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SYSTEMATIC REVIEW

Achilles and Patellar Tendinopathy Loading Programmes

A Systematic Review Comparing Clinical Outcomes and Identifying Potential Mechanisms for Effectiveness

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Abstract
Introduction Achilles and patellar tendinopathy are overuse injuries that are common among athletes. Isolated eccentric muscle training has become the dominant conservative management strategy for Achilles and patellar tendinopathy but, in some cases, up to 45 % of patients may not respond. Eccentric-concentric progressing to eccentric (Silbernagel combined) and eccentric-concentric isotonic (heavy-slow resistance; HSR) loading have also been investigated. In order for clinicians to make informed decisions, they need to be aware of the loading options and comparative evidence. The mechanisms of loading also need to be elucidated in order to focus treatment to patient deficits and refine loading programmes in future studies.
Objectives The objectives of this review are to evaluate the evidence in studies that compare two or more loading programmes in Achilles and patellar tendinopathy, and to review the non-clinical outcomes (potential mechanisms), such as improved imaging outcomes, associated with clinical outcomes.
Methods Comprehensive searching (MEDLINE, EMBASE, CINAHL, Current Contents and SPORTDiscus™) identified 403 studies. Two authors independently reviewed studies for inclusion and quality. The final yield included 32 studies; ten compared loading programmes and 28 investigated at least one potential mechanism (six studies compared loading programmes and investigated potential mechanisms).
Results This review has identified limited (Achilles) and conflicting (patellar) evidence that clinical outcomes are superior with eccentric loading compared with other loading programmes, questioning the currently entrenched clinical approach to these injuries. There is equivalent evidence for Silbernagel combined (Achilles) and greater evidence for HSR loading (patellar). The only potential mechanism that was consistently associated with improved clinical outcomes in both Achilles and patellar tendon rehabilitation was improved neuromuscular performance (e.g. torque, work, endurance), and Silbernagel-combined (Achilles) HSR loading (patellar) had an equivalent or higher level of evidence than isolated eccentric loading. In the Achilles tendon, a majority of studies did not find an association between improved imaging (e.g. reduced anteroposterior diameter, proportion of tendons with Doppler signal) and clinical outcomes, including all high-quality studies. In contrast, HSR loading in the patellar tendon was associated with reduced Doppler area and anteroposterior diameter, as well as greater evidence of collagen turnover, and this was not seen following eccentric loading. HSR seems more likely to lead to tendon adaptation and warrants further investigation. Improved jump performance was associated with Achilles but not patellar tendon clinical outcomes. The mechanisms associated with clinical benefit may vary between loading interventions and tendons.

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Conclusion There is little clinical or mechanistic evidence for isolating the eccentric component, although it should be made clear that there is a paucity of good quality evidence and several potential mechanisms have not been investigated, such as neural adaptation and central nervous system changes (e.g. cortical reorganization). Clinicians should consider eccentric-concentric loading alongside or instead of eccentric loading in Achilles and patellar tendinopathy. Good-quality studies comparing loading programmes and evaluating clinical and mechanistic outcomes are needed in both Achilles and patellar tendinopathy rehabilitation.

1 Introduction

Achilles and patellar tendinopathy are overuse injuries characterized by localized tendon pain with loading and dysfunction. Both are common among athletes and Achilles tendinopathy may also affect sedentary people. Achilles and patellar tendinopathy is the focus of this review because these are the two major locomotor tendons affected by tendinopathy. Injury to these tendons can severely impact upon recreational and everyday activities. Pathological features include altered cellularity (increased or decreased), break down in the extracellular matrix (ground substance accumulation, disorganized collagen, neurovascular ingrowth) [1, 2]. Endocrine tenocytes and nerve endings release biochemicals that are thought to have a role in tendon pain (e.g. substance P) [3, 4]. Both extrinsic (e.g. overuse) and intrinsic factors (e.g. lipid levels, genes) may predispose to injury, but pathoaetiology is poorly understood [5].

Eccentric muscle loading has become the dominant conservative intervention strategy for Achilles and patellar tendinopathy over the last decade. Eccentric loading involves isolated, slow-lengthening muscle contractions. Other contraction types have been investigated, including eccentric-concentric and isolated concentric, and, in some studies, they have been compared with eccentric loading. Previous systematic reviews have evaluated the evidence for eccentric muscle loading in Achilles [6–10] and patellar [11, 12] tendinopathy, concluding that outcomes are promising but high-quality evidence is lacking. The first aim of this review is to synthesis evidence from studies comparing two or more loading programmes in Achilles and patellar tendinopathy. The findings of this review will guide clinical decisions and identify areas for further research.

It is clear from the eccentric loading evidence that not all patients respond to this intervention. In one study, 45 % of patients were considered to have failed treatment (a less than 10-point improvement in the Achilles version of the Victorian Institute of Sports Assessment [VISA-A] score) [13]. This clearly indicates eccentric loading may not be effective for all patients with tendinopathy. Understanding the mechanisms of loading interventions in tendinopathy, and which mechanisms are associated with improved clinical outcomes, may improve rehabilitation outcomes. Loading programmes can then be targeted to patient deficits (e.g. neuromuscular deficits) and mechanisms associated with clinical outcomes can be maximized (e.g. load intensity to maximize muscle and tendon adaptation), potentially improving clinical outcomes. The second aim is to investigate the non-clinical outcomes (potential mechanisms), such as improved strength and imaging pathology, associated with improved clinical outcomes following Achilles and patellar tendinopathy rehabilitation.

2 Methods

A systematic review was undertaken following the protocol guidelines outlined in the PRISMA statement [14].

2.1 Search Criteria

A search of MEDLINE, EMBASE, CINAHL, Current Contents and SPORTDiscus™ electronic databases was undertaken from inception to June 2012. Search terms relating to exercise ('eccentric', 'rehabilitation', 'resistance training', 'exercise therapy'), pathology ('tendinopathy', 'tendinitis', etc.) and the site ('Achilles', 'patellar') were combined in the final search (Table 1 shows the MEDLINE example). Each search term was mapped to specific MeSH subject headings within each database. The reference lists of eccentric loading systematic reviews and the studies in the final yield were manually checked to identify other studies.

2.2 Selection Criteria

Studies investigating clinical outcomes of loading programmes in Achilles and patellar tendinopathy were included. This comprised any type of muscle-tendon unit loading, including eccentric, concentric, combined eccentric-concentric, isometric and stretch-shortening cycle (SSC), loading involving a fast muscle tendon unit eccentric-concentric turnaround (e.g. jumping, hopping). Human studies with a minimum follow-up period of 4 weeks and single cohort studies and trials comparing two or more groups were included. From this, broad yield studies that compared two or more loading programmes in Achilles and patellar tendinopathy formed a subgroup. This included randomized controlled trials (RCTs) and controlled clinical trials (CCTs) that were not randomized.

Table 1 Search terms in MEDLINE database

	Search term
1	'eccentric', 'concentric', 'isometric', 'training', 'exercise' (title & abstract) 'Exercise Therapy', 'Exercise', 'Rehabilitation', 'Resistance training' (MeSH)
	AND
2	'achilles tendon', 'achilles', 'tendoachilles', 'tendo-achilles', 'triceps-surae', 'patellar tendon', 'patellar ligament' (title & abstract) 'Achilles Tendon', 'Patellar Ligament' (MeSH)
	AND
3	'tendinopathy', 'tendinitis', 'tendinosis', 'partial rupture', 'paratenonitis', 'peritendinitis', 'Achillodynia' (title & abstract) 'Tendinopathy', 'Tendon Injuries' (MeSH)

Stretching alone was not considered a loading programme, but studies that compared loading with and without continued sport were included. Single cohort studies and trials that investigated one or more non-clinical or mechanistic outcome (e.g. imaging and muscle performance measures such as peak torque) were included in another subgroup.

Studies that did not include any participants with tendinopathy were excluded, as were studies if they investigated loading following another primary intervention, such as injections or surgery. Other exclusion criteria included non-English studies, abstracts, non-peer-reviewed studies, case reports and reviews.

2.3 Review Process

Two reviewers (PM, CB) independently reviewed the title and abstract of all retrieved studies and those satisfying the inclusion and exclusion criteria were included in the final yield. If there was insufficient information in the title and abstract, the full text was obtained for adequate evaluation. Disagreement between the two authors was resolved by consensus.

2.4 Quality Assessment

A modified version [15] of a scale developed to assess the quality of intervention studies in patellofemoral joint pain syndrome [16] was used to evaluate study quality. Four quality components were evaluated (participants, interventions, outcome measures, and data presentation and analysis), each scored a maximum of 10 points (40 points in total) and contained three to four items. The item relating to the control and placebo group was modified to relate to the control group only because placebo is not practical with exercise interventions. The item was scored out of 4, with 2 points for comparison to another exercise intervention and 4 points for adequate control (i.e. a wait-and-see group or equivalent comparison group minus the exercise intervention). The adequate numbers item was scored out of 2 rather than 4 and the group homogeneity item was scored out of 4 rather than 2 and modified to pertain to adequate description and homogeneity of key group characteristics (age, gender, activity, severity). Case series studies could score a maximum of 34 points (the control group and randomization items were excluded). Two reviewers independently assessed the quality of included studies and disagreement was resolved by consensus. Studies scoring greater than 70 % on the quality assessment were considered high quality.

2.5 Data Extraction and Analysis

Key data relating to sample demographics, interventions and outcomes were extracted from each study. This included study design (e.g. an RCT), groups/description of loading and sample sizes, participant demographics (age, gender, activity level) and clinical and mechanistic outcomes. Only data from loading interventions were extracted. Given the heterogeneity in interventions and outcome measures a qualitative data synthesis was performed. Definitions for 'levels of evidence' were guided by recommendations made by van Tulder et al. [17] and are shown in Table 2.

3 Results

Figure 1 shows the process of identifying studies. There were 403 studies in the initial yield after removing duplicates. Ninety-two studies were assessed in full text, and a further 60 studies were excluded, leaving a yield of 33 studies either comparing two loading programmes or evaluating at least one non-clinical outcome (potential mechanism). In the final yield there were ten studies comparing loading programmes and 29 studies investigating at least one potential mechanism (six studies compared loading programmes and investigated potential mechanisms).

The quality assessment of all studies in this systematic review is shown in the table in the Online Resource [Online Resource 1]. The mean quality score was 54 % and the range was from 26 % to 83 %. Only seven (21 %) studies achieved a high-quality rating [11, 18–23]. Five (15 %)

Table 2 Grading the recommendations for comparing loading programmes

Evidence grade	Recommendation
Strong	Consistent findings among n ≥2 high-quality studies
Moderate	Consistent findings amongst multiple low-quality studies, or one high-quality study
Limited	Findings from one low-quality study.
Conflicting	Inconsistent findings among multiple studies
None	No studies found

studies had a quality score below 40 % [24–28] and findings from these studies were not included in the recommended levels of evidence. Eleven (55 %) trials were adequately randomized [11, 18, 19, 21–23, 29–33]. Three studies did not randomize participants into groups [27, 34, 35], and the remaining studies did not adequately describe the randomization process [26, 28, 36–39]. Only seven studies (21 %) reported adequate blinding of outcome assessors [19–23, 29, 38], so experimenter bias may have influenced the findings in a majority of studies. Only two studies (6 %) adequately reported inclusion and exclusion criteria [18, 36]. In many studies, tendon pain with loading was not clear as an inclusion criterion and previous surgery or other injuries were not explicitly excluded. Forty-two percent (14 of 33) used adequate outcome measures [11, 19–23, 30, 31, 36, 39–43]. This was usually a pain outcome that was not validated, such as a visual analogue scale (VAS) or an absence of functional outcomes. Only 12 (36 %) studies used the VISA-A or patellar tendon version of the VISA questionnaire, which is a disease-specific and validated pain and functional outcome measure (0–100 points, 100 = no pain and full function). Most studies described the loading interventions partially, with the mean score for that item being 2.8 of 4 (63 %). Few studies described the speed of each contraction [28, 44] and maximum load [11, 19, 29, 45]. A key issue with this literature is that the severity and irritability of tendons is generally not reported, so tendons may be at very different places along the reactive-degenerative symptomatic spectrum, and this will influence the response to load [46].

3.1 Description of Clinical Loading Programmes

Twenty-three Achilles [21–25, 28, 30, 32–35, 37–42, 44, 45, 47–49, 51] and 11 patellar tendon studies [11, 18–20, 26, 27, 29, 31, 36, 43, 47] were included in this review (one study included both Achilles and patellar tendon cohorts [47]). A majority of studies in the Achilles (16 of 23, 70 %) and patellar tendon (6 of 10, 60 %) investigated the isolated eccentric loading programme popularized by Alfredson [35] in at least one group. One Achilles [37] (4 %)

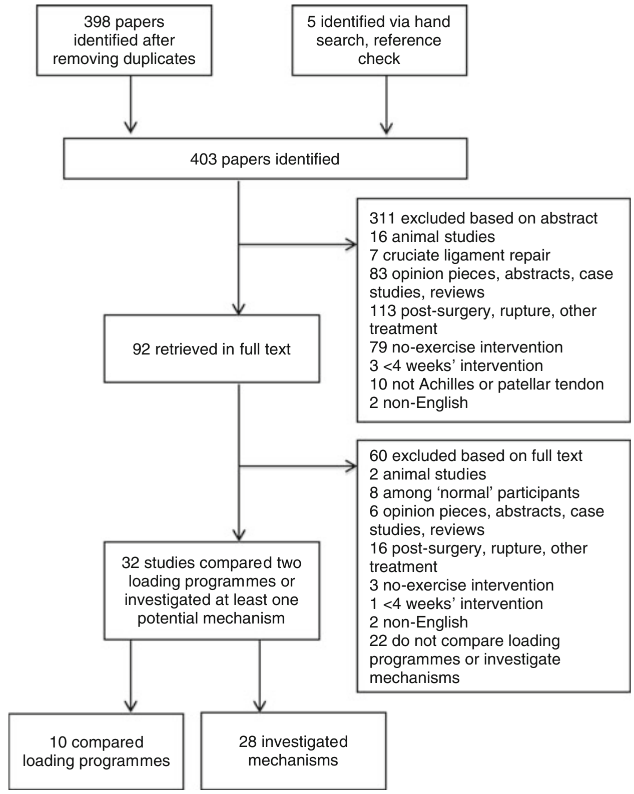

Fig. 1 Study selection flow diagram (six studies compared loading programmes and investigated potential mechanisms)

and two patellar tendon studies [29, 31] (20 %) used the eccentric-concentric Stanish and Curwin model [50]. Some studies have described this programme as 'eccentric' when it actually involves both concentric and eccentric contraction [37, 50]. In the Achilles studies, four [23, 30, 40, 41] (17 %) investigated the combined Silbernagel programme [30] involving progression from eccentric-concentric to eccentric load and, finally, faster eccentric-concentric and plyometric loading. Two patellar tendon studies [19, 20] (20 %) investigated heavy-slow resistance (HSR) loading that involves slow double leg isotonic eccentric-concentric contractions. Table 3 shows the characteristics of the four main loading programmes used in Achilles and patellar tendinopathy rehabilitation. Few studies included groups undertaking isotonic loading [29, 37], isokinetic loading [26, 47], concentric [32, 36] and flywheel loading [43].

3.2 Comparison of Loading Programmes in Achilles and Patellar Tendinopathy

Ten studies compared loading programmes in either Achilles [23, 30, 32, 37] or patellar tendinopathy [11, 19, 27, 29, 31, 36]. This included nine RCTs and one CCT. The mean quality score of studies comparing loading programmes was 57 % (range 34–83 %). Only two studies [19, 23] (20 %) had a high-quality score (>70 %) and one

Table 3 Characteristics of Alfredson, Stanish and Curwin, Silbernagel and HSR programmes

Programmes	Type of exercise	Sets, reps	Frequency	Progression	Pain
Alfredson	Eccentric	3, 15	Twice daily	Load	Enough load to achieve up to moderate pain
Stanish and Curwin	Eccentric-concentric, power	3, 10–20	Daily	Speed then load	Enough load to be painful in third set
Silbernagel	Eccentric-concentric, eccentric, faster eccentric-concentric, balance exercise [30, 41], plyometric [23]	Various	Daily	Volume, type of exercise	Acceptable if within defined limits[a]
HSR	Eccentric-concentric	4, 15–6	3×/week	15–6 RM	Acceptable if was not worse after

reps repetitions, *RM* repetition maximum

[a] Moderate (less than 5 of 10 on a visual analogue scale, 10 = worst pain imaginable); subsided by the following day

other study scored just below the cut off for a high-quality rating (68 %) [31].

Data extracted from each study comparing loading programmes and investigating mechanisms are shown in Table 4. There were 139 participants with a mean age of 44 years in the four studies comparing loading programmes in Achilles tendinopathy, with slightly more men than women (61 %), and the proportion participating in sport ranged from 57 % to 100 %.

There is limited evidence from three low-quality studies, which showed that (i) a greater proportion of patients are satisfied and return to a preinjury level of activity following eccentric, compared with concentric, loading [32]; (ii) VAS pain outcomes and patient satisfaction are greater following Silbernagel-combined loading compared with calf raises and stretching [30]; and (iii) VAS pain and return-to-sport outcomes were greater following Stanish and Curwin, compared with isotonic loading [37]. In one high-quality study there was moderate evidence, which showed that VISA-A improvement following Silbernagel-combined loading is similar whether sport is continued or not [23].

There were six patellar tendon studies including 112 participants with a mean age of 27 years. All participants were active in sports and greater than three-quarters were men (77 %). There is moderate evidence from two high-quality studies, which showed that (i) VISA improvement is comparable but patient satisfaction is greater following HSR versus eccentric loading [19]; (ii) there is no difference in change in VISA scores during a volleyball season with and without the addition of eccentric loading [11]. There is limited evidence from three low-quality studies, which showed that (i) clinical outcomes are superior following eccentric, compared with Stanish and Curwin loading [31] and concentric loading [36]; (ii) VAS pain and return-to-sport outcomes are superior following Stanish and Curwin, compared with isotonic loading [29]. In one very low-quality study, clinical outcomes were superior following eccentric compared with eccentric loading without a decline board [27].

3.3 Potential Mechanisms of Achilles and Patellar Tendinopathy Loading Programmes

Twenty-nine studies investigated non-clinical potential mechanisms of loading programmes in Achilles [21–25, 28, 30, 33–35, 37–42, 44, 45, 48, 49, 51] and patellar tendinopathy [11, 18–20, 26, 29, 43, 47]. This included 14 RCTs, two CCT's and 13 single cohort studies. Studies investigating mechanisms had a mean quality score of 54 % (range 26–79 %) and seven studies (25 %) had a high-quality rating [11, 18–22, 42]. There were 293 participants with Achilles tendinopathy in 21 studies. They had a mean age of 47 years, 79 % were active in sport and 59 % were men. One-hundred and sixty-three participants with patellar tendinopathy were investigated in eight studies. They had a mean age of 28 years, the majority were men (81 %) and almost all were active in sport (98 %).

3.3.1 Achilles

3.3.1.1 Neuromuscular and Jump Performance Outcomes

3.3.1.1.1 Eccentric Loading. There is limited evidence from one low-quality study that improved clinical outcomes are associated with increased ankle planterflexion torque [35]. There is moderate evidence from three low-quality studies, which show that (i) improved clinical outcomes are associated with increased calf work [35, 38] (ii) resolution in side-to-side ankle planterflexor work and torque deficits [34, 35].

3.3.1.1.2 Silbernagel-Combined Loading. There is limited evidence from one low-quality study, which showed that (i) improved clinical outcomes are associated with increased planterflexor endurance [30], (ii) improvement in

Table 4 Group characteristics, interventions and outcomes for each study

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Alfredson et al. [35] (1998)	CCT, AT	1. EL = 15 patients, eccentric calf drop over a step 2. Surgery = 15 patients	Mean age 44 years, 80 % men, all midportion, unilateral and runners	12 weeks; 94 % ↓ in VAS pain ($p < 0.001$), 100 % return to running	12 weeks; ↑ concentric work 14 % ($p < 0.05$), no change in eccentric work, ↑ concentric torque 11–15 % ($p < 0.05$), ↑ eccentric torque 18 % ($p < 0.01$), torque and work deficits resolved
Alfredson et al. [34] (1999)	CCT, AT	1. EL = 14 patients 2. Surgery = 10 patients	Mean age 44 years, 86 % men, all midportion, unilateral and runners	12 weeks: > 95 % ↓ in VAS pain ($p < 0.01$)	12 weeks: concentric and eccentric torque deficits resolved
Alfredson [51] (2003)	SC, AT	EL = 6 patients	Mean age 48 years, midportion	12 weeks: 75 % ↓ in VAS pain	12 weeks; no change in glutamate concentration ($p > 0.05$)
Bahr et al. [18] (2006)	RCT, PT	1. EL = 20 tendons, eccentric squat on a decline board 2. Surgery = 20 tendons	Mean age 31 years, 90 % men and all active, 14 % bilateral	3, 6, 12 months: 73–130 % improvement in VISA ($p < 0.001$)	6, 12 months: ↑ leg press 1RM (kg) 17–30 % ($p < 0.05$), no change in SJ, CMJ in both groups
Cannell et al. [29] (2001)	RCT, PT	1. Stanish and Curwin = 10 patients, all patellar = fast drop squat until thighs almost parallel 2. Isotonic = 9 patients, eccentric-concentric leg extensions and curls	Mean age 26 years, 68 % men, all active, 17 % bilateral	12 weeks: VAS pain ↓ in both groups (55 % versus 31 %, $p < 0.01$) with no difference between the groups. More returned to sport in drop squat group but not significant (90 % versus 67 %; $p > 0.05$)	12 weeks: quadriceps concentric torque did not increase in either groups, hamstring concentric torque ↑ in both groups 14–18 % ($p < 0.001$), no difference between groups
Croisier et al. [47] (2001)	SC, AT and PT	AT = 9 patients, isolated eccentric isokinetic calf; PT = 10 patients, isolated eccentric isokinetic quadriceps	Mean age 28 years, 63 % men, 84 % active, all unilateral	10 weeks: 73 % ↓ in VAS pain in AT ($p < 0.001$); 71 % ↓ in VAS in PT ($p < 0.001$)	10 weeks: concentric and eccentric torque, no deficit between sides for both AT and PT, 41 % had normalized US structure
de Jonge [22] (2010)	RCT, AT	1. EL = 34 tendons 2. EL + nightsplint = 36 tendons	Mean age 45 years, 59 % men, all midportion and active, 21 % bilateral	12 months: 51 % improvement in VISA-A ($p < 0.01$)	12 months: no change in Doppler prevalence (65 % at baseline, 71 % at follow-up). Baseline Doppler not associated with VISA-A change
Gardin et al. [48] (2010)	SC, AT	EL = 20 patients; follow-up of Shalabi 2004 study cohort	Mean age 49 years, 67 % men, 38 % active, 38 % bilateral	50 months: 95 % reported no or improved symptoms—improvement was significantly better than baseline ($p < 0.001$) and post-eccentrics ($p < 0.01$)	50 months: presence of intratendinous signal ↓ from 60 % at baseline to 10 % at follow-up ($p < 0.05$). 3.50 months: no change in tendon CSA

Table 4 continued

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Jensen and Di Fabio [26] (1989)	RCT, PT	1. Home exercise = 7 patients, quadriceps and hamstring stretches 2. Home exercise and quadriceps IEL = 8 patients (randomized another group without patellar tendinopathy into the same 2 groups)	Mean age 24 years, 52 % men (more women in group 2), all active	Change in pain not reported	8 weeks: affected: unaffected eccentric work ratio ↑ from 78 % at baseline to 106 % at follow-up. Home exercise group ↑ from 82 % at baseline to 94 %. Non-tendinopathy group performing EL ↑ from 108 % to 140 % (no p values given). At 8 weeks follow-up: pain frequency ($p = 0.80$) and intensity ($p = 0.78$) negatively correlated with affected : unaffected eccentric work ratio
Jonsson and Alfredson [36] (2005)	RCT, PT	1. EL = 10 patients 2. CL = 9 patients, identical to EL but isolated concentric component	Mean age 25 years, 87 % men, all active, 27 % bilateral	12 weeks: 2 × improvement ($p < 0.001$) in VISA in EL group versus no change in CL group. More returned to sport/satisfied in EL group (70 % versus 22 %, $p < 0.05$)	NA
Knobloch et al. [28] (2007)	RCT, AT	1. EL = 15 patients 2. Control = 5 patients	Mean age 33 years, 55 % men, 40 % midportion	12 weeks: 48 % ↓ in VAS pain ($p < 0.05$)	12 weeks: ↓ post-capillary filling pressure at 2 of 16 sites measured 9–27 % ($p < 0.05$), ↓ capillary flow at 2 of 16 sites 31–45 % ($p < 0.05$), oxygen saturation no change
Knobloch [44] (2007)	SC, AT	EL = 59 patients	Mean age 49 years, 61 % men, 83 % midportion	12 weeks: 35 % ↓ in VAS pain	12 weeks: ↓ postcapillary filling pressure at 2 of 16 sites 19–24 % ($p < 0.01$), ↓ capillary flow at 2 of 16 sites (23–35 %) $p < 0.01$), oxygen saturation no change
Kongsgaard et al. [19] (2009)	RCT, PT	1. EL = 12 patients 2. HSR = 13 patients, leg press, hack squat, squat—all double leg 3. CSI = 12 patients, 1–2 injections	Mean age 32 years, all men and active, 32 % bilateral	12, 26 weeks: 39-65 % ↑ in VISA in each group ($p < 0.01$), no difference between groups, EL group more satisfied than HSR group (70–73 % versus 22–42 %; $p < 0.05$)	12 weeks: 12–13 % ↓ in tendon AP diameter HSR group ($p < 0.01$), 45 % ↓ US colour area in HSR ($p < 0.01$), no change in EL group for either. 17 % ↑ patellar tendon CSA in eccentric group only ($p < 0.05$), no change in other groups. 7 % ↑ quadriceps muscle CSA both groups ($p < 0.01$), no difference between groups. No change in collagen content, HP, LP concentration in any group. ↑ HP : LP ratio (19 %) and ↓ pentosidine (23 %) in HSR group, no change in other groups. 8–11 % ↑ MVC in both exercise groups ($p < 0.05$). No change in stiffness and modulus in either exercise group

Table 4 continued

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Kongsgaard et al. [20] (2010)	SC, PT	HSR = 8 patients (compared with a group without tendinopathy who did not perform the exercise)	Mean age 33 years, all men and active	12 weeks: 27 % improvement in VISA ($p = 0.02$)	12 weeks: quadriceps CSA ↑ 7 %, peak knee extension moment ↑ 10 %, tendon stiffness ↓ 9 % in HSR group ($p < 0.05$). Modulus tended to decrease ($p = 0.15$) but no change in patellar tendon CSA, strain and stress. Fibril density ↑ 70 % ($p = 0.08$), fibril mean area ↓ 26 % ($p = 0.04$) in HSR group, fibril volume fraction no change. No change in non-tendinopathy group for any outcome
Langberg et al. [49] (2007)	SC, AT	EL = 6 patients (compared with a group without tendinopathy who performed the same exercise)	Mean age 26 years, all active men with midportion symptoms, all unilateral	12 weeks: 71 % ↓ in VAS pain ($p < 0.05$)	12 weeks: 4 × ↑ collagen synthesis ($p < 0.05$). No significant change in non-tendinopathy group. No change in either group in collagen degradation
Mafi et al. [32] (2001)	RCT, AT	1. EL = 22 patients 2. Mafi combined = 22 patients, eccentric-concentric theraband PF and heel raises, step-ups, skipping, hopping	Mean age 48 years, 55 % men, all midportion, 57 % active	12 weeks: more satisfied/returned to pre-injury activity in EL group (82 % versus 36 %; $p = 0.002$)	NA
Niesen-Vertommen et al. [37] (1992)	RCT, AT	1. Stanish and Curwin = 8 patients, fast eccentric calf drop, slow concentric component 2. Isotonic = 9 patients, eccentric-concentric planterflexion and dorsiflexion	Mean age 38 years men; 30 years women, 59 % men (more women in Stanish group), all midportion and active	12 weeks: VAS pain ↓ in both groups (50–72 %; $p < 0.05$), greater decrease in Stanish group ($p < 0.01$). More returned to sport/improved activity in Stanish and Curwin group but not significant (75 % versus 33 %; $p = 0.15$)	12 weeks: approximately 2 × ↑ concentric and eccentric torque in both groups ($p < 0.001$), no difference between the groups
Norregaard et al. [33] (2007)	RCT, AT	1. EL = 21 tendons, progressed to faster calf drop after 3 weeks 2. Stretching = 24 tendons, soleus and gastrocnemius stretches	Mean age 42 years, 51 % men, 3–4 patients per group had insertional, 49 % bilateral	3, 6, 12, 24, 52 weeks: improvements in symptoms and pain (18–76 %; $p < 0.01$–0.05) in both groups, no difference between the groups	12 (not 3) months: AP ↓ 9–17 % ($p < 0.05$) in both groups, no difference between the groups. 12 months: greater AP diameter initially associated with less pain intensity and better quality of life at 12 months ($p < 0.01$), but change in symptoms not correlated to change in AP

Table 4 continued

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Ohberg and Alfredson [24] (2004)	SC, AT	EL = 34 patients	Mean age 48 years, 76 % men, 62 % active, all had midportion symptoms, 37 % bilateral	Mean 28 months: 88 % had no pain during activity	Mean 28 months: 'more normal' grey-scale US appearance in 90 %, Doppler signal resolved in 78 %. More likely to have remaining Doppler if still painful ($p < 0.001$). Trend towards US abnormality remaining in tendons that were still painful ($p = 0.07$)
Ohberg et al. [25] (2004)	SC, AT	EL = 25 patients, follow-up of Ohberg 2004 study cohort	Mean age 50 years, 76 % men, 72 % active, 4 % bilateral	Mean 3.8 years: 88 % returned to pre-injury activity/satisfied	Mean 3.8 years: AP diameter ↓ 14 % ($p < 0.005$), more likely satisfied if structure resolved (86 % versus 5 %; $p < 0.001$)
Paolini et al. [38] (2004)	RCT, AT	1. EL + placebo = 33 patients 2. EL + GTN = 31 patients	Mean age 49 years, 62 % men, all midportion, 29 % bilateral	2, 6, 12, 24 weeks: pain (scale from 0 to 4) with activity ↓ 21–61 %, VAS pain with hopping ↓ 29–54 % (within group significance not reported)	2, 6, 12, 24 weeks: 2.4–2.8 × ↑ in ankle planterflexor mean total work (significance not given)
Peterson et al. [39] (2007)	RCT, AT	1. EL = 37 patients 2. Airheel brace 35 patients 3. EL and Airheel brace = 28 patients	Mean age 43 years, 60 % men, 92 % active, all had midportion symptoms, bilateral = 11 %	6, 12, 54 weeks: 10–16 % improvement in American Orthopaedic Foot and Ankle Assessment score, 20–60 % ↓ in VAS pain with activity ($p < 0.001$)	12 weeks: no significant change in tendon AP diameter
Purdam et al [27] (2004)	CCT, PT	1. EL = 8 patients 2. EL without decline board = 9 patients	Mean age 25 years, 75 % men, all active (decline squat group older, more females and more bilateral injuries but not significant)	12 weeks: VAS pain ↓ significantly in the EL group only (62 %; $p < 0.05$). More returned to pre-injury activity in EL group (75 % versus 11 %; $p = 0.04$)	NA
Romero-Rodriguez et al. [43] (2011)	SC, PT	Flywheel = 10 patients, inertial loading using flywheel device	Mean age 25 years, all active men, 50 % bilateral	6, 12 weeks: 86 % improvement in VISA ($p < 0.01$), 60 % ↓ in VAS pain ($p < 0.01$)	6 weeks: eccentric force ↑ 90 % ($p = 0.03$), concentric rectus femoris EMG ↑ 73 % ($p = 0.03$), no change in concentric force, eccentric rectus femoris EMG and bilateral CMJ height
Rompe et al. [21] (2007)	RCT, AT	1. EL = 25 patients 2. ESWT = 25 patients 3. Wait-and-see = 25 patients	Mean age = 49 years, 40 % men, 32 % active, all midportion, all unilateral	16 weeks: 57 % improvement in VISA-A ($p < 0.01$). No improvement in the wait-and-see group. More patients completely recovered or much better in the EL (60 %) versus wait and see group (24 %) [$p < 0.01$]	16 weeks: no change in AP diameter
Shalabi et al. [45] (2004)	SC, AT	EL = 25 patients	Mean age 51 years, 64 % men, 40 % active, all had midportion symptoms, 32 % bilateral	12 weeks: 40 % improvement in 5-point pain scale ($p < 0.01$)	12 weeks: tendon CSA ↓ 14 % ($p < 0.05$), intratendinous signal intensity ↓ 23 % ($p < 0.05$), pain score post correlated with change in signal/not volume

Table 4 continued

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Silbernagel et al. [30] (2001)	RCT, AT	1. Combined = 22 patients, calf raises, balance, then eccentric loading, then added speed 2. Calf raises and stretching = 18 patients	Mean age 44 years, 77 % men, all midportion and active (except 1 patient in group 2), 41 % bilateral	12, 26 weeks: VAS walking (40 %) and pain with palpation (29–57 %) ↓ in combined group only ($p < 0.05$) 26 weeks: VAS activity ↓ in both groups (57–80 %), also ↓ in combined group at 6 weeks (44 %) [$p < 0.05$]. 12 months: combined group more likely satisfied (78 % versus 38 %; $p < 0.05$) and considered themselves recovered (60 % versus 38 %, $p < 0.05$), no significant difference in return to pre-injury activity (55 % combined, 35 % calf raise/stretching)	6, 12, 26 weeks: calf endurance ↑ 14–30 % both groups, no group differences. 12, 26 weeks: ↑ CMJ height 7–30 % both groups, calf raise/stretching group also ↑ at 6 weeks, no group differences. 26 weeks: PF ROM ↑ 4 % combined group only. No change in DF at any time
Silbernagel et al. [23] (2007)	RCT, AT	1. Combined = 19 patients, identical to Silbernagel 2001 but added hopping 2. Combined + continued sport = 19 patients	Mean age 46 years, 53 % men (more women group 2), all midportion and active, 34 % bilateral	6, 12, 24, 52 weeks: VISA-A improvement in both groups ($p < 0.01$, up to 60 % combined, up to 49 % combined + sport), no difference between the groups	6, 12, 26, 52 weeks: ↑ eccentric-concentric work 20–29 % ($p < 0.05$) [no ↑ at 12 weeks in group 1]. 12, 26, 52 weeks: ↑ eccentric-concentric toe-raise power 17–26 % group 2 only ($p < 0.05$) [only ↑ at 6 weeks in group 1], no change in concentric toe-raise power in either group. 26 weeks: ↑ drop CMJ height 11 %, ↑ hop quotient 27 %, group 2 only ($p < 0.05$). No change in CMJ height in either group. 6, 26 weeks: ↓ DF ROM 5–6 %, group 2 only ($p < 0.05$)
Silbernagel et al. [41] (2007)	SC, AT	Combined = 37 patients	Mean age 46 years, 54 % men, all had midportion symptoms	12 months: 59 % improvement in VISA-A on symptomatic side ($p < 0.05$), 67 % classified as fully recovered (VISA-A ≥90)	12 months: low correlation between VISA-A scores and test battery ($r = 0.18$; $p = 0.41$) (calf raise endurance, drop CMJ height, hopping plyometric quotient, concentric toe-raise power, eccentric toe-raise power). Only drop CMJ height was significantly correlated with VISA-A scores ($r = 0.178$; $p = 0.61$, $p < 0.01$). Among the 'fully recovered' patients, 25 % had ≥90 % of unaffected side on functional test battery

Table 4 continued

Study (year)	Design	Groups, interventions	Participant characteristics[a]	Clinical outcome	Mechanistic outcomes
Silbernagel et al. [40] (2011)	SC, AT	Combined = 34 patients, follow-up of Silbernagel 2007 study cohort	Mean age 51 years, 53 % men, all active and had midportion symptoms	5 years: functional evaluation among 13 patients who were asymptomatic, 5 patients who had continued symptoms	5 years: deficit between affected and unaffected side—asymptomatics: 9 % for eccentric-concentric work ($p = 0.09$), 14 % for concentric power ($p = 0.04$). No deficit for eccentric-concentric power, drop CMJ height, hop quotient. Continued symptomatics had an 18 % deficit for concentric power ($p = 0.03$)
Van der Plas et al. [42] (2012)	SC, AT	EL = 46 patients, follow-up of de Jonge 2010 study cohort	Mean age 51 years, 91 % active, all had midportion symptoms, 26 % bilateral	5 years: 70 % improvement in VISA-A from baseline ($p < 0.001$), 12 % improvement in VISA-A from 1 year ($p = 0.006$)	5 years: AP ↓ 7 % ($p = 0.051$), Doppler present 59 % baseline and 47 % at follow-up ($p > 0.05$). VISA-A change and at 5 years was not associated with baseline Doppler. Pain presence and VISA-A at 5 years not correlated with baseline AP diameter
Visnes et al. [11] (2005)	RCT, PT	1. EL = 13 active athletes 2. Control = 16 active athletes	Mean age 27 years, 65 % men, volleyball players, 42 % bilateral	12, 18 weeks: no significant change in VISA scores, no significant difference to control group	12 weeks: ↑ bilateral CMJ height (1.2 cm, $p = 0.046$) in ET group. SJ height (uni-, bilateral), CMJ height (unilateral) no change either group
Young et al. [31] (2005)	RCT, PT	1. EL = 9 active athletes 2. Stanish and Curwin = 8 active athletes	Mean age 27 years, 77 % men, volleyball players	12 months: more likely clinically significant VISA change in EL group (94 % versus 41 %)	NA

AP anteroposterior, *AT* Achilles tendon, *CCT* controlled trial, *CL* concentric loading, *CMJ* countermovement jump, *CSA* cross-sectional area, dorsiflexion, *EL* eccentric loading, *ESWT* Extracorporeal shockwave therapy, *EMG* electromyographic activity, *GTN* glycerol tri-nitrate, *HSR* heavy slow resistance, *HP* hydroxylysyl piridinoline, *IEL* isokinetic eccentric loading, *LP* lysyl pyridinoline, *MRI* magnetic resonance imaging, *MVC* maximal voluntary contraction, *NA* not applicable, *PF* planterflexion, *PT* patellar tendon, *RCT* randomized controlled trial, *ROM* range of motion, *RM* repetition maximum, *SC* single cohort, *SJ* squat jump, *US* ultrasound imaging, *VAS* visual analogue score, *VISA* Victorian Institute of Sport Assessment, *VISA-A* VISA-Achilles version

↑, indicates increase; ↓, indicates decrease

[a] Mean age, gender, uni-versus bilateral, midportion versus insertion (for AT only) and activity. All imaging studies use ultrasound except for Shalabi et al. [101] and Gardin et al. [48] (MRI)

calf endurance and jump performance is greater with Silbernagel-combined loading versus calf raises/stretching [30]. There is moderate evidence from one high-quality and three-low quality studies, showing that (i) improved clinical outcomes are associated with improved jump performance [23, 30] (ii) improved clinical outcomes are associated with increased calf power [23] (iii) calf power and jump performance is greater with Silbernagel-combined loading when sport is continued [23] (iv) improvement in clinical outcomes is not associated with resolution in side-to-side deficits in various functional measures (planterflexor endurance, torque, power and work, jump and hop tests) [40, 41]. There is conflicting clinical evidence from one high-quality and one low-quality study that improved clinical outcomes are associated with increased planterflexion and decreased dorsiflexion range of motion [23, 30].

3.3.1.1.3 Other Loading. There is limited evidence from one low-quality study that improved clinical outcomes are associated with increased planterflexor torque following Stanish and Curwin loading but not isotonic loading [37], and increased planterflexor torque following isokinetic loading [47].

3.3.1.2 Imaging Measures

3.3.1.2.1 Eccentric Loading. There is conflicting evidence from seven low-quality studies, which show that improved clinical outcomes are associated with (i) decreased anteroposterior diameter [21, 25, 33, 39, 42]; (ii) a decrease in the proportion of tendons containing Doppler signal [22, 24, 42] (one study is high quality and shows no change in the proportion of tendons containing Doppler signal) [22]. There is conflicting evidence from two low-quality studies that investigate the same cohort at different times and found that improved clinical outcomes are associated with decreased cross-sectional area (CSA) [45, 48]. There was only one high-quality study that showed no change in tendon dimensions in association with reduced symptoms (anteroposterior diameter) [21]. There is moderate evidence from one high-quality and four low-quality studies, which show that (i) imaging (Doppler presence and anteroposterior diameter at baseline, change in anteroposterior diameter) does not predict a change in symptoms [22, 33, 42] (ii) improved clinical outcomes following isokinetic loading are associated with decreased intratendinous signal intensity [45, 48].

3.3.1.2.2 Other Loading. There is limited evidence from one low-quality study that improved clinical outcomes following isokinetic loading are associated with a decrease in the proportion of abnormal tendons on greyscale ultrasound [47].

3.3.1.3 Biochemical and Blood Flow

3.3.1.3.1 Eccentric Loading. There is limited evidence from two low-quality studies, showing that improved clinical outcomes are associated with (i) an increase in type I collagen synthesis [49], but not associated with reduced glutamate concentration [51]; (ii) reduced Achilles tendon capillary blood flow and post-capillary filling pressure [44].

3.3.2 Patellar

3.3.2.1 Neuromuscular and Jump Performance Outcomes

3.3.2.1.1 Eccentric Loading. There is moderate evidence from two high-quality studies, which showed that improved clinical outcomes are associated with (i) increased knee extensor torque [19]; (ii)increased leg press 1-repetition maximum (1RM) [18]; (iii) increased quadriceps muscle CSA [19]. There is conflicting evidence from two high-quality studies that improved clinical outcomes are not associated with improved jump performance [11, 18].

3.3.2.1.2 Heavy-Slow Resistance (HSR) Loading. There is strong evidence from two high-quality studies that improved clinical outcomes are associated with increased knee extensor torque [19, 20]. There is moderate evidence from one high-quality study that improved clinical outcomes are associated with increased quadriceps muscle CSA [19].

3.3.2.1.3 Stanish and Curwin Loading. There is limited evidence from one low-quality study that improved clinical outcomes are associated with increased knee flexor but not extensor torque [29]. There is limited evidence from one low-quality study that there is no group difference in change in knee flexor and extensor torque between Stanish and Curwin and isotonic loading [29].

3.3.2.1.4 Other Loading. There is limited evidence from two low-quality studies, which showed that; (i) torque deficits resolve following isokinetic loading [47] (ii) improved clinical outcomes are associated with increased eccentric force on a flywheel device (but not concentric force), but no change in jump performance following flywheel loading [43].

3.3.2.2 Imaging, Structural and Mechanical Property Outcomes

3.3.2.2.1 Eccentric Loading. There is moderate evidence from one high-quality study, which showed that (i) improved clinical outcomes are not associated with reduced Doppler area and anteroposterior diameter [19];(ii) increase in CSA is greater following eccentric, compared with HSR loading [19];(iii) improved clinical outcomes are not associated with change in tendon stiffness and modulus [19].

3.3.2.2.2 HSR. There is moderate evidence from two high-quality studies, which showed that improved clinical outcomes are associated with (i) reduced Doppler area and anteroposterior diameter [19]; (ii) increased fibril density, decreased fibril mean area and no change in fibril volume fraction [20]. There is conflicting evidence from two high-quality studies that improved clinical outcomes are associated with a decrease in tendon stiffness and modulus [19, 20].

3.3.2.3 Biochemical Outcomes

3.3.2.3.1 Eccentric Loading. There is moderate evidence from one high-quality study that improved clinical outcomes are not associated with change in collagen content, hydroxylysyl pyridinoline (HP) and lysyl pyridinoline (LP) concentration, HP/LP ratio, and pentosidine concentration [19].

3.3.2.3.2 HSR Loading. There is moderate evidence from one high-quality study that collagen content, HP and LP concentration do not change but HP/LP ratio increases and pentosidine concentration decreases alongside improved clinical outcomes [19].

4 Discussion

4.1 Comparison of Loading Programmes

Ten studies were identified that compared loading programmes in Achilles and patellar tendinopathy. Only two studies, both investigating patellar tendinopathy, were high quality [11, 19]. Although the Alfredson eccentric loading model is a popular clinical intervention, there is limited evidence in the Achilles tendon to support its use when compared with other loading programmes. There was limited evidence from one study that patient satisfaction/return to preinjury activity is greater following eccentric compared with concentric loading in the Achilles tendon [32]. This evidence should be interpreted with caution, as the concentric group performed different exercises that are likely to have involved a much lower load (i.e. non- or partial weightbearing initially). The Silbernagel-combined loading programme incorporates eccentric-concentric, eccentric and then faster loading and has been investigated in four Achilles tendon studies. There is limited evidence that this programme offers superior clinical outcomes to eccentric-concentric calf raises and stretching alone [30]. It is important for clinicians to appreciate that there is as much evidence for the Silbernagel-combined programme as there is for the Alfredson eccentric programme when comparing them to other loading programmes in Achilles tendinopathy. The gradual progression from eccentric-concentric to eccentric followed by faster loading may benefit patients who are unable to start with an Alfredson eccentric programme due to pain or calf weakness.

In the patellar tendon, there is conflicting evidence that eccentric loading is superior to other loading programmes. There is limited evidence that VISA improvement is greater following eccentric loading compared with concentric loading [36], and Stanish and Curwin loading [31] in patellar tendinopathy. However, there is moderate evidence that eccentric loading is equivalent on VISA outcomes and inferior on patient subjective satisfaction to HSR loading [19]. HSR loading is performed three times per week rather than twice daily, and this may explain the greater patient satisfaction. Good-quality evidence is lacking for both Achilles and patellar tendinopathy, but there is clearly benefit from loading programmes that involve eccentric-concentric muscle actions.

Some studies investigated tendon loading prior or during a competition phase. Young et al. [31] found that slow eccentric decline squats preseason, led to superior post-volleyball season patellar tendon VISA outcomes than that of the Stanish and Curwin loading. Visnes et al. [11] found eccentric decline squatting did not improve patellar tendon VISA outcomes when performed during a volleyball season. Silbernagel et al. [23] found continued sport activity did not compromise clinical outcomes at 12 months, as long as sport was gradually introduced to ensure minimal pain during and after loading. Continuing sport with rehabilitation may be more successful in Achilles tendenopathy, as sport load may be lower than typical patellar tendon loads in some sports (e.g. volleyball).

4.2 Mechanisms of Achilles and Patellar Tendon Loading Programmes

4.2.1 Neuromuscular Performance and Muscle Size

Loading was shown to be associated with improved neuromuscular outcomes (e.g. 1RM torque) in most studies. The highest level of evidence supported eccentric and Silbernagel-combined loading in the Achilles (moderate evidence) [23, 30, 34, 35] and HSR loading in the patellar tendon (strong evidence) [19, 20]. There is limited evidence for Stanish and Curwin and isokinetic loading in the Achilles [37, 47] and evidence for eccentric (moderate) and flywheel (limited) in the patellar tendon [19, 43]. There is also limited evidence that quadriceps size increase is similar following HSR and eccentric loading in the patellar tendon [19]. Overall, Silbernagel and eccentric loading in the Achilles and HSR loading in the patellar have the highest level of evidence for improving neuromuscular function in Achilles and patellar tendinopathy.

Although eccentric loading is often linked with greater muscle-tendon unit load and adaptation, this systematic review did not identify any evidence of this among tendinopathy patients. Among normal participants, eccentric loading results in greater muscle strength gains and hypertrophy (especially type II fibres) than concentric loading [52], but not when the load is equalized [52], suggesting load intensity rather than contraction type is the stimulus. There is an unfounded perception among many clinicians that eccentric muscle action always leads to greater muscle-tendon unit load than concentric and isometric contractions. During eccentric muscle action, there are less active motor units than concentric contraction when external load and speed are constant, with less resultant muscle EMG activity [53, 54] and oxygen consumption [55, 56]. This increases the force potential with eccentric contraction, but this potential can only be realized via the following two mechanisms:(i) if the external load is greater than the maximal concentric and isometric load capability; and (ii) by increasing the speed of eccentric contraction under load, as predicted by the force-velocity curve [55, 57] (Fig. 2). For example, when a sprinter increases running speed the hamstring muscle-tendon during limb deceleration will increase. Therefore, clinical eccentric loading among tendinopathy patients may not lead to a greater change in neuromuscular outcomes because load intensity is often not maximized [11, 19, 45].

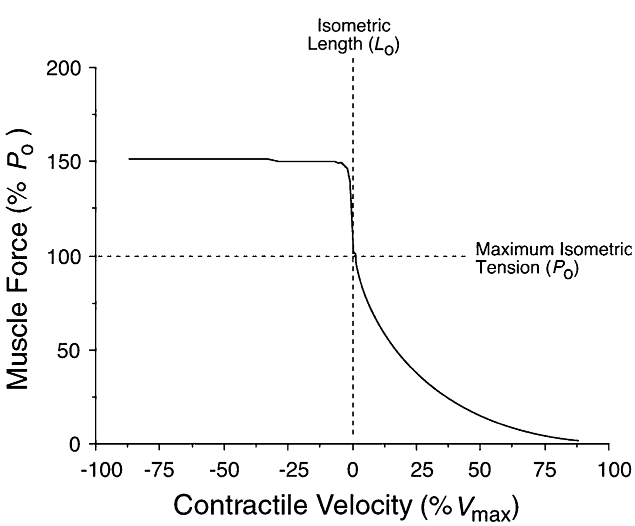

Fig. 2 Force velocity curve. L_O isometric length, P_O maximum isometric tension, V_{max} maximum velocity (reproduced from Leiber [57], with permission from Lippincott, Williams and Wilkins)

Clinically, the load potential of eccentric contractions may be limited by symptom irritability.

4.2.2 Power and Jump Performance

There is moderate evidence, which shows that calf power and jump performance improves alongside symptoms following Silbernagel-combined loading but only at 6 months [23, 30], and there is moderate evidence, which shows that improvement in both outcomes is greater if sport is continued [23]. Continued sport, as long as symptoms are stable, seems to have a specific effect on these power outcomes, which is not gained even with the Silbernagel-combined programme that includes faster calf loading and stretch-shorten cycle rehabilitation. In contrast, there is moderate evidence that jump performance is not associated with clinical improvement in patellar tendinopathy following eccentric [11, 18], and limited evidence following flywheel loading [43], even though sport was continued in these studies based on pain monitoring. A recent systematic review found some evidence for increased vertical jump performance in patellar tendon patients compared with asymptomatic cohorts, which may partly explain this finding [58].

4.2.3 Do Side-to-Side Neuromuscular and Jump Performance Deficits Resolve?

Side-to-side deficits (e.g. torque, work, endurance) were only evaluated in the Achilles tendon. There is moderate [34, 35, 47] evidence that deficits resolve in the short term (10–12 weeks), but also that they are present at longer-term follow up (12 months to 5 years) [40, 41]. It is possible that deficits recur when rehabilitation ceases, indicating that performance may need to be maintained with ongoing loading.

4.2.4 Imaging, Structure and Biochemicals

The only evidence for change in imaging measures in the Achilles tendon is decreased intratendinous signal intensity on magnetic resonance imaging (MRI) following eccentric loading (moderate evidence) [45, 48]. This review did not identify any evidence that tendon dimensions (anteroposterior diameter, CSA) and the proportion of tendons with Doppler signal change following Achilles eccentric loading, despite limited evidence for increased collagen type 1 production. In the patellar tendon, improved clinical outcomes were not associated with reduced Doppler area and anteroposterior diameter in eccentric loading, but they were following HSR (moderate evidence) [19]. There is also moderate evidence, that HSR is less likely to lead to increased patellar tendon CSA, and more likely to lead to increased pentosidine concentration and HP/LP ratio, indicative of collagen turnover [19]. This suggests that HSR has a more positive effect on tendon adaptation and remodelling if increased CSA is interpreted as increased pathology in the eccentric loading group. The effect of HSR on tendon adaptation is supported by moderate evidence of improved clinical outcomes alongside 'normalization' of tendon microstructure (increased fibril density, decreased fibril mean area) in patellar tendinopathy [20].

HSR appears to be a promising intervention for tendon adaptation, although it should be highlighted that it is only investigated in two studies, both in the patellar tendon. VISA change was similar in the HSR and eccentric loading groups, despite evidence for greater tendon adaptation with HSR [19]. Improved tendon structure may reduce the risk of recurrence. Future research is needed to explore this possibility. Pathology may improve spontaneously among tendons that are less progressed on the tendon pathology continuum [59] but, perhaps, HSR is more likely to bring about adaptation of more severely pathological tendons and partly or fully restore the loss of tendon stiffness observed in pathological tendons [60]. Tendons with less severe pathology have a better clinical and pathology prognosis and vice versa [61–63]; therefore, it is presumed there may be clinical benefit in improving severely abnormal tendon pathology if this was possible.

A likely explanation of the superior tendon adaptation with HSR may be increased load. HSR probably involved heavier tendon load (maximum load = 6RM in HSR versus 15 kg in eccentric loading (Kongsgaard M et al., personal communication), and tendon and muscle response are known to be load dependent. Kubo et al [64] compared identical volume and intensity of isometric quadriceps loading in 50° and 100° knee flexion. Patellar tendon moment arm, and therefore tendon force, was greater in 100°, and only this group demonstrated increased tendon stiffness. Arampatzis et al. [65, 66] found that an increase in tendon stiffness following chronic eccentric-concentric heavy loading was diminished at higher strain frequency (i.e. faster contraction, less time under tension, tendon strained less during loading). Tendon is viscoelastic and is more compliant (i.e. strains more) with longer duration and heavier contractions [67, 68], and strain is thought to be the stimulus for tendon adaptation [66]. The current systematic review, however, found conflicting evidence for change in tendon stiffness following HSR [19, 20], and no evidence following eccentric loading, despite evidence for biochemical adaptation (e.g. HP/LP ratio) [19]. This suggests structure and material property changes may be different or delayed in pathological tendons.

4.2.5 Muscle-Tendon Unit Compliance and Length-Tension Relationship

Although there is conflicting evidence for change in dorsiflexion and planterflexion range with Silbernagel-combined loading in this systematic review [23, 30], Mahieu et al [69] reported an increase in ankle dorsiflexion range of motion and muscle-tendon unit compliance (reduced resistance to passive stretch) after 6 weeks of eccentric loading performed without any additional load (i.e. bodyweight only) among normal participants. Increased range of motion has been demonstrated in other studies following eccentric [69–71] and eccentric-concentric loading [72], and other authors report both increased [73] and decreased [74] muscle-tendon unit compliance after chronic loaded eccentrics. Eccentric contraction has also been widely reported to lead to a rightwards shift of the length-tension curve (greater force potential at longer lengths) [75–78] (Fig. 3) and increased sarcomere length [78–81], and sarcomeres in series [82–84]. Similar changes have been demonstrated with concentric loading [78]. Clarifying whether contraction type, load intensity or other factors such as loading range of motion influence these outcomes, and whether they relate to clinical outcomes in tendinopathy, may improve effectiveness in tendinopathy rehabilitation. For example, a loading programme that achieves increased muscle-tendon unit compliance may lead to superior clinical outcomes among Achilles patients with reduced calf muscle-tendon unit compliance. The challenge may be the complex interaction between these factors (e.g. a ballet dancer with an excessive range of motion but reduced muscle-tendon unit compliance) and how to measure them clinically (e.g. muscle-tendon unit compliance).

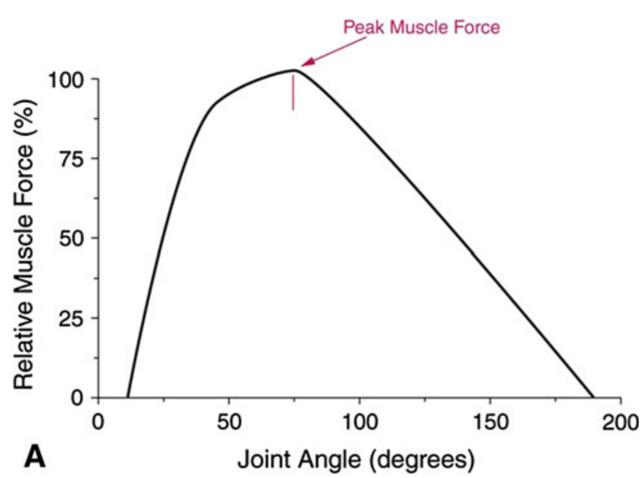

Fig. 3 Length–tension curve (muscle force is optimal near the mid-joint range and reduces at inner and outer joint ranges). Reproduced from Leiber [57], with permission from Lippincott, Williams and Wilkins

4.2.6 Blood Flow

Hypoxia has been implicated in the pathogenesis of tendinopathy and, therefore, change in microvasculature has been investigated as a potential mechanism of eccentric loading. Although there is limited evidence that Achilles capillary flow and post-capillary pressure decreased following 12 weeks of eccentric loading, this finding was only seen at 13 % of the 16 anatomical sites around the Achilles tendon that were evaluated [28, 44]. Furthermore, a recent study showed women had greater vascular improvement (decrease in post-capillary pressures) than men but less symptomatic response following eccentric loading [85, 86], questioning the link between this potential mechanism and pain.

4.2.7 Pain System

Alfredson et al. [35] hypothesized that aggressive, painful eccentric calf drops have a direct mechanical effect on neurovascular ingrowth that may be a source of pain [87]. There is no evidence that such a direct mechanical effect modulates pain, and this systematic review did not identify any evidence that a change in glutamate may explain clinical outcomes in Achilles tendinopathy. However, the popular rehabilitation approach of exposing tendon tissues to progressively more eccentric loading and SSC loading whilst monitoring and avoiding tendon irritability, is likely to have some effect on the nervous system and pain perception. This may be a change in local biochemicals that has not yet been studied, or central nervous system changes (e.g. increased inhibitory neuron activation, cortical reorganization) [88].

4.2.8 Are Isolated Eccentric Contractions Justified Clinically?

This review found only limited evidence from one study in the Achilles tendon, and conflicting evidence in the patellar tendon, which showed that isolating eccentric muscle contraction is superior to other loading [19, 31, 32, 36], and no evidence that mechanistic outcomes improve more following eccentric loading compared with other forms of loading. In fact, there is moderate evidence that imaging outcomes (Doppler area and anteroposterior diameter) may improve more following HSR compared with eccentric loading in the patellar tendon [19]. This may, in part, be because, as discussed in Sect. 4.2.1, load intensity does not seem to be maximized with clinical eccentric loading, and muscle and tendon adaptation seems to be dependent on load intensity. Nonetheless, the findings of this review suggest clinical improvement is not dependent on isolated eccentric loading in Achilles and patellar tendinopathy rehabilitation.

There may be, however, other mechanisms of eccentric muscle contractions that do not relate to load potential and were not investigated in any of the studies in this review. Eccentric contractions result in greater neural changes than concentric loading, including greater strength gains in the contralateral limb [89, 90], faster neural adaptation from strength loading [89, 91] and increased cortical excitability [92]. These changes may account for some of the early neuromuscular gains in the clinical literature (e.g. 6 weeks [43]). An interesting recent finding is that there are tendon force fluctuations (8–12 Hz) with eccentric contraction that are absent in concentric contraction [54, 93]. It is not known whether they influence muscle-tendon adaptation or are simply inherent in motor control differences (reduced active motor units with eccentric contractions). Finally, even if load potential is not maximized, load progression may be easier and faster with eccentric loading, particularly with the mechanical and metabolic advantages. Given these potential mechanisms and the evidence base surrounding submaximal eccentric loading [6], there may be an indication for isolating the eccentric component even with lower-load loading, but underlying mechanisms are not evidence based and need to be investigated.

There are potential issues with isolated eccentric muscle contraction. Delayed onset muscle soreness (DOMS) is a recognized side effect of eccentric loading, which is negligible with isometric and concentric contraction due to the absence of negative work [94]. DOMS can be minimized with graded exposure to eccentric muscle contractions. A potentially more serious issue with isolated eccentric muscle contractions in clinical populations is training specificity. Muscle training gains are known to be specific to the mode of contraction, speed and joint angle [95]. This is a particular issue in clinical populations with poorer concentric strength, who may have reduced carry-over of eccentric-to-concentric strength gains, limiting clinical outcomes and prolonging dysfunction and pain.

5 Clinical Implications

Clinicians should consider eccentric-concentric loading alongside or instead of eccentric loading in Achilles and patellar tendinopathy. Eccentric-concentric loading may be particularly important among patients with marked concentric weakness that may not recover with isolated eccentric loading, due to muscle contraction type specificity. The Silbernagel-combined programme seems an ideal progressive loading programme for this patient subgroup. Heavy load training, as in HSR or load maximized eccentric loading, may be more likely to achieve tendon adaptation and may be better suited to some patient groups (e.g. less irritable or degenerative tendon symptoms, high-load demands such as athletes).

In the Achilles tendon, continued sport may lead to specific gains that are less evident with other loading (e.g. greater improvements in jump performance). Although SSC load and continued sport has the potential to aggravate symptoms, it seems to be important in the rehabilitation process and should be implemented carefully alongside a sensible pain monitoring system [23].

Pain was an acceptable feature of rehabilitation in most studies in this review. In the Alfredson model, the goal is to increase the load until it is painful. In other models (e.g. HSR, Silbernagel combined) the goal is to progress the load so that pain is tolerated as long as it settles quickly. Equivalent or greater improvement in HSR and Silbernagel-combined loading programmes suggests that pain does not need to be the focus of loading interventions. The health professional has an important role in educating patients about acceptable loading-related symptoms.

Some studies reported continued neuromuscular and jump performance deficits at 12 months and 5 years, which may initially relate to inadequate loading or a lack of appropriate maintenance loading. This questions the length of current loading programmes and suggests suitable maintenance programmes may be necessary even when patients return to sport.

6 Future Directions

This review has highlighted a dearth of clinical evidence comparing rehabilitation programmes in Achilles and patellar tendinopathy. Rather than accepting isolated eccentric loading as the gold standard, studies are needed to investigate how load intensity, time under tension, speed, contraction type and other factors influence clinical and mechanistic outcomes. Potential confounders need to be identified and controlled, and also a change in symptoms, long-term clinical outcomes and recurrence correlated with change in potential mechanisms. Further, correlated mechanistic outcomes need to be investigated in prospective intervention studies to determine if they are causally linked with improved clinical outcomes. It is important to consider when planning future studies that tendons at different points along the symptomatic reactive-degenerative spectrum may respond very differently to loading interventions.

No studies have investigated isometric loading in tendinopathy. During isometric contraction, time under tension can be maximized to allow greater tendon strain, which is a likely stimulus for tendon adaptation. Further, DOMS is minimal, loading can be performed in a range that is not painful and tendon compression can be minimized. Tendon compression that occurs near the end of joint range is thought to be involved in pathoetiology of insertional tendinopathy [96–98]. A potential disadvantage is joint angle-specific strength gains [99, 100], although carry-over to other angles is greater when loading is not performed at optimal length-tension range. Given the potential benefits of isometric loading, it warrants investigation in clinical studies.

Various subgroups may also benefit from different loading programmes. For example, end-of-range loading may change muscle-tendon unit compliance and the length-tension relationship, which may potentially have a positive effect on clinical outcomes in some patient groups. Patients with concentric weakness may benefit from concentric-eccentric loading rather than isolated eccentric loading, at least initially. Some patients may have greater potential for tendon adaptation (e.g. younger, healthier) and may respond more to heavy loading. Clarifying these potential effects in clinical populations may allow subgrouping of patients into rehabilitation programmes based on specific deficits, ultimately improving clinical effectiveness.

There is a paucity of evidence relating to change in central and peripheral pain mechanisms with Achilles and patellar tendinopathy rehabilitation. There has long been debate regarding the source of pain in tendinopathy and current evidence suggests that neurovascular ingrowth, as well as endocrine tenocytes, may have a role in local production of pain biochemicals. Several questions remain. Do change in biochemicals other than glutamate (e.g. substance P), or central changes (e.g. cortical reorganization) influence symptomatic response with rehabilitation? Does painful loading facilitate these changes?

7 Conclusion

This systematic review has identified limited and conflicting evidence that clinical outcomes are superior with eccentric loading compared with other loading programmes in Achilles and patellar tendinopathy, respectively, questioning the currently entrenched clinical approach to these injuries. There is equivalent evidence for Silbernagel-combined (Achilles) and greater evidence for HSR loading (patellar).

Improved neuromuscular performance (e.g. torque, work, endurance) was consistently associated with improved clinical outcomes so may partly explain clinical benefit with Achilles and patellar tendon rehabilitation. For this non-clinical outcome, Silbernagel-combined and eccentric (Achilles tendon) as well as HSR loading (patellar tendon) had the highest level of evidence. Improved jump performance was associated with Achilles but not patellar tendon clinical outcomes. In contrast, improved imaging outcomes such as anteroposterior diameter and Doppler signal/area were associated with patellar tendon (HSR only) but not Achilles clinical outcomes. HSR was also associated with greater evidence of collagen turnover when compared with eccentric loading. The mechanisms associated with clinical benefit may vary between loading interventions and tendons. HSR appears to be a promising intervention for tendon adaptation but caution is needed in interpreting findings as only two studies, both in the patellar tendon, investigate this loading intervention.

This systematic review found that there is at least equivalent clinical evidence, and greater evidence for improvement in some potential mechanisms such as neuromuscular performance and imaging following eccentric-concentric compared with isolated eccentric loading. This suggests that there is little clinical or mechanistic evidence for isolating the eccentric component, although it should be made clear that there is a paucity of good-quality evidence, and several potential mechanisms, such as neural adaptation and central nervous system changes (e.g. cortical reorganization), have not been investigated. Among asymptomatic participants, load intensity, which can be maximized with eccentric loading, may be a stimulus for muscle-tendon adaptation, but this is often not optimized in clinical studies, perhaps due to symptom irritability.

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