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Review

Can we really say getting stronger makes your tendon feel better? No current evidence of a relationship between change in Achilles tendinopathy pain or disability and changes in Triceps Surae structure or function when completing rehabilitation: A systematic review

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ABSTRACT

Objectives: Determine if improvements in pain and disability in patients with mid-portion Achilles tendinopathy relate to changes in muscle structure and function whilst completing exercise rehabilitation.
Design: A systematic review exploring the relationship between changes in pain/disability and muscle structure/function over time, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.
Methods: Six online databases and the grey literature were searched from database inception to 16th December 2022 whereas clinical trial registries were searched from database inception to 11th February 2020. We included clinical studies where participants received exercise rehabilitation (±placebo interventions) for mid-portion Achilles tendinopathy if pain/disability *and* Triceps Surae structure/function were measured. We calculated Cohen's d (95 % confidence intervals) for changes in muscle structure/function over time for individual studies. Data were not pooled due to heterogeneity. Study quality was assessed using a modified Newcastle–Ottawa Scale.
Results: Seventeen studies were included for synthesis. No studies reported the relationship between muscle structure/function and pain/disability changes. Twelve studies reported muscle structure/function outcome measures at baseline and at least one follow-up time-point. Three studies reported improvements in force output after treatment; eight studies demonstrated no change in structure or function; one study did not provide a variation measure, precluding within group change over time calculation. All studies were low quality.
Conclusions: No studies explored the relationship between changes in tendon pain and disability and changes in muscle structure and function. It is unclear whether current exercise-based rehabilitation protocols for mid-portion Achilles tendinopathy improve muscle structure or function.
Systematic review registration: PROSPERO (registration number: CRD42020149970).

Practical implications

- It is unclear whether current exercise rehabilitation protocols in Achilles tendinopathy improve muscle structure and/or function.
- Caution should be taken if advising patients that exercise rehabilitation for Achilles tendinopathy is effective by virtue of improvements in muscle structure or function.

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- There was a lack of data available from completed trials, and a potential influence of measurement error on our results leading to a lack on confidence in any data reported by included studies.

1. Introduction

Loading protocols are considered standard care for managing Achilles tendinopathy and involve targeted exercise rehabilitation of the Triceps Surae to improve structure and function.[1] Different loading protocols exist for treating the symptoms and improving function in this condition (e.g. heavy eccentric calf training or heavy slow resistance training).[2] No programme appears superior to others for improvements in pain and disability, and the mechanisms underpinning the efficacy of these interventions remain unknown.[2]

What causes tendon pain is unclear, as are the mechanisms responsible for clinical improvement with loading protocols.[3] Improvement in pain and/or disability when completing loading protocols in the presence of tendinopathy may be related to improvements in muscle structure and function[4,5] and it is a common clinical belief that improvements in muscle strength will reduce Achilles tendon pain.[6] However, the role of strength as a moderator to pain and disability for common musculoskeletal conditions, such as hip and knee osteoarthritis is lacking.[7] Furthermore, interventions that have minimal impact on muscle structure and function (e.g. shock wave therapy or shoe heel raise inserts) are as effective for pain and disability as loading protocols in Achilles tendinopathy,[8,9] suggesting other mechanisms may improve symptoms. Improvement of symptoms has been observed within four weeks of commencing a loading programme (likely before muscle structure adapts[1]), which supports a hypothesis that other mechanisms contribute to clinical improvements in pain and disability.

Improvements in Triceps Surae structure and function may act as a stress shield to the Achilles tendon and contribute to improvements in symptoms of mid-portion Achilles tendinopathy.[5] However, current loading protocols, such as heavy eccentric calf training, do not conform to guidelines that would maximise Triceps Surae function.[4,10] Contributors to the overall function of the Triceps Surae include muscle structure, strength, endurance and power production (elements that can be measured in different ways).[11,12] Muscle structure is a measure of the size and architecture of the Triceps Surae and can positively relate to force production through absolute cross-sectional area[13] and arrangement of the muscle fibres.[14] Strength is a measure of maximal force output, endurance is a measure of the capacity to perform repeated tasks at a submaximal level for a large number of repetitions and power production is the ability to produce force rapidly.[12,15]

We wanted to answer the simple clinical query of whether changes in muscle structure/function relate to changes in Achilles tendon pain/disability whilst performing exercise rehabilitation, which we aimed to investigate with two research questions:

1. Are improvements in Triceps Surae muscle structure and function associated with an improvement in mid-portion Achilles tendinopathy pain and/or disability?
2. How effective are rehabilitation protocols for improving Triceps Surae structure and function in people with mid-portion Achilles tendinopathy (in the context of changes in pain and/or disability)?

2. Methods

Reporting of this systematic review exploring the relationship between changes in pain/disability and muscle structure/function over time was guided by the PRISMA recommendations.[16] The review protocol was prospectively registered (PROSPERO registration number: CRD42020149970) with existing literature, and relevant PROSPERO registrations screened to ensure no existing review had been conducted, or was being conducted.

We included studies of humans aged 18 years and over, who had a diagnosis of mid-portion Achilles tendinopathy. Mid-portion tendinopathy affects the body of the tendon approximately 2–7 cm proximal to the insertion (depending on the length of an individual's Achilles tendon) whereas insertional tendinopathy occurs near the tendon insertion onto the calcaneus.[17] The two presentations are distinct clinical entities.[17,18] Studies that did not state whether the included population was mid-portion or insertional were included. Studies where the population was mixed (i.e. mid-portion and insertional Achilles tendinopathy) were included if the majority of participants had mid-portion Achilles tendinopathy. We contacted authors and requested the data from participants with mid-portion Achilles tendinopathy. Studies that predominantly included insertional tendinopathy (e.g. insertional only) were excluded. Studies that included participants with other causes of heel pain were excluded.

Intervention studies using loading protocols were included. If the loading protocol intervention was combined with additional intervention(s) (e.g. laser or education), we excluded the treatment arm that received the additional intervention. If the loading protocol was combined with a sham intervention (e.g. sham laser), we included the treatment arm that received the sham intervention.

We included studies with self-reported measures of pain with loading, pain over a specified time-frame and disability.[19,20] Therefore, measures that only assessed pain without function or over time were excluded. For example, studies that only reported pain with palpation measured on a visual analogue scale were excluded.

Muscle structure was defined as the size and architectural properties of the Triceps Surae and any outcome measures that could assess this were included. Muscle function was broadly categorised as including strength, endurance, power production and/or plyometric capacity so any outcome measures assessing these elements were included.

Randomised and non-randomised intervention studies, cohort studies and case series were included if (i) at least one study arm used a loading protocol to treat mid-portion Achilles tendinopathy, and (ii) measured pain (with loading or pain over a specified timeframe) or disability, and (iii) any outcome measure of muscle structure or function was assessed at baseline and follow-up. Only the eligible arm(s) of multi-arm trials were included and subsequently treated as an individual cohort study for the purposes of this systematic review. Studies were included regardless of their publication status, provided they were complete and had data available. Reviews were excluded. We translated one study to English for screening and no other studies required translation.

Search strategies using free text terms (Appendix A) were implemented within electronic databases (PubMed, OVID (Medline), CINAHL (EBSCO), Cochrane Library, Web of Science and SPORTDiscus) from inception to 16th December 2022. We searched electronic databases of the grey literature (Proquest and OpenGrey) and clinical trial registries (Australia and New Zealand clinical trial registry, clinicaltrials.gov and the World Health Organization International Clinical Trials Registry Platform) from inception to 11 February 2020. Reference lists of reviews and retrieved articles were checked for additional studies missed in the electronic database search. The ePublication lists of key journals in the field (i.e., journals with included studies) were screened to identify studies yet to be indexed.

Records were exported to reference management software, EndNote 20, and Covidence. Duplicates were removed. Two review authors (MM and MT) independently screened the titles and abstracts of potentially eligible records. If it was unclear from the title and abstract whether an article met the inclusion criteria, the full text was obtained and screened. Disagreements were resolved by consensus or a third review author (WG) if consensus could not be reached. Studies were not anonymised prior to assessment.

Corresponding authors of study protocols, trial registrations or conference abstracts were contacted to determine if the study was completed, and subsequently request access to the final dataset/publication. Corresponding authors were also contacted in the event two studies

appeared similar, to determine if the publications represented a single trial.

Two review authors (MM and MT) independently assessed study quality for each study using a modified version (Appendix B) of the Newcastle–Ottawa Scale. Each domain of the scale was judged as low quality, unclear quality or high quality.[21] The scale was modified given no tool exists for assessing study quality in correlation studies. We pilot tested our modified Newcastle–Ottawa scale prior to using it in the systematic review. Disagreements were resolved by consensus or a third review author (WG) if consensus could not be reached.

The overall quality judgement for each study was assigned based on the lowest study quality criterion from all domains. Studies were classified as unclear for attrition bias if they did not state how many people had completed the assessment of muscle structure and function at all time points. To be high quality due to measurement error, studies had to determine reliability of the muscle structure and function outcome measures for the participants with mid-portion Achilles tendinopathy, and use either a validated tool or the gold standard assessment tool. We assessed study quality for comparative studies by treating each arm of a randomised trial as a separate cohort.

Studies with sample sizes fewer than 50 were considered at high risk of small study bias, studies with samples between 50 and 200 were considered at moderate risk of small study bias and studies with sample sizes greater than 200 were considered at low risk of small study bias.[22,23]

We considered the influence of small study biases and methodological quality on the outcomes reported by included studies. Studies at high risk of small study bias and of low quality were considered unlikely to represent a true within group change over time, whereas studies with low risk of small study bias and high quality were considered to likely represent a true within group change over time.

Two review authors (MM and MT) independently extracted data from all included studies using Microsoft Excel. Discrepancies were resolved by consensus. The following data items were extracted: primary author, year of publication, study design (including study affiliation, funding information and study sponsor), study population (diagnosis, diagnostic criteria and whether imaging was used), sample size (including sample size at baseline and final follow-up point), baseline demographics (mean (SD) age, height, weight, BMI, gender and duration of pain), loading intervention, 12 items of the TIDieR checklist,[24] follow-up time points for both short-term (<4 weeks) and longer-term (>4 weeks) follow-ups and mean, standard deviation, sample size and statistical relationship (correlation and/or crude or adjusted odds/risk ratios) between the change in pain and/or disability and the change in the measure of muscle structure or function from baseline to follow-up within four weeks of the intervention (short-term follow-up) and baseline to all follow-up points whilst completing the intervention > four weeks (long-term follow-up).

Where the mean (SD) for measures of muscle structure and function was not available the corresponding author was contacted to provide these data.

As no study provided the data necessary for a meta-analysis of correlation, no synthesis was possible for Objective One. Due to substantial differences in the loading protocols performed, and the methods used to assess muscle structure and function, the data for longitudinal changes in muscle structure and function (Objective Two) were not pooled and are instead described using a qualitative synthesis.

Demographic data for all studies were presented as count, mean and standard deviation (or the non-parametric equivalent). The results of the individual studies are presented with muscle structure and function outcomes grouped under the assessment type (e.g. isometric versus isokinetic dynamometry). The magnitude of change from baseline is provided by 'Cohen's d' and 95 % confidence intervals (95 % CI) for the within group change for muscle structure and function were also calculated using https://www.psychometrica.de/effect_size.html. The data used from this review are available via the full-text of included studies excluding the study by Van der Vlist which was provided upon request and not publicly available.

We planned a meta-analysis of correlation using the Hunter–Schmidt method in R to determine the population effect ($\bar{r}$).[25,26] However, due to an absence of appropriate data, meta-analysis was precluded. We planned to evaluate statistical heterogeneity using I^2 with substantial statistical heterogeneity being classified as $P < 0.10$.[27] Additionally, we planned to assess funnel plots for each correlation of interest. Assessment of heterogeneity and funnel plots were not undertaken due to the lack of meta-analysis and small numbers of studies (<10 studies per outcome domain) for each outcome domain.

To account for bias, we planned sensitivity analyses of studies that used a combined loading protocol and sham intervention[8,28–34] as well as studies that did not clearly define the tendinopathy diagnosis (i.e. midportion or insertional).[28,35–37] However, given the absence of appropriate data, we were unable to conduct this.

3. Results

4538 records were identified, and 36 records, representing 29 trials, met the selection criteria (Fig. 1, Appendix C). Appendix C summarises how duplicate studies and trial registries were managed.[38] Appendix D summarises the study information. Seventeen completed studies, inclusive of 25 cohorts, had data available for extraction and synthesis.[8,28–37,39–42]

Demographic information is provided in Table 1. All studies provided some measure of muscle structure and function. Three studies performed isometric dynamometry of ankle plantarflexion force output.[34,35,43] Six studies performed isokinetic dynamometry of ankle plantarflexion force output.[33,36,39–42] Six studies assessed the heel-raise capacity.[8,28–30,32,44] Two studies assessed jump capacity.[32,42] One study used ultrasound to assess gastrocnemius fascicle length, pennation angle and thickness[31]; one study used shear wave elastography to measure tissue elasticity.[37] All 17 studies reported that clinical diagnosis was used to establish participants had mid-portion Achilles tendinopathy. However, the reporting quality of diagnostic criteria varied.

Studies had large amounts of missing data relating to the reporting of descriptive data for baseline and follow-up outcomes for muscle structure and function. Nine studies did not report outcomes at all follow-up periods.[28–31,33,36,37,39,41] No studies analysed correlations.[8,28–37,39–42]

Across the 17 trials, representing 25 cohorts, there were 432 participants with a mean (SD) age ranging from 20.1 (1.8) to 55 (6.5) years. Twenty-two of the cohorts reported the proportion of females included, which varied from 0 % to 86 % with seven cohorts not including any females.[29,42,43] Sixteen cohorts reported BMI with the mean BMI ranging from 21.5 to 31.1.[8,29,32,34,35,37,41–44]

All studies were assessed as being overall of low quality (Appendix E).[8,28–37,39–44] No studies analysed correlations or controlled for major confounders. One study adjusted the primary analysis (i.e. age, sex, BMI and duration of symptoms).[34] Two studies were high quality in relation to measurement bias (13 %).[39,40] All cohorts had a sample size of 50 or fewer and a high risk of small study bias.[8,28–37,39–44]

No studies reported the relationship between changes in pain and disability and changes in muscle structure and function when completing exercise rehabilitation.[8,28–37,39–44]

All studies reported significant within-group improvement in either pain or disability following exercise rehabilitation.[8,28–37,39–44]

Two studies (n = 53), representing three cohorts, assessed muscle structure using either greyscale ultrasound or shear wave elastography (Appendix F).[31,37] Neither study had significant within group change over time (Appendix G). However, based on small sample sizes, and low-quality studies it is currently unclear whether current rehabilitation protocols result in changes to ankle plantar flexor muscle structure.

Three studies (n = 51), representing six cohorts, investigated isometric ankle plantar flexion joint torque (Appendix H).[34,35,43] One of the six cohorts had significant within group change over time

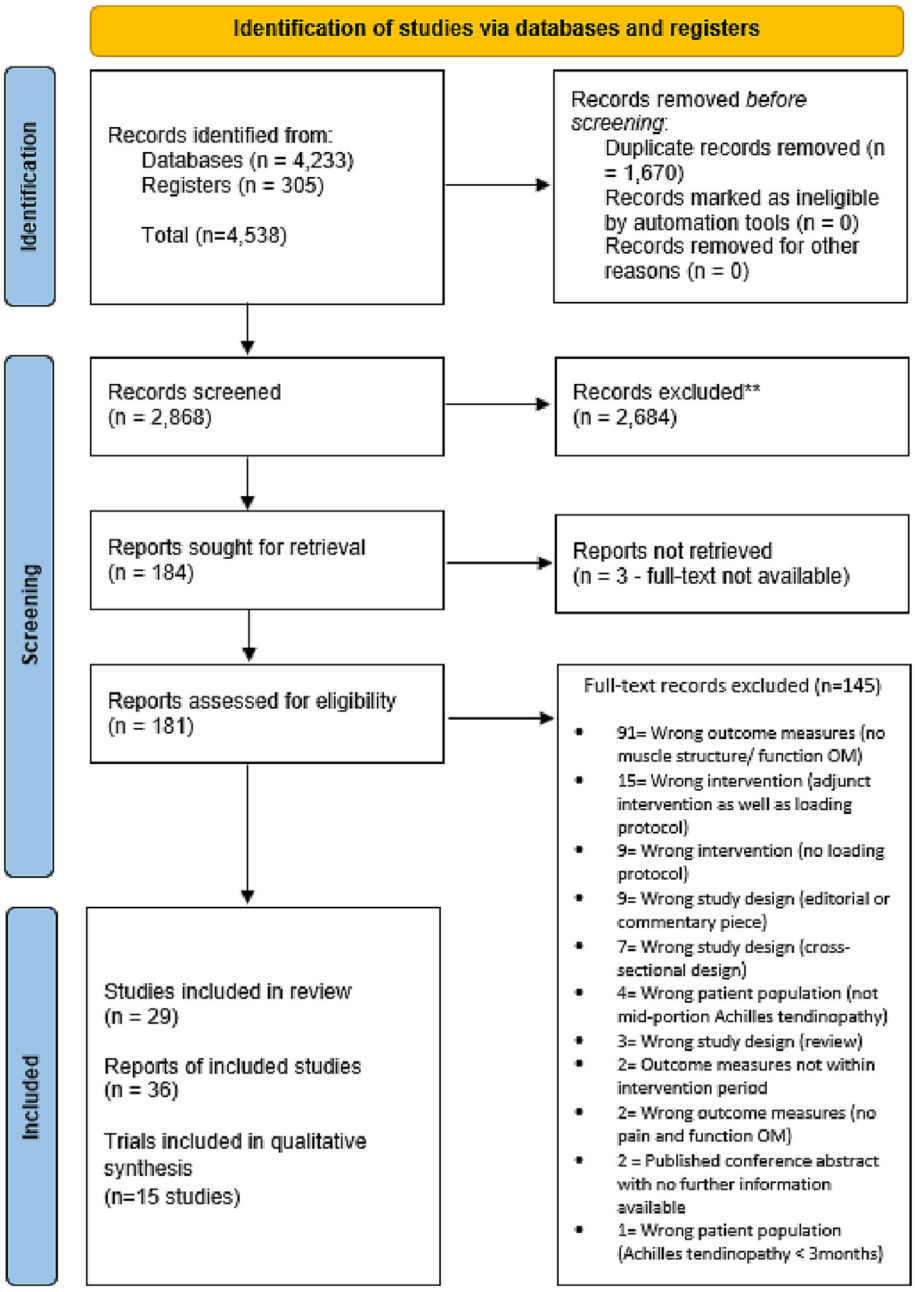

Fig. 1. PRISMA flow chart.

(Appendix G). However, based on small sample sizes, and low-quality studies it is currently unclear whether current rehabilitation protocols result in changes to isometric ankle plantar flexion joint torque.

Six studies, representing eight cohorts, investigated plantar flexion joint torque using isokinetic dynamometry at varied speeds and assessment procedures (Appendix I).[33,36,39–42] Three studies did not supply any data on follow-up isokinetic dynamometry scores following their loading intervention[36,39,41] and one study supplied mean values but no measure of variance.[33] Two studies with data[40,42] demonstrated conflicting results with one study showing improvement in plantar flexor joint torque[42] and the other showing no change[40] following rehabilitation (Appendix G). However, based on small sample sizes, and low-quality studies it is currently unclear whether current rehabilitation protocols result in changes to isokinetic ankle plantar flexion joint torque.

Six studies, representing eight cohorts, investigated performance of the heel raise capacity (Table 2).[8,28–30,32,44] Two studies did not supply any data on follow-up heel raise test scores following their loading intervention.[29,30] One study, representing two cohorts, did not assess heel raise capacity on the affected side only but instead split to left/right leg.[44] One cohort (n = 12), had significant improvements in the left leg only at 12 weeks, with no improvements, in any leg demonstrated at the six-week follow-up in either cohort.[44] None of the remaining three studies with data (n = 135) had significant within group change over time within the affected limb (Appendix G). However, based on small sample sizes, and low-quality studies it is currently unclear whether current rehabilitation protocols result in changes to heel raise capacity.

Two studies, representing four cohorts, investigated plyometric performance (Appendix J).[32,42] The two studies demonstrated conflicting results: one study reported improvement in plyometric performance[42] and the other reported no change[32] (Appendix G). However, based on small sample sizes, and low-quality studies it is currently unclear whether current rehabilitation protocols result in changes to plyometric performance.

Table 1
Study characteristics.

Study	Year	Exercise intervention	Adjuncts (e.g. placebo)	Sample size, n	Female, sex %	Mean (SD) age, years	Mean (SD) height, cm	Mean (SD) weight, kg	Mean (SD) BMI, kg/m^2	Mean (SD) duration of symptoms, months	Intervention adherence (%)
Alfredson[40]	1998	Eccentric	No	15	20 %	44.3 (7)	Not reported	Not reported	Not reported	18.3 (not reported)	Not reported
Alfredson[39]	1999	Eccentric	No	14	13 %	44.2 (7.1)	Not reported	Not reported	Not reported	17.8 (not reported)	Not reported
Astrom[28a]	1992	Eccentric	Yes	33	24 %	35 (not reported)	Not reported	Not reported	Not reported	2 (0.75)	Not reported
Boesen[29]	2017	Eccentric	Yes	20	0 %	40.9 (6.6)	183.5 (20.4)	89.7 (22.1)	26.6 (not reported)	7.7 (9.35)	70 % performed >75 % of intervention
Brown[30]	2006	Eccentric	Yes	26	39 %	46.3 (Not reported)	175 (not reported)	81.5 (not reported)	26.6 (not reported)	10.9 (not reported)	Not reported
Crill[31]	2014	Eccentric	Yes	25	Not reported	53.3 (17.5)	Not reported	Not reported	Not reported	Not reported	Not reported
Hasani	2021	Isotonic: High repetition, high time-under-tension	No	12	0 %	42.0 (11.4)	177.8 (6.2)	89.0 (17.9)	28.0 (4.6)	11.0 (39.0)	58 %
		Isotonic: High repetition, low time-under-tension	No	12	0 %	43.0 (11.3)	176.6 (10.3)	97.0 (18.1)	31.1 (5.3)	54.0 (83.0)	49 %
		Isotonic: Low repetition, high time-under-tension	No	12	0 %	41.6 (7.2)	178.1 (8.2)	84.6 (17.1)	26.6 (4.4)	18.0 (30.0)	58 %
		Isotonic: Low repetition, low time-under-tension	No	12	0 %	46.3 (11.9)	175.0 (8.2)	94.5 (13.7)	30.6 (6.4)	12.0 (36.0)	68 %
Horstmann[41]	2013	Eccentric	No	19	47 %	45.7 (8.5)	173.3 (8.9)	74.5 (10.3)	24.8 (2.7)	Not reported	100 %
Gatz[37a]	2020	Eccentric	No	15	60 %	55 (6.5)	174 (9.6)	76.4 (14.7)	25 (3.5)	32 (28.15)	100 % for 4 weeks, 50 % afterwards.
	2020	Eccentric and Isometric	No	15	66 %	47 (16.1)	177 (9.16)	75.7 (12.1)	25 (2.27)	23 (19.4)	100 % for 4 weeks, 50 % afterwards.
Masood[35a]	2014	Eccentric	No	10	30 %	27.9 (4)	175.5 (5)	66.5 (5)	21.6 (not reported)	10.4 (8)	81 %
Niesen-Vertommen[36a]	1992	Eccentric	No	8	50 %	31 (2.6)	Not reported	Not reported	Not reported	3.7 (not reported)	Not reported
	1992	Concentric	No	9	33 %	28.7 (3.2)	Not reported	Not reported	Not reported	3.6 (not reported)	Not reported
Rabusin[8]	2020	Eccentric	Yes	50	52 %	45.6 (9.8)	172.6 (10.7)	89.9 (22)	28.8 (not reported)	22.5 (not reported)	60–79 %
Ryan[44]	2022	Eccentric	No	14	50 %	45 (9.4)	173 (8,7)	76 (10.7)	25.4 (3.3)	14 (16.2)	79.5 %
		Eccentric	No	16	50 %	41.5 (8.2)	176 (9.5)	80 (15.8)	25.9 (5.1)	10 (7.2)	72.0 %
Silbernagel[32]	2007	Silbernagel Protocol A	Yes	19	37 %	44 (8.8)	179 (9)	80.7 (15)	25.2 (not reported)	48 (84.5)	Not reported
	2007	Silbernagel Protocol B	No	19	58 %	48 (6.8)	177 (8)	78.7 (11.6)	25.1 (not reported)	24.4 (40.8)	Not reported
Tumilty[33]	2008	Eccentric	Yes	10	40 %	42.5 (8.5)	Not reported	Not reported	Not reported	Not reported	Not reported
Van der Vlist[34]	2020	Progressive	Yes	41	46 %	48.9 (9.9)	Not reported	Not reported	27.6 (5.1)	Not reported	72 %
Yu[42]	2013	Concentric	No	16	0 %	20.4 (1.3)	172.5 (2)	64.3 (6.4)	21.5 (not reported)	12.1 (1.3)	Not reported
	2013	Eccentric	No	16	0 %	20.1 (1.8)	171.1 (3.2)	63.5 (4.5)	21.7 (not reported)	11.3 (2.9)	Not reported

Legend: n = number, SD = standard deviation, cm = centimetre, kg = kilogrammes, BMI = body mass index, kg/m^2 = kilogrammes per metres squared.
[a] Participants were defined as 'Achilles tendinopathy' or included a portion of insertional tendinopathy patients.

4. Discussion

Loading protocols are prescribed for mid-portion Achilles tendinopathy as standard care.[1] One rationale for prescribing loading protocols is to improve the structure and function of the Triceps Surae muscle, thus shielding the Achilles tendon and improve symptoms via modulation of aggravating loads.[5] Due to the small number of studies, sample size, quality of reporting and low overall quality of included studies, it is not possible to conclude whether loading protocols do or do not impact muscle structure and function as the results presented within this study are unlikely to represent the true within group change over time.

Only four of twenty-five cohorts reported a significant change in within-group effect sizes over time, with one of those studies including uninjured limbs[44] and all studies were classified as low quality. Excluding Ryan et al.[44], the two studies to show improvements in muscle function were performed in an exclusively male population[42,43] with one cohort being substantially younger than other studies.[42] The jump test used by Yu et al.[42] is also less likely to be as specific to the stretch-shortening cycle of the Achilles tendon as the jump tests used by Silbernagel et al.[32] and may explain some of these differences in results.

The results of this systematic review are unable to support a strong relationship between improvements in muscle structure/function and tendon pain/disability given no studies have currently investigated this outcome. This outcome was surprising given the clinical dogma that muscular adaptation is, in part, responsible for clinical improvements in pain and/or disability within tendinopathy patients.[6] Our results challenge current thinking related to the mechanisms underpinning improvements in patients with tendinopathy who are completing rehabilitation and highlight the need of future research to explore this relationship.[5] Furthermore, this review has highlighted the lack of conclusive evidence that current rehabilitation protocols are effective at changing participants muscle structure and function over time.

Table 2
Intervention outcomes on heel raise capacity.

Study	Year	Exercise intervention	Outcome measure	Baseline mean (SD), n	0–4 weeks mean (SD), n [Cohen's d (95 % CI)]	5–8 weeks mean (SD), n [Cohen's d (95 % CI)]	9–16 weeks mean (SD), n [Cohen's d (95 % CI)]
Astrom[28]	1992	Eccentric	Repetitions to failure	28 (18), 33	36 (20), 33 [0.42 (−0.07 to 0.91)]	Not reported	Not reported
Boesen[29]	2017	Eccentric	Total work	Not reported	Not assessed	Not reported	Not reported
Brown[30]	2006	Eccentric	Repetitions to pain	Not reported	Not assessed	Not reported	Not reported
Rabusin[8]	2020	Eccentric	Repetitions to failure	17.9 (11.2), 50	Not assessed	Not assessed	21.6 (10.3), 40 [0.34 (−0.08 to 0.76)]
Ryan[44]	2022	Eccentric Cohort A	Repetitions to failure	Left: 20.8 (8.7), 14 Right: 22.6 (8.2), 14	Not assessed	Left: 25.0 (8.8), 12 [0.48 (−0.30 to 1.26)] Right: 24.8 (9.5), 12 [0.25 (−0.52 to 1.02)]	Left: 28.8 (11.6), 12 [0.79 (−0.01 to 1.59)] Right: 28.7 (10.6), 12 [0.65 (−0.14 to 1.44)]
		Eccentric Cohort B	Repetitions to failure	Left: 25.9 (11.9), 16 Right: 25.3 (10.6), 16	Not assessed	Left: 30.2 (15.5), 12 [0.32 (−0.44 to 1.07)] Right: 28.7 (10.9), 12 [0.32 (−0.44 to 1.07)]	**Left: 38.2 (18.1), 12 [0.83 (0.05 to 1.61)]** Right: 33.9 (14.6), 12 [−0.08 to 1.46]
Silbernagel[32]	2007	Silbernagel Protocol A	Concentric power	227 (90), 26	Not assessed	251 (117), 26 [0.23 (−0.32 to 0.78)]	244 (99), 25 [0.18 (−0.37 to 0.73)]
			Eccentric–concentric power	313 (126), 26	Not assessed	350 (157), 26 [0.26 (−0.29 to 0.81)]	393 (178), 25 [0.52 (−0.04 to 1.08)]
			Total work, J	1909 (942), 25	Not assessed	2427 (1154), 23 [0.49 (−0.08 to 1.07)]	2445 (1228), 25 [0.49 (−0.07 to 1.05)]
		Silbernagel Protocol B	Concentric force	202 (108), 25	Not assessed	205 (93), 23 [0.03 (−0.54 to 0.60)]	204 (98), 24 [0.02 (−0.54 to 0.58)]
			Eccentric–concentric force	277 (144), 21	Not assessed	336 (128), 21 [0.43 (−0.14 to 1.00)]	303 (183), 24 [0.16 (−0.40 to 0.72)]
			Total work, J	1716 (1021), 25	Not assessed	2146 (1049), 23 [0.42 (−0.16 to 0.99)]	2051 (1020), 24 [0.33 (−0.24 to 0.89)]

Legend: SD = standard deviation, n = number, J = joules, not reported = these data were collected but not reported within the study, not assessed = these data were not assessed. Bold = 95% confidence intervals do not cross zero.

Increased force output through the local muscle (e.g. Triceps Surae) may more effectively modulate load through the tendon and improve symptoms.[45] The poor study quality and small numbers of included studies notwithstanding, the lack of force output gains we observed might explain why a large proportion of patients continue to experience symptoms following rehabilitation.[1] One of the reasons for the apparent lack of improvement of muscle structure and function with these loading protocols may be the differences in these protocols to accepted resistance training protocols.[10] The parameters of the eccentric training protocol may be more of a stretch, as opposed to strength, protocol[4] as other eccentric exercises would be expected to alter muscle structure (in healthy participants) when designed according to accepted resistance training guidelines.[46]

The eccentric protocol is a one-size-fits-all approach, does not conform to suggested repetition or volume quantum, does not conform to suggested training frequency and provides no information on rest durations or time under tension. This lack of comparability is not surprising given the eccentric protocol was published over ten years prior to the American College of Sports Medicine position statement on resistance training.[10] The lack of definitive results may be that the majority of cohorts with data used an eccentric protocol (64 %) and weighted the results. However, the only study to report consistent positive results on muscle force output used an eccentric protocol[42] and the one study that largely conformed to recommended guidelines reported no improvement in muscle force output.[34] Alternatively, the lack of change to muscle structure and function may be due to abnormal cortical inhibition, which has been demonstrated in patellar tendinopathy[47] but has yet to be investigated within Achilles tendinopathy.

An alternative explanation for the apparent lack of improvement in muscle structure and function is that outcome measures inaccurately quantified force output. Only two cohorts were high quality in relation to measurement error[39,40] which diminishes confidence in any conclusions drawn. However, the studies with low risk of measurement error used the eccentric protocol and did not demonstrate any significant improvement in plantar flexion force output.[40]

Other biopsychosocial mechanisms are likely associated with improvements in clinical symptoms following exercise rehabilitation. Differences in tendon structure between people with Achilles tendinopathy and controls are present in cross-sectional studies[48,49] and are also seen in similar populations, such as patellar tendinopathy.[50] However, changes in tendon structure over time with rehabilitation are inconsistent and the relationship of these changes to tendon symptoms is unclear.[51–53] In most loading trials, improvements in tendon-related disability happen in a timeframe that is unlikely to be driven by changes in muscle structure (i.e. <4 weeks).[1] Cross-sectional studies have identified alterations in peripheral mechanical sensitivity in patients with Achilles tendinopathy.[54–56] Changes in these features whilst completing a loading protocol may indicate clinical improvement, even when muscle structure and function remain unchanged. Therefore, interventions that are designed to target not only muscle structure and function, but also central and peripheral processing deficits, may represent an appropriate treatment target for rehabilitation protocols.[47,57]

We performed a detailed search of published and grey literature to reduce the chance of publication bias. However, whilst we were able to identify numerous relevant trials (n = 29) the main limitation of this review was the lack of data available from completed trials (n = 17) and the potential influence of measurement error.

5. Conclusion

It is unclear whether current rehabilitation protocols for mid-portion Achilles tendinopathy improved muscle structure and/or function when completing rehabilitation. No studies analysed the relationship between changes in pain and disability and changes in muscle structure and function with rehabilitation. All studies reported

improvements in pain/disability, however only three of seventeen trials demonstrated improvement in muscle function with rehabilitation. All studies were low quality.

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Confirmation of ethical compliance

Not applicable.

CRediT authorship contribution statement

MM, MT and WG conceived the review. MM, MT, WG and CA designed the protocol. MM performed all searches. MM and MT performed all screening, extraction, and risk of bias assessment. MM and PC performed all analysis. All authors contributed to interpretation of results and manuscript preparation.

Declaration of interest statement

MM, MT, JD and SD have received speaker fees for lectures on tendinopathy. ER has received speaker fees for lectures on tendinopathy and has designed an app for anterior knee pain rehabilitation. PC and WG declare that they have no conflict of interest. CA is the Editor-in-Chief at Journal of Orthopaedic & Sports Physical Therapy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2023.03.007.

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