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Structure and function of the Achilles tendon and plantarflexors after non-surgical management of Achilles tendon rupture: A cross-sectional study

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A R T I C L E I N F O

Keywords:
Conservative management
Triceps surae

A B S T R A C T

Background: Achilles tendon rupture (ATR) impacts the structure and function of the tendon and triceps surae. We aimed to describe recovery at different time points after injury using ultrasound imaging, strength testing and patient reported outcomes.

Methods: Cross-sectional study design, collecting data from 15 different non-surgically managed participants at six independent rehabilitation time points (week 0, 8, 10, 16, 26, 52 post ATR). Outcomes included ultrasound tissue characterisation (UTC), isometric plantarflexor strength, Achilles tendon rupture score (ATRS), Euroqol 5-dimension, hospital anxiety and depression scale and Tampa Scale for Kinesiophobia. UTC echo type percentage is reported as aligned fibrillar structure (AFS) and disorganised fibrillar structure (DFS).

Findings: Participants mean (SD) age was 48 years (15.8), 91 % male, body mass index 29kg/m2 (4.3) and 54 % was white British. Primary mechanism of injury was sport (71 %).

Ruptured tendon cross-sectional area (CSA) was 303.55 mm^2 (90.43) at 10 weeks and 218.18 mm^2 (61.82) at 52 weeks post ATR. For the ruptured tendon, later assessment time points were associated with decreased AFS but had no association with DFS.

Isometric plantarflexor strength on the ruptured limb at 52 weeks was 61.3 kg (20.8) or 0.7x bodyweight (BW). Non-ruptured plantarflexor strength was 93.3 kg (29.5) or 1.1x BW. Leg symmetry index at 52 weeks was 67 %. ATRS at 52 weeks was 75.1 (16.5).

Conclusion: Substantial tendon remodelling may occur during the initial 52 weeks post ATR, CSA was 28 % lower from 10 weeks to 52 weeks. At 52 weeks there was persistence of fibrillar disorganisation, isometric plantarflexor weakness and reduced function.

Trial registration: ClinicalTrials.gov ID: NCT05676632.

1. Background

Acute Achilles tendon ruptures (ATRs) most commonly occur in middle age during sporting activity (Lantto et al., 2016). The incidence of ATR and the use of non-surgical management strategies are rising (Briggs-Price et al., 2024; Lantto et al., 2016; Sheth et al., 2017; Svedman et al., 2024). Non-surgical approaches offer a cost-effective alternative to surgical management (Koltsov et al., 2020) and are the

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predominant management strategy in the United Kingdom (UK) (Kearney et al., 2015).

Ultrasound assessment following ATR provides an insight into prognostic factors such as tendon cross-sectional area (CSA) (Zellers et al., 2019). Ultrasound Tissue Characterisation (UTC) provides more detailed and quantifiable data than traditional B-mode ultrasound (Rabello et al., 2021). Few studies have used UTC to evaluate tendon structure after ATR (Dams, 2021; Nunes et al., 2021). Dams (2021) completed an initial UTC study to understand the adaptations in tendon architecture post ATR. The study identified that tendon structure remains compromised over the first year after ATR. However, only proportions of the four identifiable echo types were presented with no indication of tendon cross-sectional area or absolute quantity of aligned or disorganised fibres.

Persistent strength deficits occur in the plantarflexors following ATR (Hoeffner et al., 2022). ATR studies in the UK that have investigated strength have not included modern functional bracing techniques that promote early weightbearing and mobilisation (Lawrence et al., 2017). More recent studies have included functional bracing protocols with a dynamised orthosis (Naskar et al., 2022; Yassin et al., 2020). However, these studies only collected calf raise repetitions without quantifying calf raise height and did not collect plantarflexor force data. Calf raise height is associated with Achilles length and ankle kinematics and allows overall calf work to be quantified (Brorsson et al., 2017; Silbernagel et al., 2012). Alternate approaches have included measuring calf girth to provide an indication of muscle volume (Aujla et al., 2019). However, calf muscle volume has a limited relationship with plantarflexor strength following ATR (Mashimo et al., 2023). A valid and reliable strength assessment is required to understand the strength deficits following functional bracing and rehabilitation in the UK.

The Achilles tendon rupture score (ATRS) is a reliable and valid measure of function following ATR (Carmont et al., 2023). The ATRS is widely used and has been collected alongside health-related quality of life outcomes such as the EQ-5D-5L (Costa et al., 2020). Although there is a lack of studies reporting outcomes specific to wider health determinants such as anxiety, depression and fear of movement (kinesiophobia). Studies have identified that kinesiophobia is negatively correlated with symptoms and return to activity post ATR (Olsson et al., 2012; Slagers et al., 2021). However, there are no studies reporting measures of kinesiophobia and psychological wellbeing following non-surgical management in the UK. Further investigations are needed to understand the patient reported outcomes (PROMs) of non-surgically managed ATR.

We aimed to assess the structural adaptations of the Achilles tendon using UTC, the strength of the plantarflexors, and PROMs over one year for non-surgically managed ATR.

2. Methods

2.1. Trial design

This observational study has a repeated cross-sectional design. Data were collected from individuals diagnosed with ATR receiving rehabilitation in a National Health Service (NHS) trust between June 2023 and February 2024. The study protocol was approved by the medical ethics committee and prospectively registered with ClinicalTrials.gov (number NCT05676632). We adhered to the STROBE guideline for reporting of cross-sectional studies (von Elm et al., 2007).

2.2. Participants

All individuals received a clinical diagnosis of ATR (NICE, 2020) confirmed in a specialist ATR clinic following referral from the emergency department or urgent care centre. Following assessment, participants were routinely managed using the LAMP or Covid-modified LAMP (CM-LAMP) protocols consisting of 8 weeks of functional bracing using a Vacoped boot (Table 1). Both regimes used the same immobilisation period (8 weeks), but the CM-LAMP allowed the patients to alter the boot dynamization (ankle position and movement range) at home. Following this, participants were referred to an NHS physiotherapy service to receive guided rehabilitation. Physiotherapy involved individualised care including strengthening and range of motion exercises. Participants were recruited from an NHS Achilles Tendon Rupture Clinic or Achilles Tendon Rupture Class. All patients attending the clinic or class during the study period were invited to participate. They were provided a participant information document and given the opportunity to discuss the study with the lead researcher. All participants signed an informed consent form prior to completing study outcomes.

2.3. Study procedure

Independent groups of participants completed assessments at one of six time points during ATR rehabilitation: at initial presentation to the ATR service (week 0), on functional brace removal (week 8), or at 10-weeks, 16-weeks, 26-weeks or 52-weeks post ATR (supplementary material 1). All individuals who were at the rehabilitation time points during the study period were eligible to participate. Study assessment procedures and time points are displayed in Table 2. Participants were not provided their individual findings until they had completed all study outcomes. Demographic data, comorbidities and mechanism of injury was self-reported by participants.

2.4. Study outcomes

2.4.1. Ultrasound Tissue Characterisation

The UTC SMART system (UTCImaging, Stein, The Netherlands) was used and consisted of conventional ultrasound equipment (multi-frequency 5–16 MHzlinear-array transducer). UTC scans for both the affected and non-affected Achilles tendons were completed using a standardised protocol with participants prone in a maximal passive dorsiflexion position (Rabello et al., 2021). For participant safety the affected limb did not complete UTC assessments at week 0 and week 8. Four different echo types are identified using a computer algorithm and represent tendon integrity and fibrillar disorganisation: (I) highly stable, (II) medium stable, (III) highly variable, and (IV) constantly low intensity and variable distribution (van Schie et al., 2010). The intra-class correlation coefficient for intraobserver (0.97–0.99) and interobserver reliability (0.89–0.99) was excellent in previous studies quantifying pathological Achilles tendon structure (de Jonge, Tol et al., 2015; Paantjens et al., 2022).

Assessment and analysis of UTC images adhered to recommended criteria (Rabello et al., 2021). Any artefacts that could influence analysis

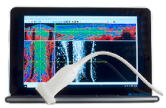
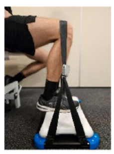
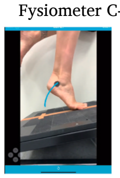
Table 1
Key elements of the Leicester Achilles Management Protocol (LAMP) and Covid-Modified LAMP (CM-LAMP) functional bracing protocols.

Time (weeks)	LAMP	Boot[a]
0–4	Locked in 30° plantarflexion	
4–6	Dynamised 15–30° plantarflexion	
6–8	Dynamised 0–30° plantarflexion	
8	Boot Removed	
	CM-LAMP	
0–2	Locked in 30° plantarflexion	
2–8	Dynamised range increase 5° per week (e.g., week 2–3 allows 5° from 25 to 30° plantarflexion)	
8	Boot Removed	

[a] VACOped Functional Brace.

Table 2
Study outcomes and assessment points.

Table 2. Summary of assessment procedures and time points for the non-affected and affected limbs of participants with an Achilles tendon rupture treated conservatively.

Procedures	Limb	Time Points					
		Week 0	Week 8[a]	Week 10	Week 16	Week 26	Week 52
 Ultrasound Tissue Characterization	Non-affected	✓	✓	✓	✓	✓	✓
	Affected	X	X	✓	✓	✓	✓
 Fysiometer C-Station MVIC	Non-affected	✓	✓	✓	✓	✓	✓
	Affected	X	X	✓	✓	✓	✓
 Calf Raise App Strength-Endurance Test	Non-affected	✓	✓	✓	✓	✓	✓
	Affected (criteria met[b])	X	X	✓	✓	✓	✓
Patient Reported Outcomes Questionnaires	Not applicable	✓	✓	✓	✓	✓	✓

Abbreviations. MVIC, maximal voluntary isometric contraction.
[a] Removal of the functional brace on the affected limb.
[b] Achieved their bodyweight equivalent of force in kilograms (kg) during the MVIC test on the affected limb.

were reviewed by a second researcher (SO) to assess whether the image would be excluded. The region of tendon interest encompassed the full 8 cm segment extending proximally from the calcaneus and was analysed with a contour interval of 4 mm (20 slices) using a window size of 17. The interpolation function was used to merge the contour intervals. Tendon CSA was calculated using pixel size and echo type percentage reported as aligned fibrillar structure (AFS) (echo type I and II) and disorganised fibrillar structure (DFS) (echo type III and IV).

2.4.2. *Strength assessments*

Maximal voluntary isometric contraction (MVIC) of the plantarflexors was measured using the Fysiometer C-station (Fysiometer ApS, Denmark), a valid and reliable tool for quantifying maximal isometric plantar flexor muscle strength (O'Neill et al., 2023). For participant safety the affected limb did not complete plantarflexor strength assessments at week 0 and week 8. Initial MVIC testing of the affected limb was completed two weeks after the removal of the functional brace (Table 2).

Consistent with previous studies, MVIC testing was completed in plantargrade (O'Neill et al., 2023) (Table 2). The testing procedure followed a previously validated method for assessing plantarflexor strength, with the peak from three maximal contractions used as main outcome (O'Neill et al., 2023). Participants were seated in the C-Station with the ankle positioned in plantargrade. The foot was securely fixed to the footplate and straps were used across the thigh to ensure stabilisation. After three familiarisation trials, participants were instructed to perform three maximal voluntary isometric plantarflexion contractions with strong verbal encouragement provided throughout. A rest period of 60 s was allowed between trials to minimise fatigue. Additional to maximal force output in kilograms, MVIC was reported as a strength to bodyweight ratio (MVIC/Bodyweight). Limb Symmetry Index (LSI) was calculated as a percentage for plantarflexor MVIC ((Affected limb/Non-affected Limb) x100).

If the participant achieved their bodyweight equivalent of force in kilograms (kg) (kg force/body mass = 1) during the MVIC test of their affected side, then a calf raise test was performed (Table 2). The calf raise test was performed using the "calf raise app" following a standardised protocol (Fernandez et al., 2023). The calf raise test was performed on the unaffected side for all participants regardless of MVIC score. The single leg calf raise test for endurance was performed barefoot with the participant standing on a box with an incline of 10°. An audio player with a metronome every 2 s was used to maintain the frequency of 30 calf raises per minute. Calf raise repetition, peak height and total work was measured using the calf raise app.

2.4.3. *Patient Reported Outcomes (PROMs)*

Achilles tendon symptoms and function, health related quality of life, kinesiophobia, and anxiety and depression were measured at each time point using the questionnaires listed.

- Achilles Tendon Rupture Score (ATRS) (Nilsson-Helander et al., 2007). The ATRS consists of 10 items addressing pain, stiffness, strength, and activity limitations. Each item is scored from 0 (major limitations) to 10 (no limitations), yielding a total score ranging from 0 to 100, with higher scores indicating better function.
- EuroQol- 5 Dimension (EQ-5D-5L) (Herdman et al., 2011). The EQ-5D-5L assesses five health dimensions, each rated across five severity levels. It produces an index score from 0 to 1 and a visual analogue scale (VAS) from 0 to 100 for self-rated overall health where higher scores indicate better health.
- Tampa Scale of Kinesiophobia (TSK) (Bjelland et al., 2002; Lundberg et al., 2004). The TSK is a 17-item questionnaire measuring pain-related fear of movement. Total scores range from 17 to 68 with higher scores indicate greater fear of movement.
- Hospital Anxiety and Depression Scale (HADS) (Bjelland et al., 2002; Zigmond and Snaith, 1983). The HADS is a 14-item self-report questionnaire consisting of two 7-item subscales (anxiety and depression) with higher scores indicating greater symptom severity.

2.5. *Data analysis*

Data were analysed using SPSS (V28.0, IBM, New York, USA). Data distribution was assessed for normality using the Shapiro-Wilk test and reported as means or medians with standard deviations (SD) or interquartile ranges (IQR).

A linear regression was used to examine the relationship between assessment time point (independent variable) and AFS and DFS (dependant variables) for both limbs. We adjusted the analyses for the predefined variables age (continuous), sex (male/female) and ethnicity (white British/other ethnicity). Alpha was set at 0.05.

3. Results

A total of 112 individuals were approached to participate, 90 participants were successfully recruited with 15 different participants completing assessments at each time point. Demographic variables, Body Mass Index (BMI), waist circumference, number of comorbidities, mechanism of injury (sporting/non-sporting) and ethnicities are reported for all participants in Table 3. All participants were managed non-surgically. Time from ATR to entering the bracing protocol was under 2 weeks for all participants. The CM-LAMP protocol was used for 90 % (n = 81) of participants with the remaining participants completing the LAMP protocol. Three participants reported a previous ATR on the same side. No participants reported an ATR on the contralateral side. One participant at week 52 assessment reported contralateral Achilles pain prior to ATR.

Excluding week 0 and week 8 for safety reasons, UTC was completed at all time points for all participants. Following review from a second researcher (SO), four UTC images were excluded from analysis due to inadequate contact of the UTC system caused by an air bubble or scanner positioning (week 0 n = 1, week 16 n = 2, week 52 n = 1).

Aligned fibrillar structure (AFS) and disorganised fibrillar structure (DFS) for both limbs at each assessment point are displayed in Fig. 1. Echo type distribution percentage for non-ruptured and ruptured tendons are presented in Fig. 2. UTC outcome tables are provided in supplementary material 2.

The ruptured tendon displayed a larger CSA at all time points and CSA began to reduce from 16 weeks. CSA was 28 % lower from 10 weeks to 52 weeks in the ruptured tendon (10 weeks: 303.55 mm^2 (90.43), 52 weeks: 218.18 mm^2 (61.82)). The cross-sectional area of DFS on the affected side was 30 % lower when comparing week 10 to week 52 (Fig. 1), although the percentage of disorganised fibres remained similar (31-30 %) (Fig. 2).

For the ruptured tendon, the association between AFS and assessment time point was statistically significant ($p = 0.04$). Later assessment time points were associated with decreased AFS. The association between DFS and assessment time point was not statistically significant. For the non-affected side, the association between assessment time point and both DFS and AFS was statistically significant ($p = < 0.05$). Later assessment time points were associated with greater DFS and AFS.

MVIC score, MVIC normalised to bodyweight for both limbs, and LSI between limbs for each assessment point are displayed in Table 4. Calf raise scores for the affected and non-affected limbs are provided in Table 5. For the affected side, only 3 (26 weeks n = 2, 52 weeks n = 1) participants met the requirements to complete the calf raise test.

ATRS, EQ-5D, HADS and TSK findings are reported in Table 6.

4. Discussion

This is the first study to cross-sectionally describe the fibre distribution and strength measures in individuals with an ATR treated non-surgically across a 12-month period. This study successfully recruited from an NHS service and reflects individuals with ATR presenting to, and receiving rehabilitation in an NHS hospital trust. Participant age, gender and mechanism of injury was consistent with previous ATR studies in the UK (Briggs-Price et al., 2024; Carmont et al., 2023; Costa et al., 2020; Keene et al., 2019; Maffulli et al., 1999).

UTC imaging was performed in individuals managed non-surgically post-ATR. The greater CSA of the ruptured tendon compared with the non-affected limb at all time points indicates time-based differences in the Achilles tendon in response to the initial trauma. The difference of tendon CSA (28 %) and disorganised fibrillar structure (30 %) between the individual groups suggests that substantial remodelling may occur in the tendon. Although CSA differed between groups, disorganised echo types (III and IV) consistently accounted for approximately one third (33 %) of the ruptured Achilles tendon at each assessment point, compared with 15 % in the non-affected limb. Previous studies combining surgical and non-surgical approaches also reported a consistent echo type percentages over 3, 6 and 12-months, although CSA was not reported (Dams, 2021). The lack of echo type adaptation has been proposed to be due to poor remodelling capacity in the Achilles tendon (Dams, 2021). Nonetheless, this study identified substantial differences in CSA between the assessments post ATR, suggesting capacity for CSA change may exist.

The non-affected tendon displayed greater disorganised tissue than reported in healthy individuals in their fourth decade (de Jonge, Rozenberg et al., 2015). However, the current study included a greater number of male participants than previous UTC data. Despite high levels of disorganised echo structure in the contralateral tendon, only one participant reported symptoms. Individuals experiencing an ATR have a nearly 200-fold increased risk of a contralateral tendon rupture (Årøen et al., 2004). The increased asymptomatic collagen disruption in the non-affected limb may provide an insight to the high rates of contralateral rupture in the ATR population.

This is the first study in the ATR population to use validated, portable plantarflexor strength testing suited to the NHS outpatient clinic setting (O'Neill et al., 2023). Participants had a plantarflexor strength deficit of 33 % on the affected side at 12 months. This is greater than the deficit of

Table 3
Participant demographics, BMI, waist circumference, mechanism of injury, number of comorbidities.

Assessment Time Point		Baseline (n = 15)	Week 8 (n = 15)	Week 10 (n = 15)	Week 16 (n = 15)	Week 26 (n = 15)	Week 52 (n = 15)	Overall (n = 90)
Age -y		45.5 (16.2)	50.3 (13.2)	48.3 (17.0)	47.1 (17.6)	50.1 (14.4)	49.2 (18.2)	48.43 (15.8)
Male (%)		15 (100 %)	13 (86.7 %)	14 (93.3)	14 (93.3)	14 (93.3)	12 (80)	82 (91.1)
BMI -kg/m2		28.3 (4.0)	29.7 (4.1)	27.8 (3.9)	28.0 (3.8)	30.9 (6.0)	28.0 (3.5)	28.8 (4.3)
Waist Circumference -cm		96.3 (10.2)	101.0 (8.4)	94.8 (8.5)	94.5 (10.5)	104.8 (15.2)	97.7 (11.2)	98.2 (11.2)
MOI Sporting (%)		13 (86.7)	10 (66.7)	13 (86.7)	12 (80.0)	7 (46.7)	9 (60.0)	64 (71.1)
Number of Comorbidities - Median		0	0	1	0	1	1	1
Ethnicity (%)	White British	10 (66.7)	9 (60)	7 (46.7)	10 (66.7)	6 (40)	7 (46.7)	49 (54.4)
	Asian/British Asian	3 (20)	3 (20)	4 (26.7)	2 (13.3)	4 (26.7)	3 (20)	19 (21.1)
	Black/Black British	1 (6.7)	1 (6.7)	2 (13.3)	1 (6.7)	2 (13.3)	1 (6.7)	8 (8.9)
	White	–	2 (13.3)	1 (6.7)	1 (6.7)	3 (20)	4 (26.7)	11 (12.2)
	Chinese	1 (6.7)	–	1 (6.7)	1 (6.7)	–	–	3 (3.3)

n = 15 at each assessment time point. Values are given as mean and standard deviation.
Abbreviations: MOI = mechanism of Injury.

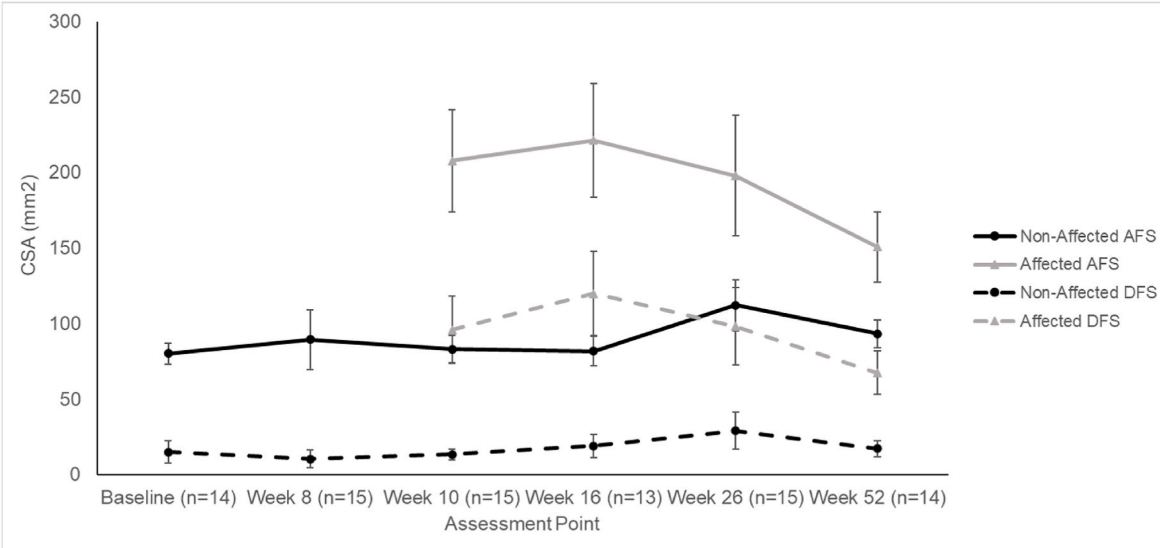


Fig. 1. Cross-sectional area of aligned and disorganised fibres between groups.

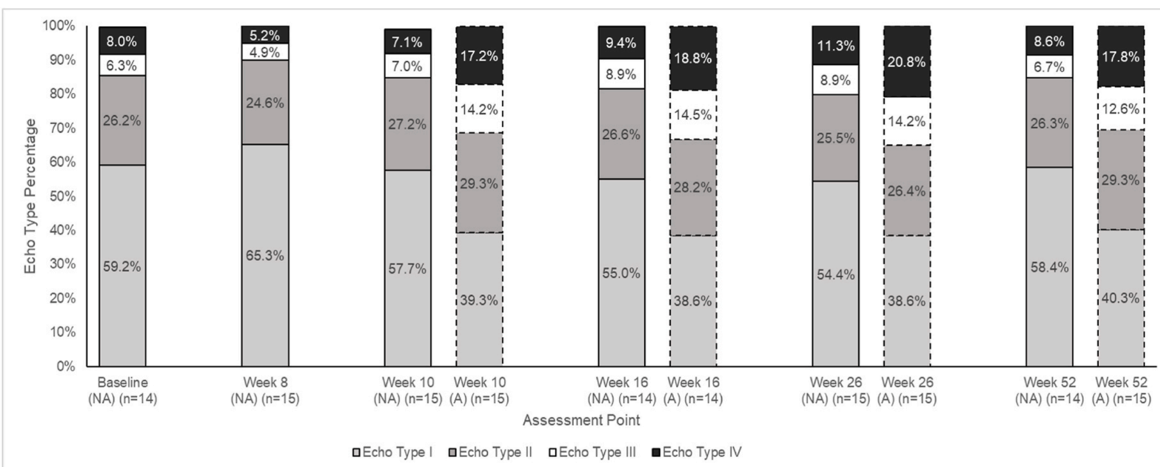


Fig. 2. Ultrasound Tissue Characterisation Echo Type Distribution expressed in Percentages in the Non-Affected (solid bars) and Affected (hashed bars) Limbs. Echo Type I: Highly Stable; Echo Type II: Medium Stable; Echo Type III: Highly Variable; Echo Type IV: Constantly Low Intensity and Variable Distribution.

Table 4
Isometric plantarflexor strength scores.

Assessment Time Point	Non-Affected Force - kg	Affected Force -kg	Mean Difference (95 %CI)	Non-Affected Force Normalised -/BW	Affected Force Normalised -/BW	Mean Difference (95 %CI)	LSI - %
Baseline (n = 14)	96.8 (44.3)			1.1 (0.5)			
Week 8 (n = 15)	91.4 (31.0)			1.0 (0.4)			
Week 10 (n = 15)	95.2 (28.35)	37.1 (12.8)	58.1 (45.1, 71.2)	1.1 (0.4)	0.4 (0.1)	0.7 (0.5, 0.9)	40.7 (10.9)
Week 16 (n = 15)	107.2 (21.0)	51.8 (12.3)	55.4 (44.8, 65.9)	1.2 (0.3)	0.6 (0.2)	0.6 (0.5, 0.8)	49.2 (12.1)
Week 26 (n = 15)	79.0 (27.9)	50.8 (27.6)	28.2 (20.1, 36.3)	0.9 (0.4)	0.6 (0.3)	0.3 (0.2, 0.4)	63.1 (16.9)
Week 52 (n = 15)	93.3 (29.5)	61.3 (20.7)	32.0 (21.8, 42.2)	1.1 (0.3)	0.7 (0.2)	0.4 (0.3,0.5)	66.8 (13.7)

n = 15 at each assessment time point. Values are given as mean and standard deviation.
Abbreviations BW = bodyweight. LSI=Limb Symmetry Index between limb isometric plantarflexor strength.

16–21 % reported by Lantto et al. (2016) following cast and Vacoped management. However, alternative strength testing protocols and assessment time points may explain the different findings. At 24 month follow up, Fischer et al. (2021) reported a full return of plantarflexor strength in the ruptured limb on seated isokinetic testing following cast and Vacoped boot management. The replicability of Fischer's (2021) strength testing protocol is limited due to insufficient detail in the report, and the absence of test re-test reliability data limits its application. Neither Lantto (2016) or Fischer et al. (2021) normalised strength data to bodyweight and Fischer (2021) did not report bodyweight preventing a retrospective comparison. As plantarflexor force is used to propel bodyweight in functional movements, normalising strength outcomes to bodyweight will identify the individual's relative strength. The lack of consistency in outcomes in ATR studies has been identified (Spennacchio et al., 2016). In comparison to isokinetic dynamometry, the testing protocol in this study required less time and

Table 5
Calf raise scores test metrics.

Assessment Time Point	Non-Affected Reps	Non-Affected Total Work	Non-Affected Peak Height	Affected Reps	Affected Total Work	Affected Peak Height
Week 10	21.8 (7.9)	1116.2 (531.0)	8.1 (2.4)			
Week 16	22.1 (6.1)	1186.0 (390.0)	7.9 (2.2)			
Week 26	21.2 (7.5)	1145.1 (489.0)	8.2 (2.8)	14.5 (0.7)	634.7 (37.1)	6.3 (0.5)
Week 52	28.2 (15.0)	1294.8 (818.2)	7.1 (1.8)	25	1161.0	5.69

Values are given as mean and standard deviation. Non-affected calf raises week 10 n = 15, week 16 n = 14, week 26 n = 14, week 52 n = 14. Affected calf raises week 26 n = 2, week 52 n = 1.

Table 6
ATRS, EQ-5D, HADS, TSK outcomes.

Assessment Time Point	ATRS	EQ-5D Index	EQ-5D VAS	HADS A	HADS D	TSK
Baseline	29.3 (28.8)	0.37 (0.3)	59.1 (32.9)	8.7 (3.2)	6.6 (3.7)	42.9 (4.8)
Week 8	28.7 (24.3)	0.62 (0.3)	60.0 (26.7)	5.6 (3.1)	4.6 (2.6)	39.7 (6.8)
Week 10	33.3 (16.2)	0.71 (0.2)	67.0 (25.7)	5.1 (4.0)	3.9 (3.5)	37.4 (8.3)
Week 16	42.2 (20.3)	0.80 (0.1)	67.0 (27.2)	3.7 (3.7)	3.7 (3.3)	36.5 (7.6)
Week 26	60 (20.9)	0.84 (0.2)	77.8 (23.2)	4.9 (4.2)	3.5 (3.2)	32.1 (7.3)
Week 52	75.1 (16.5)	0.91 (0.1)	75.0 (23.0)	5.2 (3.3)	3.2 (1.8)	34.7 (4.8)

n = 15 at each assessment time point. Values are given as mean and standard deviation.
Abbreviations: ATRS=Achilles tendon rupture score, EQ-5D = EuroQol-5 Dimension, HADS A = Hospital anxiety and depression score anxiety subscale, HADS D = Hospital anxiety and depression score depression subscale, TSK=Tampa scale for kinesiophobia.

used portable equipment with established reliability and strength metrics (O'Neill et al., 2023). Future studies should consider validated strength testing protocols (test position, bodyweight correction and contraction modes) to provide greater comparison between studies.

ATRS values at 12 months were consistent with previous cast and functional bracing protocols in the NHS (Aujla et al., 2019; Costa et al., 2020; Hutchison et al., 2015). Previous UK studies have found ATRS scores plateau between 70 and 75 around 9 months (Costa et al., 2020; Hutchison et al., 2015) and 23 months (Aujla et al., 2019). It is suspected that the limited ATRS progression is due to individuals not returning to the final criteria of running, jumping and hard physical labour. The strength deficit found in this study may identify why individuals have difficulties with activities requiring greater physical exertion. Alternatively, kinesiophobia has been shown to relate to physical activity expectations including time to run on even ground following ATR (Slagers et al., 2021). In this study, participants continue to meet the medium/moderate threshold for kinesiophobia at 12 months (Alghamdi et al., 2021; Chimenti et al., 2021). However, when considering psychological wellbeing through the HADS, only anxiety met the stated threshold at the initial assessment (Zigmond and Snaith, 1983). This indicates that the population experience movement related fear that does not significantly impact overall anxiety and depression. Qualitative investigations are needed to investigate the factors influencing kinesiophobia, anxiety and the impact on returning to activity.

4.1. Study limitations

A cross-sectional design and limited sample size restrict the ability to understand the relationship between the outcomes measured. In addition, conducting inferential analysis with a limited sample may increase the risk of type two error. A longitudinal design with a larger sample will allow the trajectory of recovery post ATR to be understood and provide a more robust understanding of the relationship between outcomes.

Another limitation was the requirements placed on participants to complete the calf raise test. As the first study implementing this strength testing procedure, the MVIC strength requirements were selected for participant safety. Given that only three participants met these requirements, they may have been too restrictive. However, the inclusion of MVIC testing allowed an earlier insight into strength recovery post ATR. Future studies should consider implementing the calf raise test based on time post ATR in addition to MVIC strength requirements.

5. Conclusion

Substantial tendon remodelling may occur during the initial 12 months post ATR, with CSA 28 % and DFS 30 % higher at week 10 compared to week 52. Despite this, disorganised echo types consistently accounted for around one third of the ruptured Achilles tendon at each assessment point, compared with 15 % in the non-affected limb. There is persistence of fibrillar disorganisation, isometric plantarflexor weakness, and reduced function in individuals at 12 months. Larger longitudinal studies are needed to understand the trajectory of recovery and the relationship between tendon structure, strength and PROMs.

CRediT authorship contribution statement

Samuel Briggs-Price: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Tom Yates:** Writing – review & editing, Supervision, Conceptualization. **Jitendra Mangwani:** Writing – review & editing, Supervision, Conceptualization. **Maneesh Bhatia:** Writing – review & editing, Supervision, Conceptualization. **Annette Jones:** Writing – review & editing, Data curation. **Klaudia Mielcarek:** Writing – review & editing, Data curation. **Amy Solaini:** Writing – review & editing, Data curation. **Shing Yan Leung:** Writing – review & editing, Data curation. **Karin Gravare Silbernagel:** Writing – review & editing, Supervision, Conceptualization. **Kim Hebert-Losier:** Writing – review & editing, Supervision, Conceptualization. **Robert-Jan de Vos:** Writing – review & editing, Supervision, Conceptualization. **Neal L. Millar:** Writing – review & editing, Supervision, Conceptualization. **Bill Vicenzino:** Writing – review & editing, Supervision, Conceptualization. **Seth O'Neill:** Writing – review & editing, Supervision, Data curation, Conceptualization.

Ethics approval

This study was granted ethical approval by Hampstead Research Ethics Committee (22/PR/1672).

Availability of data and material

All relevant data are available at 10.25392/leicester.data.28815491.

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This study was completed as part of a PhD programme.

Competing interests

The authors declare that they have no competing interests. One of the authors (KHL) is the developer of the free-to-use Calf Raise application. The data for this study were obtained from independent researchers (SBP, AJ, KM, SO) not related to the development of the Calf Raise application.

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Appendix A. Supplementary data

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