-year OHS, WOMAC, VR-12 physical and mental health scores were determined for each component. Missing data were handled using pairwise deletion, meaning that all available observations were used for each analysis without requiring complete data across all variables. Missing data may be due to incomplete questionnaires, non-returned questionnaires, or study withdrawal. Because implant use was strongly structured by calendar time, with the predecessor implant predominantly used between 2003 and 2013 and the successor implant between 2010 and 2023, the two cohorts were not exchangeable in time. As a result, implant group was highly correlated with era-related factors including patient selection, perioperative care, rehabilitation pathways, registry completeness, and PROM collection practices. To avoid confounding implant effects with secular trends, we did not perform a pooled regression with implant as a single exposure across eras. Instead, analyses were conducted within each implant era to evaluate outcome trajectories and prognostic factors in the clinical context in which each implant was used. We compared categorical variable proportions between implants using Chi-squared and Fisher's exact tests. Mean age, BMI, and preoperative, 1-year, 5-year, and 10-year PROMs between implants were compared

using independent Student's or Welch's *t*-tests in presence of unequal variance. Because not all patients had both preoperative and postoperative scores available, comparisons between preoperative and postoperative means were conducted using independent samples *t*-tests rather than paired analyses. Mean preoperative, 1-year, 5-year, and 10-year PROMs within each cohort were compared using ANOVA and post-hoc Tukey. Postoperative observations with OHS < 27 categorised as "poor" [6] were extracted to investigate distinct patient characteristics.

To determine influential patient characteristics on preoperative and postoperative PROMs in each cohort, we performed multiple linear regression with post-hoc residual analysis, influence statistics, variance inflation factor, and Durbin-Watson. Preoperative scores were included as predictors of postoperative scores and thus significant predictors of preoperative scores were removed from postoperative analysis to prevent confounding. Statistical significance was set at $p < 0.05$ with 95% confidence intervals (CI) derived for all testing.

Results

A total of 1630 (Rimfit $n=1267$; ECF $n=363$) primary THAs met the inclusion criteria. Follow-up occurred up to a period of 10 years. Of these, 1365 patients (84%) (Rimfit $n=1102$; ECF $n=263$) had at least one completed PROM and were included in the analyses (Table 1). Due to variable follow-up completion and missing covariate data, the number of patients included differed between analyses and time points; the sample size for each analysis is reported in the corresponding tables. Assumptions of multiple linear regression were checked and met. Normality was evaluated visually using Q-Q plots of residuals. Initial models using untransformed outcome data in the Rimfit cohort's postoperative OHS and WOMAC PROMs showed deviations from normality in the residuals. However, the analysis was not intended for prediction, but rather to examine associations between patient variables and PROMs. Results are considered robust despite this noted departure from normality. The large sample size improves the precision of the estimates and statistical power but does not eliminate the potential for residual confounding or other sources of bias inherent in observational registry data.

There was a significantly higher proportion of ASA 2 ($p=0.004$), ASA3 ($p=0.007$), and publicly funded patients ($p<0.001$) in the Rimfit than the ECF cohort. No significant difference in mean age or BMI between cohorts or between any of their six subgroups (sex, age, BMI, ethnicity, funding, or ASA rating) was noted, except for where the ECF mean BMI was statistically higher in ASA 3 patients ($p=0.031$).

Table 1 Patient characteristics between implant comparison

	Both	Rimfit	ECF	P-value
Total, n (%)	1365 (100%)	1102 (80.73%)	263 (19.27%)	—
Age (mean $\pm$ SD)	71.39 $\pm$ 8.60	71.39 $\pm$ 8.52	71.38 $\pm$ 8.67	0.991
BMI (mean $\pm$ SD)	28.00 $\pm$ 4.85	28.00 $\pm$ 4.93	28.01 $\pm$ 4.75	0.970
Sex, n (%) ^a				
Male	543 (39.78%)	423 (38.38%)	120 (45.63%)	0.031
Female	822 (60.22%)	679 (61.62%)	143 (54.37%)	0.031
ASA, n (%) ^b				
1	195 (14.52%)	146 (13.46%)	49 (18.63%)	0.041*
2	824 (60.37%)	660 (60.88%)	164 (62.36%)	0.401
3 and 4	324 (24.12%)	278 (25.65%)	46 (17.49%)	0.007*
Missing	22	18	4	—
Funding, n (%) ^c				
Public	588 (43.17%)	501 (45.59%)	87 (33.08%)	<0.001*
Private	774 (57.63%)	598 (54.41%)	176 (66.92%)	<0.001*
Missing	3	3	—	—
Ethnicity, n (%) ^d				
NZEU	1258 (94.80%)	1016 (94.43%)	242 (92.02%)	0.102
Māori	64 (4.82%)	55 (5.11%)	9 (3.42%)	0.315
Other	5 (0.38%)	5 (0.46%)	0	0.180
Missing	26	26	0	—

ASA, American Society of Anesthesiologists grading; BMI, Body mass index; ECF, Exeter Contemporary Flanged cup; NZEU, New Zealand European; Rimfit, Exeter X3 Rimfit cup

^aValues represent the number and percentage of males and females; ASA, 1, 2, 3 and 4, public and private funding, and NZ, European, Māori and other ethnicity within each cohort

*Significance set at $p < 0.05$

Missing values have not been included in proportion calculations

PROMs comparison

PROM comparisons between implants can be found in Table 2. No significant difference in mean preoperative, 1-year, 5-year, or 10-year OHS, WOMAC, or VR-12 physical function scores between implants was noted. VR-12 mental scores were significantly higher preoperatively (2.5 points, $p=0.005$), at 1-year (1.4 points, $p=0.042$), and at 5-year (2.1 points, $p=0.004$) in the Rimfit. Within implants, there was a significant time effect across all PROMs examined ($p<0.001$). Post-hoc Tukey revealed significant improvements from baseline PROMs compared to 1, 5, and 10-years ($p<0.001$). There were no statistically significant differences in mean PROMs within implant cohorts

between 1, 5, and 10 years, except where the Oxford 5-year score was significantly better than the 1-year score in the Rimfit, supporting limited divergence in longer-term outcomes. Given the limited sample size at 10 years and lack of significant difference between 1, 5, and 10-year PROMs, we used 1-year PROMs as the postoperative score for further comparisons due to its substantial sample size.

Poor postoperative scores

There were 67 patients with poor postoperative OHS (<27) [6] scores ($n=60$, Rimfit $n=53$, 6.3%; ECF $n=7$, 3.4%). There was no significant difference in patient characteristic proportions of poor postoperative scores, mean age (ECF 74.9 ± 10.1 ; Rimfit 71.6 ± 8.3 years, $p=0.566$) or BMI (ECF 26.6 ± 3.6 kg/m²; Rimfit 29.3 ± 4.7 kg/m², $p=0.106$), ethnic groups ($p=0.580$), ASA ratings ($p=0.217$), or funding ($p=0.684$) between the cohorts. The small number of observations in the ECF cohort made it challenging to analyse in further detail (Supplementary Table 1).

Linear regression: preoperative PROMs

Funding source was the strongest predictor (i.e., largest coefficient) of baseline PROMs in both cohorts. Publicly funded patients reported substantially worse preoperative scores than privately funded patients, including ~8–10 lower OHS, ~16–23 higher WOMAC, ~5–6 lower VR-12 physical, and ~7–14 lower VR-12 mental scores. These differences exceeded our distribution-based MCID across all PROMs. Sex was also a significant predictor, with males scoring ~2–3 points better in OHS and VR-12 mental and physical, and ~4–8 points better on WOMAC compared to females. BMI showed a small statistically significant effect on preoperative scores (OHS ≈ -0.25 ; WOMAC $\approx 0.5-0.9$) per 1 BMI unit increase, in both cohorts. In the Rimfit, other significant preoperative predictors included higher ASA ratings (i.e., higher comorbidity burden) associated with ~2–8 worse WOMAC and ~3–6 worse VR-12 physical and mental scores, and Māori ethnicity associated with ~6 points lower preoperative VR-12 mental scores compared with NZ Europeans.

Linear regression: postoperative PROMs

Linear regression for postoperative PROMs was performed using the 1-year postoperative scores for regression due to its larger sample size and lack of significant difference between 1-year, 5-year, and 10-year postoperative scores. Preoperative PROMs consistently exhibited the largest predictive contribution to postoperative scores across PROMs in both cohorts, with each 1-point worse preoperative score

Table 2 Preoperative and postoperative PROMs comparison

PROM	Rimfit					ECF					p-value [§]
	n	Mean	SD	Diff [95% CI] [†]	MCID [‡]	n	Mean	SD	Diff [95% CI] [†]	MCID [‡]	
Oxford (0–48)											
Pre-op	837	18.23	± 8.96		4.48	263	17.75	± 8.73		4.37	0.446
Post-op 1-year	842	41.29	± 7.42	23.06 [22.25, 23.82]		238	41.30	± 7.06	22.43 [21.06, 23.81]		0.985
Post-op 5-year	490	42.88	± 6.85			180	41.62	± 8.46			0.074
Post-op 10-year	124	41.64	± 8.67			139	41.30	± 9.58			0.763
WOMAC total (0–96)											
Pre-op	827	54.23	± 18.51		9.26	262	54.82	± 19.27		9.64	0.663
Post-op 1-year	810	14.12	± 14.09	40.15 [38.60, 41.71]		235	12.36	± 12.68	40.40 [37.65, 43.15]		0.069
Post-op 5-year	483	12.41	± 14.29			179	13.18	± 14.47			0.540
Post-op 10-year	124	15.38	± 17.23			137	14.66	± 16.32			0.730
VR-12 physical (0–50)											
Pre-op	836	27.61	± 8.21		4.11	263	26.52	± 8.22		4.11	0.658
Post-op 1-year	840	44.01	± 10.57	17.05 [16.12, 17.97]		240	43.36	± 10.98	16.37 [14.88, 17.87]		0.405
Post-op 5-year	487	44.43	± 10.37			183	43.55	± 11.76			0.280
Post-op 10-year	125	42.23	± 11.34			138	43.51	± 10.49			0.344
VR-12 mental (0–50)											
Pre-op	836	46.36	± 12.76		6.38	263	43.82	± 12.85		6.43	0.005*
Post-op 1-year	840	53.31	± 9.40	6.49 [5.49, 7.48]		240	51.91	± 9.41	7.23 [5.41, 9.04]		0.042*
Post-op 5-year	487	53.97	± 10.00			183	51.78	± 8.31			0.004*
Post-op 10-year	125	55.16	± 8.86			138	53.87	± 9.26			0.250

ECF, Exeter Contemporary Flanged cup; MCID, Minimal clinically important difference (distribution-based); Pre-op, preoperative; Rimfit, Exeter X3 Rimfit cup; SD, standard deviation; VR-12, Veterans Rand 12-item health survey; WOMAC, Western Ontario and McMaster Universities Index

[†]Difference calculated between the mean preoperative score and the mean 1-year postoperative score

[‡]MCID calculated using the distribution method of 0.5 × SD of the preoperative score

[§]p-value represents the comparison of the Rimfit score to the ECF score for that period

*Significance level set at $p < 0.05$

associated with a 0.18–0.53-point worse postoperative score depending on the PROM and implant type. In the Rimfit cohort, age at surgery was an additional significant predictor of poorer postoperative OHS, WOMAC, and VR-12 physical scores (≈ -0.1 to -0.3 per year). In the Rimfit cohort, ethnicity was also a clinically meaningful predictor, with Māori patients having significantly worse postoperative OHS (≈ -5 points), WOMAC (≈ -6 points), and VR-12 physical (≈ -8 points) scores compared with NZ European. In the Rimfit cohort, BMI was significant only for postoperative VR-12 mental scores, with higher BMI associated with poorer postoperative outcomes. In the ECF cohort, age at surgery predicted worse postoperative VR-12 physical scores (≈ -0.40 per year). ASA 3 was also associated with worse postoperative WOMAC (7.7 points) and VR-12 physical (5.6 points) scores compared to ASA 1. The R^2 values (0.08–0.34) from the regression analyses indicate that the included predictors explain only a modest proportion of outcome variance.

Discussion

A strength of our study is the consistency in key operative factors minimising variation in surgical technique, including the same cemented stem, hospitals, and overlapping surgical personnel. The shared geographic catchment confirms similar underlying demographics, which reinforces cohort comparability.

Preoperative PROMs comparison

This study addresses an important evidence gap by evaluating the Rimfit's 10-year suitability as a replacement for the ECF cemented cup. Distribution-based MCID estimates provide a useful benchmark to interpret the clinical meaningfulness of observed PROM changes [16, 18]. The OHS, WOMAC, and VR-12 physical scores all demonstrated substantial and statistically significant improvements from preoperative to postoperative PROMs, far exceeding our MCID thresholds of ≈ 4.5 , ≈ 9 , and ≈ 6 respectively in both cohorts. Previous research by Yeo et al. [19] indicated improved physical function after THA, with OHS and WOMAC improvements being good indicators of THA success. The

VR-12 mental scores in our study showed more modest clinical changes but also exceeded our MCID of ~6 and ~7 in the Rinfat and ECF, respectively.

Postoperative PROMs comparison

No statistically significant differences between 1-year, 5-year, and 10-year mean physical postoperative scores within each cohort were noted. All mean postoperative OHS scores exceeded the excellent threshold score of 41 [6]. These findings indicate positive PROM outcomes are achieved using both implants, which are sustained over a 10-year period. This consistency reinforces the implants provide comparable physical outcomes, despite surgeries occurring in two different 10-year intervals. Significantly better preoperative mental health scores in the Rinfat cohort suggest baseline differences in psychological wellbeing between groups that cannot be attributable to implant characteristics. The persistence of higher mental health scores at 1 and 5 years postoperatively is therefore most plausibly explained by the significant influence of preoperative outcomes on postoperative outcomes, rather than an effect of the implant itself [20]. The absence of differences at 10 years further supports this interpretation, suggesting that early postoperative disparities reflect baseline psychological profiles and early recovery trajectories, which converge over time as longer-term mental wellbeing becomes increasingly influenced by aging and broader psychosocial factors [21]. Registry-based literature cautions that comorbidity prevalence and patient health status often change over time, demonstrated by an increase in comorbidity rates and rising prevalence of specific conditions (e.g., diabetes and renal disease) over recent decades in THA populations [22]. The higher proportion of ASA 3 patients within the Rinfat cohort aligns with documented temporal trends in arthroplasty populations [23], with the comorbidity differences between our cohorts likely reflecting evolving patient health profiles [22, 23]. The relatively small sample of poor OHS scores (<27) investigated revealed no difference between the cohorts other than the increased proportion of ASA 2 in the Rinfat cohort, reaffirming no stark differences between cohorts other than comorbidities.

Linear regression preoperative PROMs

Funding source, as well as female sex and BMI, appear to consistently impact preoperative outcomes. Publicly funded patients showed worse preoperative scores, likely due to longer wait times [24], limited supportive care, higher comorbidities, barriers to health literacy, unemployment [25], and systemic inequities that result in patients needing greater disease severity to become eligible for surgery [26]. Female

sex has frequently been associated with poorer pre- and postoperative PROMs in THA. Females tend to present for surgery with greater pain, functional limitations, and comorbidity burden [27], which may partly reflect differences in pain perceptions, bone morphology, and delayed access to surgery [28]. Alongside these factors, higher rates of obesity and osteoporosis can influence surgery [29], recovery, and perceived outcomes [30]. Females need to be considered a priority in future risk stratification models [31] with female-specific management potentially beneficial [30].

Body mass index as a predictor of poorer preoperative PROMs in both cohorts, and higher ASA ratings in the Rinfat cohort, also suggests that comorbidity burden may significantly impact recovery trajectories, aligning with findings that a higher number of comorbidities introduces a higher risk of postoperative complications. Several studies [23, 32, 33] highlighted the value of documenting comorbidities in greater detail. While indices such as ASA correlate with THA outcomes, they provide limited guidance for individualised treatment. Podmore et al. [32] noted that specific conditions influence recovery differently, and Jensen et al. [33] found that implant survival hazard ratios are affected by cardiac, endocrine, oncologic, and mental health conditions in both univariate and multivariate analysis. It may be prudent for regional registries like the one analysed here to record more detailed comorbidity data and to pursue future comorbidity specific THA research to determine which comorbidities may predict the poorest outcomes.

Preoperatively, Māori presented significant and clinically meaningful poorer preoperative VR-12 mental scores, indicating ethnic disparity in health outcomes even before surgery. Such disparities could be related to psychosocial, cultural, and systemic factors [34]. Results must be interpreted with caution, however, given the limited number of NZ Māori in the ECF group ($n=9$) restraining our ability to robustly analyse preoperative PROMs.

Linear regression postoperative PROMs

In both cohorts, preoperative PROMs consistently demonstrated the largest predictive contribution to postoperative outcomes, consistent with previous studies [8, 35, 36]. Outside of preoperative scores, age at surgery influenced both cohorts while NZ Māori ethnicity predicted poorer physical postoperative outcomes in the Rinfat cohort, and ASA 3 comorbidity status in the ECF cohort. The limited number of Māori in our study hinders the robustness of analyses, limits regression modelling, and precludes assessment of ethnicity as a true, independent predictor, highlighting Māori underrepresentation in THA surgery. In our study, Māori represented ~5% of the cohort, a clear underrepresentation considering Māori represent 30.6% of the population in the

Bay of Plenty region [37]. Contributing factors for Māori under representation may include structural (colonisation, governance, socioeconomic) and intermediary (education, work, accessibility, lifestyle) determinants, highlighting the need to address upstream systemic and cultural barriers, not just surgical implants [38, 39].

Whether preoperatively or postoperatively, all patient factors investigated influenced patient outcomes to a certain extent. Although our results provide some insight, the low coefficient of determination of our models ($R^2 \sim 0.34$ at best) indicates that other potential influencers may affect scores more readily or assist in explaining a greater proportion of PROM variance, such as smoking status [40], activity levels [41], postoperative rehabilitation, health literacy, education, and care [42]. Considering the ECF implant is no longer used in NZ, the outcomes of the Rimpler linear regression models may be more relevant to future comparative studies with other specific implants.

The rationale for examining 10-year PROMs was to assess whether incremental advances in polyethylene design translate into sustained patient-perceived benefit over the longer term. Given the similarity in implant geometry and fixation, large early differences were not anticipated; rather, any potential differences were hypothesised to emerge with longer follow-up, where polyethylene durability may plausibly influence pain, function, or activity [43]. While radiographic outcomes and implant survivorship are critical measures of implant performance, PROMs capture the patient experience of that performance. The absence of clinically meaningful differences in 10-year PROMs therefore suggests that both designs provide durable and comparable PROMs, complementing existing survivorship data.

Conclusion

From a patient outcomes perspective, the Rimpler cup shows no significant difference in PROMs to the ECF at 10 years, with both implants demonstrating sustained improvements in PROMs and no statistically significant differences in physical function outcomes over 10 years. The Rimpler cohort presented with superior VR-12 mental scores preoperatively, sustained at 1-year, and at 5-year suggesting baseline differences in mental wellbeing. Socioeconomic status, sex, and comorbidity status (i.e., ASA) were identified as significant clinical predictors of poorer preoperative physical outcomes in both cohorts. For the Rimpler, Māori ethnicity was a predictor of poorer preoperative mental health and postoperative physical PROM scores. Postoperatively, older age at surgery was detrimental to PROMs outcomes in both cohorts. Findings should be interpreted within the temporal and health-system context in which each implant was used.

Limitations

Our analysis included patients with at least one completed PROM, representing 1360 of 1630 (84%) total THA recipients. Patients without any PROMs may differ systematically from responders, for example in baseline health, engagement with care, or postoperative outcomes. While the proportion of missing PROMs was relatively small and similar across groups, this selection may introduce bias and limit generalisability of our findings to the full cohort.

As with all registry-based analyses, this study is subject to selection bias. Inclusion was limited to patients captured by the registry and to those with at least one completed PROM, which may preferentially include more engaged or higher-functioning patients and lead to overestimation of postoperative outcomes. Differences in funding status and temporal changes in referral patterns, surgical practice, and PROM collection may also influence baseline characteristics and observed outcomes independent of implant choice. These factors should be considered when interpreting the findings, and causal inferences should be made with caution. While the large sample size improves precision and statistical power, it does not eliminate the possibility of bias or residual confounding.

The width of follow-up windows reflects the pragmatic nature of registry-based PROM collection, where follow-up timing is not fixed but occurs within predefined intervals. To minimise potential bias, 1-year follow-up was selected as the primary analytical endpoint due to the largest sample size, greatest temporal clustering of responses and lack of statistically significant differences observed in mean PROMs across 1-, 5-, and 10-year follow-up, suggesting that variation in follow-up timing did not meaningfully influence comparative conclusions.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00590-026-04734-w>.

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Author contributions All authors contributed to the conceptualisation of the study and developed the methodology. GC, TL, SM and AV were responsible for data acquisition and provided technical, administrative, and material support. Data analysis and interpretation were performed by A.P. and C.J. A.P. drafted the manuscript with critical revisions and academic input from K.H.L., T.L. and C.J. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Data availability Accessibility of protocol, raw data, and programming code can be obtained from the authors by request.

Declarations

Competing interests Two authors have disclosed paid presentations for Stryker in 2023. One author has a Training and Education contract for Stryker. All other authors declare that they have no actual or perceived conflict of interest to disclose.

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Appendix E. Wintec lightening talks presentation

Wintec Research Lightning Talks

On Tuesday 13 August, a Research Lightning Talks event was held in Events Room 1, with an excellent range of short presentations and Q & A and was attended by about 45 staff from across the institution.

Our presenters were:

Adrian France CBE

The Accountability of Olympic Sport Organisations

Patricia McClunie-Trust CHSP

Graduate entry nursing students development of a sense of self as a nurse: An infographic

Amy Pearce CSSHP

How "hip" are you? Outcomes of Total Primary Hip replacement for Osteoarthritis

Matthew Bannister SoMA

Playing Aldous Harding - "The Jim Carrey of the indie world"

Sanaz Ghoreishi CASPI

Investigation of Liquid Smoke Applications from the Pyrolysis of Kanuka Woodchips

Mohammad AL-Rawi CEID

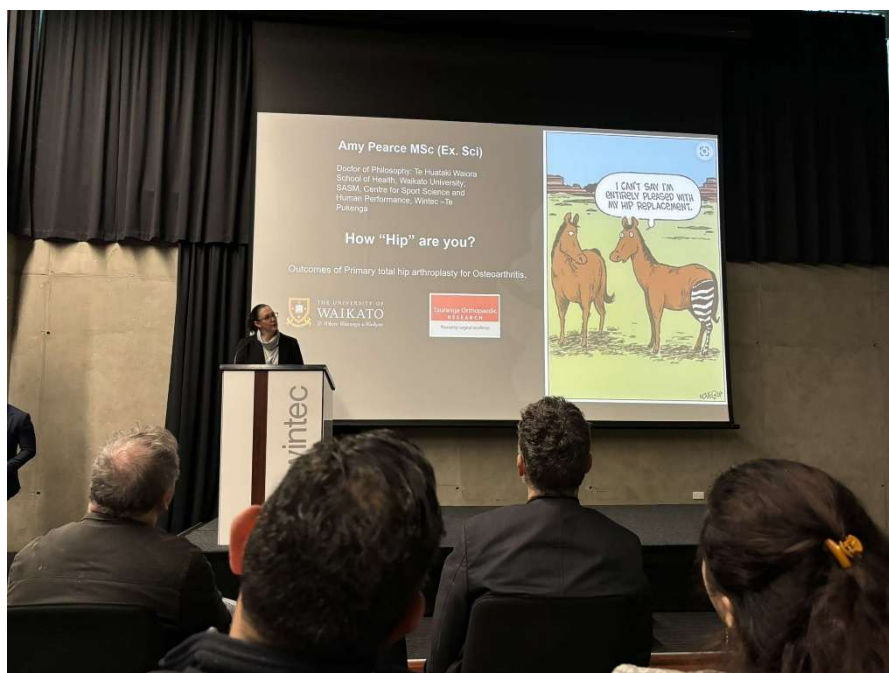
Investigation of Type A Aortic Dissection using Computational Modelling

David Williams CSSHP

How can Pākehā authentically embed mātauranga Māori into their teaching practice

Our dynamic MC Ryan Overmayer (CSSHP) did a fantastic job of bringing the event to life, and very generously sponsored the spot prize, which was won by an observant Anna Mischefski (CEFP).

A huge thank you to Ryan, Aimee, our attendees and our excellent presenters.



Appendix F. Tauranga public lecture series presentation



**TAURANGA
PUBLIC
LECTURE
SERIES**
RESEARCH CAFE

University of Waikato - Tauranga
23 October 2023 · 🌐

EVENT ALERT - Tauranga Public Lecture Series

Join Dr Kim Hébert-Losier and three of her PhD candidates from The University of Waikato Adams Centre for High Performance Sport for 'Research Cafe', where they will present talks on their latest research.

👉 Dr Kim Hébert-Losier - How strong are your calves? There's an app for that!

🏃 Anna Butcher - ACL injuries in growing athletes: The link between maturation and biomechanics

🏥 Amy Pearce - How 'hip' are you? Joint replacement outcomes in the Bay of Plenty

👟 Andrew Fife - To buy or not to buy: The running shoe store dilemma.

Appendix G. Tauranga Orthopaedic Research final presentation (2025)



Comparing cemented and hybrid outcomes in primary total hip replacement surgery for osteoarthritis: A PhD research overview

An observational analysis of survival rates and patient-reported outcomes in cemented and hybrid primary total hip arthroplasty. This research provides a comprehensive comparison of two THA methods with 6 patient specific factors.

Amy Pearce
Supervisors: Ass.Prof. Kim Hebert-Losier and Dr Chaitanya Joshi
University of Waikato, School of Health

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Appendix H. Abstract submission (International Society of Arthroplasty Registries, Lund, Sweden May 2026)



January 14th, 2026

Dear Participant,

The ISAR Scientific Committee has now assessed all abstracts received for the 15th International Congress of Arthroplasty Registries, which will be held in Lund, Sweden, May 30-June 1, 2026.

The overall calibre of abstracts received this year was very high, and the Committee noted that the shortlisting process was particularly challenging. Following review of your submissions, we are pleased to inform you that your abstract have been accepted for a **Podium presentation**.

No. 51 – 10-year outcomes of cemented and hybrid constructs in primary total hip arthroplasty for osteoarthritis: a NZ regional registry population study

A provisional program, with session details and the allotted time and date for your presentation, will be sent in March.

Each presentation is allocated 5-minute presentation time followed by a 5-minute discussion after every 3 presentations.

You will find further information regarding the meeting in the attached Invitation and General Information as well as links for registration and hotel reservation on the ISAR website at www.isarhome.org. Please note that the Early Bird rate expires March 31st. Regarding hotel reservations our blocking expire April 30th and see the Invitation letter.

Acta Orthopaedica will be the official journal for abstracts presented at ISAR 2026 in Lund. Authors are welcome to submit full manuscripts to *Acta Orthopaedica* after abstract submission to ISAR, either before or after the presentation at the meeting. Manuscripts should be submitted online at <https://www.manuscriptmanager.net/ao>. Please check the box if your scientific work is going to be or has been presented during an ISAR 2026.

We are very much looking forward to welcoming you to Lund!

Maziar Mohaddes

Chairman of the Local Organizing Committee

Encl.

Invitation Letter – General Information
Info Workshop No. 1 and No. 2

Further Information:

For enquiries related to abstract submission/acceptance, program, registration and payment please contact the ISAR team at info@isarhome.org

No. 51

10-year outcomes of cemented and hybrid constructs in primary total hip arthroplasty for osteoarthritis: a NZ regional registry population study

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Presenter: Amy Pearce

Introduction

The choice between hybrid and cemented fixation in total hip arthroplasty (THA) continues to vary internationally despite evidence suggesting comparable long-term outcomes. This study firstly evaluated the survivorship and patient-reported outcomes (PROMs) of a commonly used hybrid and cemented construct within a regional arthroplasty register. Secondly, we investigated sociodemographic predictors of poorer outcomes.

Materials and Methods

We compared the 10-year survival and PROMs of prospectively collected primary THA data from a regional New Zealand joint registry, with either an Exeter Trident Series 1/Exeter V40 stem (hybrid) or Exeter X3 Rimfit/Exeter V40 stem (cemented) construct. PROMs included Oxford Hip Score, WOMAC, VR-12 physical and mental health data preoperatively and at 1-, 3-, and 10 years postoperatively (n = 2331). Survival was assessed with multivariable Cox regression and sensitivity analyses. Predictors of PROMs were examined using multivariable linear models adjusting for demographic, clinical, and funding-related variables. Model performance was assessed using R².

Results

Survival of the hybrid and cemented constructs was equivalent (~95% at 10 years), with no significant differences in revision risk. Postoperative PROMs at 1-, 3-, and 10 years were clinically similar between constructs. Across all models, the most consistent predictor of poorer postoperative PROMs was poorer preoperative score. Preoperative physical PROMs were most influenced by public funding status, followed by higher comorbidity and sex (female); mental health PROMs showed similar patterns with the addition of Māori ethnicity. Age and BMI also influenced Postoperative PROMs. Model R² values ranged from 0.08–0.31, indicating substantial unmeasured contributors to outcome.

Discussion

Hybrid and cemented THA demonstrate comparable survival and patient-reported outcomes. More importantly, regional registry data highlight population-specific determinants, particularly sociodemographic factors, that strongly shape preoperative status and thereby postoperative recovery. Our rich regional PROMs dataset provides context-specific insight for our surgeons, supporting equitable and evidence-driven decision-making.

Appendix I. Ethical approval

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road
Hamilton, New Zealand

Human Research Ethics Committee
Roger Moltzen
Telephone: +64021658119
Email: humanethics@waikato.ac.nz



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

15 May 2023

Amy Pearce
Te Huataki Waiora School of Health
DHECS
By email: ap617@students.waikato.ac.nz

Dear Amy

HREC(Health)2023#12 : Longitudinal Analysis of Total Joint Arthroplasty Outcomes

Thank you for your clear and detailed responses to the Committee feedback.

We are now pleased to provide formal approval for your project.

Please contact the Committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

Emeritus Professor Roger Moltzen MNZM
Chairperson
University of Waikato Human Research Ethics Committee

Appendix J. Supplementary information for systematic review

Pubmed	pubmed	quality	RCT and Obs	scopus
(((((primary hip replacement) OR (primary hip arthroplasty)) AND (osteoarthritis)) AND (cement*)) AND (hybrid))		54 very good		6
(((((hip replacement) OR (hip arthroplasty)) AND (osteoarthritis)) AND (cement*)) AND (hybrid))		107 very good		11
(((((total hip replacement) OR (total hip arthroplasty)) AND (osteoarthritis)) AND (cement*)) AND (hybrid))		107 very good		
(((((primary hip replacement) OR (primary hip arthroplasty)) AND (osteoarthritis)) AND (cement*)) OR (hybrid))	613 002			3022
(((((primary hip replacement) OR (primary hip arthroplasty)) AND (osteoarthritis))		3559 YUCK		398
(((((primary hip replacement) OR (primary hip arthroplasty)) AND (osteoarthritis)) AND (WOMAC)		299 MEH		52
(((((primary hip replacement) OR (primary hip arthroplasty)) AND (osteoarthritis)) AND (OXFORD)		266 MEH		28
((hip replacement) OR (hip arthroplasty)) AND (osteoarthritis) AND (cement*) OR (uncemented) AND (hybrid)		280 very good		21
((primary total hip replacement OR primary total hip arthroplasty) AND (cement* OR hybrid) AND (Osteoarthritis))		724		86
((primary total hip replacement OR primary total hip arthroplasty) AND (cement* AND hybrid)		165 very good		12
((primary total hip replacement OR primary total hip arthroplasty) AND (cement* OR hybrid))		2838 very good		209
((primary total hip replacement OR primary total hip arthroplasty) AND (cement* OR hybrid) AND (Osteoarthritis) AND (OXFORD))		33 very good		3
((primary hip replacement OR primary hip arthroplasty) AND (outcomes) AND (Osteoarthritis))		2162		
((primary hip replacement OR primary hip arthroplasty) AND (outcomes) AND (uncemented AND cement*))		281 very good		35
((primary hip replacement OR primary hip arthroplasty) AND (outcomes) AND (uncemented OR cement*))				
(((("hip arthroplasty") OR ("hip replacement")) AND (acetabul*)) AND (osteoarthritis))		1988		
(((("hip arthroplasty") OR ("hip replacement")) AND (acetabul*)) AND (osteoarthritis) AND "WOMAC"		102		
(((("hip arthroplasty") OR ("hip replacement")) AND (acetabul*)) AND (osteoarthritis) AND "outcome"		1172		
(((("hip arthroplasty"[Title/Abstract] OR ("hip replacement"[Title/Abstract]) AND (acetabul*[Title/Abstract]) AND (osteoarthritis[Title/Abstract]) AND "outcome"[Title/Abstract]		486		
(((("hip replacement") OR ("hip arthroplasty")) AND ("cement*")) OR ("uncemented") AND ("osteoarthritis") AND ("acetabul*"))		745		
(((("hip replacement"[Title/Abstract] OR ("hip arthroplasty"[Title/Abstract]) AND ("cement*"[Title/Abstract]) OR ("uncemented"[Title/Abstract]) AND ("osteoarthritis"[Title/Abstract]) AND ("acetabul*"[Title/Abstract])		378		
((((("hip replacement"[Title/Abstract] OR ("hip arthroplasty"[Title/Abstract]) OR "THR" OR "THA" AND ("cement*"[Title/Abstract]) OR ("uncemented"[Title/Abstract]) AND ("osteoarthritis"[Title/Abstract]) AND ("acetabul*"[Title/Abstract])		791		
((((("hip replacement" OR (hip arthroplasty) OR (THR) OR (THA)) AND (cement*) OR (uncemented) AND (osteoarthritis) AND (acetabul*)		791		
(((((((hip replacement[Title/Abstract] OR (hip arthroplasty[Title/Abstract]) OR (THR[Title/Abstract]) OR (THA[Title/Abstract]) AND (cement*[Title/Abstract]) AND (uncemented[Title/Abstract]) AND (osteoarthritis[Title/Abstract]		125		
(((((((hip replacement) OR (hip arthroplasty) OR (THR) OR (THA)) AND (cement*)) OR (uncemented) AND (osteoarthritis) AND (acetabul* OR "cup")		961		253
total hip replacement fixation methods in osteoarthritis		579		

Outcomes of cemented versus hybrid primary total hip replacement for arthritis. A systematic review and meta-analysis.

Inclusion Types of Study

Randomised control trials

Observational studies including Retrospective, joint registry.

Excluded types of study

Case studies

Reviews

Systematic reviews (should have already been removed)

Included Terminology

"TOTAL" Hip replacement (both acetabular cup and a femoral stem)

"PRIMARY" Hip Replacement (First time hip, NOT a revision)

"HIP REPLACEMENT" OR "HIP ARTHROPLASTY"

"OSTEOARTHRITIS" only

Studies comparing or including both FULLY CEMENTED (both acetabular cup AND femoral stem)

AND

HYBRID (Cementless/uncemented/press-fit/threaded acetabular cup AND cemented stem)

Included Outcomes

ANY Patient reported outcome measures (Oxford Hip score/OHS, HOOS, WOMAC, SF-36, VR12 etc) up to at LEAST 1 YEAR.

Survivorship

Failure rate

Excluded terminology

Partial or "HEMIARTHROPLASTY", OR "RESURFACING" OR "BILATERAL"

MORTALITY

Studies on only one type of fixation ("CEMENTED" only, OR "CEMENTLESS" only, OR "HYBRID" only)

Studies that include/compare total "CEMENTED" and "CEMENTLESS" only

Studies that include only Cemented or Cementless acetabular cups with no info on the femoral fixation method

Anything other than "OSTEOARTHRITIS" ie: dysplasia, rheumatoid arthritis, rapidly destructive arthropathy, dislocation, fractures, Osteonecrosis, juvenile arthritis.

Appendix K. Example data collection form for systematic review

	Author	Date	Title	info	outcomes investigated	n	actors/predictor	statistical analysis	results	bilateral	subgroups	register/area	include	
4	Bloemhevel	2002	Comparable mortality but higher revision rate after uncemented compared with cemented total hip arthroplasties in patients 80 years and older: report of 43,053 cases of the Dutch Arthroplasty Register .	observational study mortality rate and revision rate (80 years and older)	mortality and revision risk in cemented, uncemented, hybrid, reverse hybrid	incidence of revision at 1, 3 and 5 years- Kaplan Meier net revision rate with CI and competing risk with mortality. Cox regression. Hazard ratio with CI	39 984 cemented 22005, hybrid 3243	ASA, age, sex, approach and head size	mortality stratified by age, sex, ASA and fixation method, multivariable cox regression for independent risk factors. Revision kaplan meier, competing risks analysis with adjustment	Mortality is comparable but revision rate is higher after uncemented compared with cemented THA in patients 80 years and older, higher risk of revision for uncemented.	only 1 of the hips was included in bilateral surgery	OA only >80 years from males and females and ASA	Dutch register, 2007 - 2015,	yes
5	Carlsson	2006	Stepwise introduction of a bone-conserving osseointegrated hip arthroplasty using RSA and a randomized study: I. Preliminary investigations--52 patients followed for 3 years.	RCT 52 patients, no hybrid here										
6	Clohisy JC	2001	Matched pair analysis of cemented and cementless acetabular reconstruction in primary total hip arthroplasty. J Arthroplasty 16:697-705	matched pair/ matched cohort cemented cups with cemented stems, uncemented stems and uncemented cups and 39 hybrid (cup outcomes only with no direct stem details)										
7	Conroy	2008	Risk factors for revision for early dislocation in total hip arthroplasty	observational 65 992 PTHA, 58109 PTHA osteo	revision procedure in which dislocation was listed as the reason for revision		20445 hybrid, cemented 8945	age sex femoral head size	logistic regression	age and sex have no significant effect on revision for dislocation, decreasing head diameter is associated with increased risk, cementless acetabulum higher risk	does not directly state hybrid and fully cemented but the results are included	varied diagnosis, risk of revision due to early dislocation factors not general survivorship or PROMS	Australian Arthroplasty Register 1999-2004	
8	Dale, H	2020	Perioperative, short-, and long-term mortality related to fixation in primary total hip arthroplasty: a study on 79,557 patients in the -Norwegian Arthroplasty Register.	patient survival analysis, mortality risk post surgery, perioperative death										
9	Ekman	2019	Early postoperative mortality similar between cemented and uncemented hip arthroplasty: a register study based on Finnish national data.	observational study Mortality rates only not outcomes										
10	Eskelinen	2005	Total hip arthroplasty for primary osteoarthritis in younger patients in the Finnish arthroplasty register: 4 665 Primary replacements followed for 0-22 years	Observational Finnish AR (risk of revision up to 22 years 1980 and 2001) Cups and stems analysed seperately										
11	Garland	2017	Risk of early mortality after cemented compared with cementless total hip arthroplasty: a nationwide matched cohort study	Matched cohort study. Subsequent analysis included hybrid and reverse hybrid mortality rate										
12	Gwynne-Jones	2020	Cemented or uncemented acetabular fixation 12in combination with the exter universal stem	long term observational study (surgeries that occurred between 1999-2005 at 15 year follow up)	implant survival - Primary- revision for any reason secondary - aseptic loosening, wear and osteolysis		total 1086, cemented 632, hybrid 454	age group interaction	Summary statistics, Chi squared tests for categorical, Fishers exact tests, mann whitney u, competing risks survival analysis, cumulative incidence curves	For young women, hybrid implants that employ adequate press-fit acetabular fixation and either highly crosslinked PE or ceramic bearings may provide the best balance of early improvement in outcome, revision risk, and cost	not stated	All indications for surgery included other than fracture	Otago hospital and NZJR records 1999-2005	no
13	Havelin	2009	The Nordic Arthroplasty Register Association A unique collaboration between 3 national hip arthroplasty registries with 280,201 THRs	survival and revision risk 1995-2006 Observational, comparison of denmark, sweden and norway (info on hybrid and cemented Kaplan meier)	implant survival only		Denmark 69 242, Sweden 140 821, Norway 70 138	survival, <60 and > 60	kaplan meier, cox regression analysis and estimation of survival with RR of revision	mixed results? Sweden and Norway had high proportion of cemented prostheses and better overall survival the Denmark who had the highest proportion of uncemented. But only basic kaplan meier shows the hybrid	not stated	Many diagnoses, <60 and >=60	Nordic arthroplasty register 1995-2006	no
14	Hesseling	2019	Fast Starters, Slow Starters, and Late Dippers: Trajectories of Patient-Reported Outcomes after Total Hip Arthroplasty: Results from a Dutch Nationwide Database	Observational Dutch AR (up to 1 year) No dates in abstract prospective data, OA, 3 months, 6 month and 12 months	OHS up to 1 year post op	Latent class modeling to classify subgroups (OHS) Multivariable multinomial logistic regression analysis	6030 total 1233 cemented, 273 hybrid	age (>75 and equal to or <75, sex, smoking, BMI, ASA, Charnley class, previous procedures, surgery type, fixation method	multivariable, multinomial logistic regression (latent basis model for the growth pattern in all models)	female, .75, obesity, ASA III or IV, lower prep health, lateral approach and fixationb reduced progress	not stated	primary diagnosis OA, <75and >75	Dutch 2014-2016	yes
15	Hooper	2009	Revision following cemented and uncemented primary total hip replacement: A seven-year analysis from the New Zealand joint registry	Observational NZJR Rate of revision (1999 and December 2006)	rate of revision, by reason type of fixation and age		cemented 16005 (302 revised), hybrid 15189 (134 revised)	cemented, hybrid and reverse hybrid; revision rate with respect to age categories <55, <65 <75 and >75	calculated per 100 years and kaplan meier	cemented lowest rate of revision overall, uncemented had lowest rate of aseptic loosening. Px under 55 have highest rate sof revision (have the hips for longer anyway)	not stated	Any diagnosis but primary only, <55, 55-64, 65-74 and >75	NZJR 1999-2006	no
16	Jameson	2015-02	Have cementless and resurfacing components improved the medium-term results of hip replacement for patients under 60 years of age? Acta Orthop 86(1), 7-17	Observational cement, cementless and hybrid included- worldwide registry data	PROMS, revision risk and cost; OHS and EQSD optimal and suboptimal cemented, uncemented, hybrid, resurfacing. Most common brands only	PROMS at 6 months but Survivorship data can be included. OA only	cemented survival analysis (1552) PROMS(163); hybrid for survival analysis(3238) PROMS (131)	patient summary statistics, <60, OHS and EQSD, sex, age and ASA, cost PREOP AND 6 month pots ONLY	competing risk models and hazard ratios, ANCOVA for PROMS	In young women, hybrids offer a balance of good early functional improvement and low revision risk. Fully cementless and resurfacing components are more costly and do not provide any additional benefit for younger patients.	not stated	OA only; male and female; <60 years	England and wales (2003 and 2010)	yes- survivors hip data

Appendix L. Te Whatu Ora patient-reported outcomes request and confidentiality



10th February 2023

Tauranga South

TAURANGA 3112

Dear [REDACTED],

You have recently been seen by the orthopaedic team at Tauranga Hospital and added to the waiting list for a **Right Hip Joint Replacement**.

Tauranga Orthopaedic Research is contacting you on behalf of the hospital, asking that you complete the following questionnaires relating to the level of pain and disability that your effected joint causes you.

By asking you now, and then again 1 year after the surgery, we can measure the benefit that the surgery has hopefully achieved for you.

Your results are matched to your operation record and provide your personal follow-up.

By being completed personally, they offer the best indication of your outcome.

In the future, these surveys can also check on your progress and give a clue if there is a problem developing with the joint replacement.

Your questionnaire results are also anonymously pooled with all the other people undergoing joint replacement surgery in the Bay of Plenty region. This system gives us the best long term monitoring program possible, to ensure the highest quality care and outcomes. This benefits not just you, but also future patients.

Please be reassured that if you choose not to take part, you will receive the usual care and treatment and you are free to withdraw at any time, without having to give a reason.

Thank you very much for your co-operation.

PRIVACY STATEMENT/CONFIDENTIALITY

The information collected from your survey is held securely and in confidence by the Tauranga Orthopaedic Research Society Inc.

No material which could personally identify you will be used in any reports or scientific study, except for information relating directly to your treatment which will be passed to your orthopaedic surgeon.

You are entitled to request access to, or the correction of, personal information held about you. If you wish to have access to that information, to have it corrected, or if you have any questions about the information held about you, please contact:

Tauranga Orthopaedic Research Coordinator

Private Bag 12-506
Tauranga 3143
Telephone (07) 543 1861
Fax (07) 543 5287
Email: torsi@orthocentre.co.nz

If you have any questions or concerns about your rights as a participant, you can contact an independent health and disability advocate. This is a free service provided under the Health and Disability Commissioner Act.

Telephone: (NZ wide) 0800 555 050
Free Fax (NZ wide): 0800 2787 7678 (0800 2 SUPPORT)
Email: advocacy@hdc.org.nz

Appendix M. Tauranga Orthopaedic Research Oxford Hip Score questionnaire



S4 Oxford Hip Score

Patient Name _____ ID _____ Side ☐ Right ☐ Left

Date of review: ____/____/____

Follow up period: PreOp OR _____ weeks/months/years (circle one)

Please answer the 12 questions below.

1. During the past 4 weeks... How would you describe the pain you usually have from your hip?

☐ None ☐ Very mild ☐ Mild ☐ Moderate ☐ Severe

2. During the past 4 weeks... Have you had any trouble washing and drying yourself (all over) because of your hip?

☐ No trouble at all ☐ Very little trouble ☐ Moderate trouble ☐ Extreme difficulty ☐ Impossible to do

3. During the past 4 weeks... Have you had any trouble getting in and out of the car or using public transport because of your hip? (whichever you would tend to use)

☐ No trouble at all ☐ Very little trouble ☐ Moderate trouble ☐ Extreme difficulty ☐ Impossible to do

4. During the past 4 weeks... Have you been able to put on a pair of socks, stockings or tights?

☐ Yes, easily ☐ With little difficulty ☐ With moderate difficulty ☐ With extreme difficulty ☐ No, Impossible

5. During the past 4 weeks... Could you do household shopping on your own?

☐ Yes, easily ☐ With little difficulty ☐ With moderate difficulty ☐ With extreme difficulty ☐ No, Impossible

6. During the past 4 weeks... For how long have you been able to walk before pain from your hip becomes severe (with or without a stick)

☐ No pain – more than 30 minutes ☐ 16- 30 minutes ☐ 5-15 minutes

☐ Around the house only ☐ not at all - pain severe on walking

7. During the past 4 weeks... Have you been able to climb a flight of stairs?

- ☐ Yes, easily ☐ With little difficulty ☐ With moderate difficulty ☐ With extreme difficulty ☐ No, impossible
-

8. During the past 4 weeks... After a meal (sat at a table) how painful has it been for you to stand up from a chair because of your hip?

- ☐ Not at all painful ☐ Slightly painful ☐ Moderately painful ☐ Very painful ☐ Unbearable
-

9. During the past 4 weeks... Have you been limping when walking, because of your hip?

- ☐ Rarely/Never ☐ Sometimes or just at first ☐ Often, not just at first ☐ Most of the time ☐ All of the time
-

10. During the past 4 weeks... Have you had any sudden, severe pain – shooting, stabbing or spasms from the affected hip?

- ☐ No days ☐ Only 1 or 2 days ☐ Some days ☐ Most days ☐ Every day
-

11. During the past 4 weeks... How much has pain from your hip interfered with your usual work (including housework)?

- ☐ Not at all ☐ A little bit ☐ Moderately ☐ Greatly ☐ Totally
-

12. During the past 4 weeks... Have you been troubled by pain from your hip in bed at night?

- ☐ No nights ☐ Only one or two nights ☐ Some nights ☐ Most nights ☐ Every night
-

Finally, please check back that you have answered each question.

Thank you very much.

Appendix N. Tauranga Orthopaedic Research WOMAC questionnaire



S10 Womac

Patient Name _____ ID _____ Side ☐ Right ☐ Left

Date of review: ____/____/____

Follow up period: PreOp OR _____ weeks/months/years (circle one)

P: These questions concern the amount of pain you are currently experiencing in your hips or your knees. For each situation, please enter the amount of pain you have recently experienced. How much pain do you have...

1. Walking on a flat surface	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
2. Going up or down stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
3. At night while in bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
4. Sitting or lying	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
5. Standing upright	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

M: These questions concern the amount of joint stiffness (not pain) you are currently experiencing in your hips or your knees. Stiffness is sensation of restriction or slowness in the area around which you move your joints.

6. How severe is your stiffness after first waking in the morning?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
7. How severe is your stiffness after sitting, lying or resting later in the day?	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme

F: These questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you are experiencing. What degree of difficulty do you have with...

8. Descending stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
9. Ascending stairs	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
10. Rising from sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
11. Standing	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
12. Bending to floor	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
13. Walking on flat	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
14. Getting in/out of car	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
15. Going shopping	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
16. Putting on socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
17. Rising from bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
18. Taking off socks/stockings	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
19. Lying in bed	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
20. Getting in/out bath	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
21. Sitting	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
22. Getting on/off toilet	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
23. Heavy domestic duties	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme
24. Light domestic duties	☐ None	☐ Mild	☐ Moderate	☐ Severe	☐ Extreme



VR12 GENERAL HEALTH SURVEY

Patient Name _____ ID _____ Side ☐ Right ☐ Left
 Date of review: ____/____/____ Follow up period: PreOp OR ____ weeks/months/years (circle one)

1) In general, would you say your health is:

- ☐ 1. Excellent
☐ 2. Very Good
☐ 3. Good
☐ 4. Fair
☐ 5. Poor

2) The following questions are about activities you might do during a typical day.

Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	☐ 1	☐ 2	☐ 3
Climbing several flights of stairs	☐ 1	☐ 2	☐ 3

3) During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	No, none of the time	Yes, a little of the time	Yes, some of the time	Yes, most of the time	Yes, all of the time
Accomplished less than you would like	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Were limited in the kind of work or other activities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

4) During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	No, none of the time	Yes, a little of the time	Yes, some of the time	Yes, most of the time	Yes, all of the time
Accomplished less than you would like	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Didn't do work or other activities as carefully as usual	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5) During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

- ☐ 1. Not at All
☐ 2. A Little Bit
☐ 3. Moderately
☐ 4. Quite a Bit
☐ 5. Extremely

These questions are about how you feel and how things have been with you during the past 4 weeks.
For each question, please give the one answer that comes closest to the way you have been feeling.

6) How much of the time during the past 4 weeks...

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	☐	☐	☐	☐	☐	☐
Did you have a lot of energy?	☐	☐	☐	☐	☐	☐
Have you felt downhearted and blue?	☐	☐	☐	☐	☐	☐

Now, we'd like to ask you some questions about how your health may have changed.

7) During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?

- ☐ 1. All of the time
- ☐ 2. Most of the time
- ☐ 3. Some of the time
- ☐ 4. A little of the time
- ☐ 5. None of the time

8) Compared to one year ago, how would you rate your physical health in general now?

- ☐ 1. Much better
- ☐ 2. Slightly better
- ☐ 3. About the same
- ☐ 4. Slightly worse
- ☐ 5. Much worse

9) Compared to one year ago, how would you rate your emotional problems (such as feeling anxious, depressed or irritable) now?

- ☐ 1. Much better
- ☐ 2. Slightly better
- ☐ 3. About the same
- ☐ 4. Slightly worse
- ☐ 5. Much worse

The Veterans Health Study (SDR-91006.S VA Health Services Research and Development Service) The VR-12 Health Survey item content was developed and modified from the Veterans RAND 36-item Health Survey.

Appendix O. New Zealand joint registry primary hip arthroplasty surgical data form

VERSION: 10 NOV 2023		PRIMARY HIP REPLACEMENT	
☐ TOTAL HIP ARTHROPLASTY		☐ RESURFACING ARTHROPLASTY	
		☐ HEMIARTHROPLASTY	
NEW ZEALAND JOINT REGISTRY - DO NOT PLACE IN PATIENT NOTES - TO BE RETAINED IN THEATRE SUITE			
DATE		THEATRE NO.	
ASA CLASS 1 2 3 4 [PLEASE CIRCLE]		HOSPITAL NAME	
BMI		STICK PATIENT LABEL HERE PLEASE PLACE IMPLANT LABELS ON THE REVERSE 	
CONSULTANT [IF DIFFERENT FROM PATIENT LABEL]			
☐ LEFT - SIDE - RIGHT ☐ IF BILATERAL THEN DO SEPARATE FORMS			
FUNDING		SURGEON TO CHECK & SIGN PLEASE →	
☐ ACC		☐ Private	
		☐ DHB	
		☐ DHB Outsourced	

PREVIOUS OPERATION ON INDEX JOINT | TICK ALL THAT APPLY |

- ☐ None
☐ Hip Arthroscopy
☐ Internal fixation for juxtaarticular fracture
☐ Osteotomy
☐ Other (SPECIFY) _____

DIAGNOSIS

- ☐ Osteoarthritis
- ☐ Rheumatoid arthritis/other inflammatory
- ☐ Acute fracture NOF
- ☐ Old fracture NOF
- ☐ Avascular necrosis
- ☐ Developmental dysplasia / Congenital dislocation
- ☐ Tumour
- ☐ Other (SPECIFY) _____

APPROACH [TICK ALL THAT APPLY]

- ☐ Posterior
- ☐ Anterior
- ☐ Superior
- ☐ Lateral
- ☐ Trans-trochanteric (osteotomy)

SURGICAL ADJUNCTS [TICK IF USED]

- ☐ Computer Navigation
- ☐ Robotic assisted

SYSTEMIC ANTIBIOTIC PROPHYLAXIS

NAME: _____

OPERATING THEATRE

- ☐ Conventional
- ☐ Laminar Flow or similar

OPERATING TIME

Start Skin Time: _____

Finish Skin Time: _____

SURGEON ATTIRE

- ☐ Space Suits/Helmet Fan: ☐ One-piece Toga or ☐ Sterile Hood and Gown
- ☐ Conventional Gown

PRIMARY SURGEON

- ☐ Consultant ☐ Adv Trainee Unsupervised ☐ Adv Trainee Supervised ☐ Basic Trainee

DO NOT PLACE IN PATIENT NOTES - TO BE RETAINED IN THEATRE SUITE

Cement [IF MORE THAN ONE MIX IS USED ONLY ONE CEMENT STICKER IS REQUIRED]

Femur ☐ Yes ☐ No

Acetabulum ☐ Yes ☐ No

PLACE CEMENT STICKER OR COMPLETE

Cement Name:

Cement Antibiotic (if present):

Femur

Please do not fold placed stickers
bar coded label

Acetabulum

Please do not fold placed stickers
bar coded label

Femoral head

Please do not fold placed stickers
bar coded label

Augments

Please do not fold placed stickers
bar coded label

IMPORTANT

IF A BILATERAL PROCEDURE TWO COMPLETED FORMS ARE REQUIRED

Appendix P. New Zealand joint registry patient consent form

NEW ZEALAND JOINT REGISTRY
Established by the New Zealand Orthopaedic Association



Department of Orthopaedic Surgery and Musculoskeletal Medicine
Christchurch Hospital
Private Bag 4710
Christchurch 8140

E-mail: jinny.willis3@cdhb.health.nz

CONSENT FORM

TO BE FILED IN PATIENT NOTES

REQUEST FOR INTERPRETER			
English	I wish to have an interpreter	Yes	No
Maori	E hiahia ana ahau ki tetahi kaiwhakamaori/kaiwhaka pakeha korero	Ae	Kao
Samoan	Oute mana'o ia iai se fa'amatala upu	Ioe	Leai
Tongan	Oku ou fiema'u ha fakatonulea	Io	Ikai
Cook Island	Ka inangaro au i tetai tangata uri reo	Ae	Kare
Niuean	Fia manako au ke fakaaoga e taha tagata fakahokohoko kupu	E	Nakai

The New Zealand Orthopaedic Association has a New Zealand Joint Registry which records the technical data on all artificial joint replacement surgery performed in New Zealand, eg, the different types of artificial joints implanted, whether cemented or not, how long the operation took, the need to use antibiotics. The Register will provide independent data on the performance of these artificial joints over many years. The data will be used in the future for an audit of joint replacement outcomes and will identify the factors which will provide the best long term surgical results for New Zealanders.

You are asked for your consent to allow your name, address, date of birth, national health index number along with the technical data on your joint surgery to be forwarded to the Registry.

We need this information in order to track the outcome over many years of your artificial joint replacement.

No other personal information will be entered without your written consent and it will not be possible to identify your name from any information taken from the data base for audit purposes.

If you wish to withdraw from the Register, you may do so by writing to the New Zealand Joint Registry, Department of Orthopaedic Surgery and Musculoskeletal Medicine, Christchurch Hospital. Withdrawing from the Register will not affect your current or future health care in any way.

Mr John McKie
Registry Supervisor

I consent to my name, address, date of birth, national health index number along with the technical data on my joint surgery being forwarded to the New Zealand Joint Registry.

Signed: Date:

Name: (Please print)

NJR005

Appendix Q. Co-author forms for Chapter 2, 3 and 4.



Co-Authorship Form

School of Graduate Research
The University of Waikato
Private Bag 3105
Hamilton 3240, New Zealand
Phone +64 7 838 5096
Email: SGR@waikato.ac.nz
Website: <http://www.waikato.ac.nz/students/research-degree>

This form is to accompany the submission of any PhD that contains research reported in published or unpublished co-authored work. **Please include one copy of this form for each co-authored work.** Completed forms should be included in your appendices for all the copies of your thesis submitted for examination and library deposit (including digital deposit).

Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 2- Systematic Review: Pearce, A., Butcher, A. & Hébert-Losier, K. Outcomes of cemented ar hybrid primary total hip arthroplasty for osteoarthritis: A systematic review with narrative synthesis: Orthop Trauma Surg 145, 388 (2025). <https://doi.org/10.1007/s00402-025-06007-3>

Nature of contribution
by PhD candidate

Full responsibility for study design, review execution, data analysis, narrative synthesis, and writing the manuscript.

Extent of contribution
by PhD candidate (%)

90%

CO-AUTHORS

Name	Nature of Contribution
Anna Butcher	Second, blinded abstract and title screening, full text screening
Kim Hebert-Losier	Methodology, supervision, writing review and editing

Certification by Co-Authors

The undersigned hereby certify that:

- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- ❖ that the candidate wrote all or the majority of the text.

Name	Signature	Date
Anna J Butcher	 Anna Butcher (Feb 18, 2025 13:25:18 GMT+13)	02/12/2025
Kim Hebert-Losier		02/12/2025

July 2015

Co-Authorship Form

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 3- Pearce, A., Joshi, C., Chan, G. et al. 10-year survival comparison of two cemented implants in primary total hip arthroplasty for osteoarthritis: a New Zealand regional study. Arch Orthop Trauma Surg 495 (2025). <https://doi.org/10.1007/s00402-025-06092-4>

Nature of contribution by PhD candidate	Full responsibility for study design, review execution, data analysis, narrative synthesis, and writing the manuscript.
Extent of contribution by PhD candidate (%)	90%

CO-AUTHORS

Name	Nature of Contribution
Chaitanya Joshi	Methodology, formal analysis
Kim Hebert-Losier	Supervision, conceptualization, writing review and editing
Georgina Chan	Conceptualization, data curation, resources, validation
Tony Lamberton	Conceptualization, data curation, resources, validation
Simon MacLean	Conceptualization, data curation, resources, validation
Andrew Vane	Conceptualization, data curation, resources, validation

Certification by Co-Authors

The undersigned hereby certify that:

- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- ❖ that the candidate wrote all or the majority of the text.

Name	Signature	Date
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Kim Hebert-Losier	Kim Hebert-Losier	02/12/2025
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Simon MacLean	S. MacLean	02/12/2025
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July 2015

Co-Authorship Form

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 4- Pearce A, Joshi C, Chan G, et al. 15-year patient-reported outcomes of a cemented flanged cup and stem combination in primary total hip arthroplasty: a New Zealand study. *HIP International*. 2025(010). doi:10.1177/11207000251371132

Nature of contribution by PhD candidate	Full responsibility for study design, review execution, data analysis, narrative synthesis, and writing the manuscript
Extent of contribution by PhD candidate (%)	90%

CO-AUTHORS

Name	Nature of Contribution
Chaitanya Josh	Methodology, formal analysis
Kim Hebert-Losier	Supervision, conceptualization, writing review and editing
Georgina Chan	Conceptualization, data curation, resources, validation
Tony Lamberton	Conceptualization, data curation, resources, validation
Simon MacLean	Conceptualization, data curation, resources, validation
Andrew Vane	Conceptualization, data curation, resources, validation

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- that the candidate wrote all or the majority of the text.

Name	Signature	Date
Chaitanya Josh	C. Joshi	25/02/2026
Kim Hebert-Losier	K. Hebert-Losier	25/02/2026
Georgina Chan	G. Chan	25/02/2026
Tony Lamberton	T. Lamberton	25/02/2026
Simon MacLean	S. MacLean	25/02/2026
Andrew Vane	A. Vane	25/02/2026

Appendix R. Proposed additions to the New Zealand joint registry

1. Enhanced Comorbidity Detail (Diagnosis-Level, Not Category-Level). Replace broad ASA-only classifications with specific, clinically meaningful diagnostic fields. Use already existing ICD-10-AM condition diagnostic coding

Include:

- a. Musculoskeletal and pain-related conditions including but not limited to:
 - i. Chronic pain syndrome / central sensitisation
 - ii. Fibromyalgia
 - iii. Chronic low back pain (duration >3 months)
 - iv. Neuropathic pain conditions
 - v. Osteoarthritis severity in other major joints
- b. Metabolic and cardiovascular conditions including but not limited to:
 - i. Type 1 and Type 2 diabetes (coded separately)
 - ii. Diabetes control markers (HbA1c)
 - iii. Obesity class (BMI numeric + class I/II/III derived)
 - iv. Hypertension (treated/untreated)
 - v. Hyperlipidaemia
 - vi. Chronic kidney disease stage (1–5)
- c. Mental health conditions including but not limited to:
 - i. Depression (treated/untreated; primary vs secondary)
 - ii. Anxiety disorders
 - iii. PTSD
 - iv. Bipolar disorder
 - v. Substance use disorders (alcohol, opioids, stimulants; with “active” vs “past” status)
- d. Inflammatory and autoimmune Conditions including but not limited to:
 - i. Rheumatoid arthritis (disease activity categorical: low/moderate/high if available)
 - ii. Psoriatic arthritis
 - iii. Systemic lupus erythematosus
 - iv. Other inflammatory arthropathies
- e. Other high-impact conditions including but not limited to:
 - i. COPD / asthma severity
 - ii. Chronic liver disease
 - iii. Dementia / mild cognitive impairment
 - iv. Frailty score (e.g., Clinical Frailty Scale categorical 1–9)
- f. Pain and functional status detail (preoperative) (WOMAC)
 - i. PROMs are useful, but more granular pain profiles improve predictive accuracy.
 - ii. Average opioid use (morphine-equivalent daily dose)

- g. Functional variables including
 - i. Use of walking aids (none, stick, frame)
 - ii. Non walking or wheelchair bound
 - iii. Falls in last 12 months (0, 1–2, ≥3)
 - iv. Preoperative physiotherapy utilisation (yes/no + weeks attended)
- 2. Access to care
 - a. Time from GP referral to orthopaedic clinic
 - b. Time from clinic to surgery
 - c. Distance travelled to surgical centre (km, categorical or numeric)
- 3. Social stability
 - a. Housing security (stable / temporary / unstable)
 - b. Employment status
 - c. Social support availability (lives alone / with whānau / supported living)
- 4. Perioperative and rehabilitation detail
 - a. Perioperative
 - i. Smoking status (current/former/never)
 - ii. Hazardous alcohol use (AUDIT-C categorical)
 - iii. Preoperative anaemia (yes/no + Hb value)
 - iv. Preoperative vitamin D deficiency (yes/no if tested)
 - b. Postoperative rehabilitation
 - i. Physiotherapy dose (number of sessions attended within first 3 months)
 - ii. Mode of rehabilitation (in-person, home-based, online)
 - iii. Early complications (wound issues, readmission within 90 days—specific ICD-10 codes)
- 5. PROMs-related enhancements
 - a. Collect PROMs at referral (baseline at system entry)
 - b. Add a mental health PROM (e.g., VR-12) to interpret EQ-5D anxiety/depression
 - c. Māori-specific wellbeing metric (e.g., culturally adapted EQ-5D extension). While the standard EQ-5D is used, some researchers note that it may not fully capture the holistic, indigenous, or spiritual dimensions of Māori health.
- 6. Data linkage fields
 - a. NHI-based linkage to primary care data
 - b. Linkage to pharmacy dispensing (opioids, antidepressants, NSAIDs)
 - c. Linkage to ACC history (previous musculoskeletal claims)
 - d. Linkage to social welfare datasets (for socioeconomic trajectory)