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The implementation of resistance training principles in exercise interventions for lower limb tendinopathy: A systematic review

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ABSTRACT

Objectives: The primary purpose of this systematic review is to examine the literature on resistance training interventions for lower limb tendinopathy to evaluate the proportion of interventions that implemented key resistance training principles (specificity, progression, overload, individualisation) and reported relevant prescription components (frequency, intensity, sets, repetitions) and reported intervention adherence.

Design: Two reviewers performed a qualitative systematic review after screening titles and abstracts based on eligibility criteria. Identified papers were obtained in

full text, with data extracted regarding the implementation of resistance training principles. Included articles were evaluated by the Cochrane risk of bias tool, with a scoring tool out of 10 used for implementation and reporting of the 5 key principles. Scientific databases were searched in November 2020 and included Medline, CINAHL, AMED, and Sportsdiscus.

Results: 52 randomised controlled trials investigating resistance training in five different lower limb tendinopathies were included. Although most studies considered the principles of progression (92%) and individualisation (88%), only 19 studies (37%) appropriately described how this progression in resistance was achieved, and only 18 studies (35%) reported specific instruction on how individualisation was applied. Adherence was considered in 27 studies (52%), with only 17 studies (33%) reporting the levels of adherence. In the scoring criteria, only 5 studies (10%) achieved a total maximum score of 10, with 17 studies (33%) achieving a maximum score of 8 for implementing and reporting the principles of specificity, overload, progression and individualisation.

Conclusion: There is meaningful variability and methodological concerns regarding the application and reporting of resistance training principles, particularly progression and individualisation, along with intervention adherence throughout studies. Collectively, these findings have important implications for the prescription of current resistance training interventions, including the design and implementation of future interventions for populations with lower limb tendinopathies.

Introduction

Recent evidence has highlighted the enormous global burden of musculoskeletal disorders, with approximately 1.3 billion prevalent cases and 121,300 deaths due to musculoskeletal disorders in 2017, as well as 138.7 million disability-adjusted life years (Safiri et al. 2020). Tendinopathies of the lower limb represent some of the most common musculoskeletal disorders, with a high prevalence in both the general sedentary population and athletic individuals (Minetto et al. 2020;

Ganestam et al. 2016; Riel et al. 2019). Prevalent tendinopathies such as Achilles, patellar and plantar heel cause chronic pain, disability, functional and activity limitations and impaired quality of life (Abat et al. 2017). Despite a range of treatment options being available, exercise and particularly different forms of resistance training are most often implemented and recommended, however only moderate long-term effectiveness for improving pain and function has been demonstrated (Girgis and Duarte, 2020; Cardoso et al. 2019; Riel et al. 2019; Dimitrios 2015). Recently, the extent of heterogeneity within tendinopathy populations has been highlighted, with a host of individual factors been shown to influence risk and onset of tendinopathy, as well as outcomes to treatment such as resistance training (Steinmann et al. 2020). Therefore, the response of individuals to exercise interventions can be diverse and multifactorial, due to the interactions of a plethora of factors (Ferreira et al. 2020; Dean et al. 2017). Response to resistance training may be dependent on tendinopathy type and stage on the continuum, duration, age, individual intrinsic and extrinsic factors as well as exercise parameters such as the type, dose, duration, frequency, volume and intervention adherence (Barratt et al. 2017; Morrissey 2015). Therefore, it is plausible that applying a generic and standardised resistance training approach to a largely heterogenous tendinopathy population may reduce the full potential utility of the approach for improving outcomes in tendinopathy.

Resistance training interventions are typically based on the key core resistance training principles of specificity, overload and progression, which when applied appropriately can ensure sufficient challenge and adaptation of the human neuromuscular system (Fleck 2011; Fleck and Kraemer 2014; Haff and Triplett 2015). Although not considered a core principle of resistance training, the principle of individualisation has recently received increased attention and when exercise interventions are individually tailored, outcomes have been shown to be improved compared to standardised interventions (Jones et al. 2016; Mann et al. 2014; Borressen and Lambert 2009). Individualisation of exercise prescription may also be highly relevant in tendinopathy due to its heterogenous nature, and as such leading tendinopathy researchers and clinicians have stressed the importance of individualising exercise treatments to improve outcomes (Abat et al. 2017; Silbernagel et al. 2014). Implementing key resistance training principles can help

to appropriately manipulate key training variables such as training load, volume and duration, which may impact on clinical outcomes (Hasani et al. 2020). Consequently, given the importance of optimising the key resistance training principles within tendinopathy treatment interventions, determining the extent to which these scientific principles are currently implemented may be considered integral for guiding further research and clinical recommendations for tendinopathy (Malliaras et al. 2015). It is essential that the scientific principles of resistance training are correctly applied and reported within interventions, in order to achieve optimal exercise dosages and stimulus, and to allow for an appropriate evaluation of their feasibility and effectiveness within tendinopathy populations. Therefore, a systematic evaluation of the individual components, principles and prescription of resistance training within the current lower limb tendinopathy literature is warranted.

Despite the plethora of systematic reviews examining the effectiveness of exercise interventions for lower limb tendinopathies, including resistance training, there have been no comprehensive reviews examining the application and reporting of key resistance training principles within interventions (Clifford et al. 2020; Van der Vlist et al. 2020; Vander Doelen et al. 2020; Lim et al. 2018; Malliaras et al. 2013; Murphy et al. 2019; Babatunde et al. 2018; Challoumas et al. 2019). It could be considered a highly important objective to determine the extent to which the key scientific training principles have been implemented due to inadequate long-term outcomes of resistance training for lower limb tendinopathies (Silbernagel 2014; Riel 2019). Despite this importance, the application of key principles has not been adequately investigated and reported in previous systematic reviews. An understanding of the current adoption of resistance training principles may present an avenue for improving the implementation of key principles appropriately, which may improve the utility of resistance training interventions and long-term outcomes for tendinopathy patients.

Objective

The primary purpose of this systematic review was to examine the current literature on resistance training interventions for lower limb tendinopathies and evaluate the proportion of studies that implemented key resistance training principles (specificity, progression, overload, individualisation) and reported relevant prescription components (frequency, intensity, sets, repetitions) and reported adherence.

METHODS

Design

This was a qualitative systematic review with a priory eligibility criterion established and applied to the search strategy prior to conducting literature searches.

Eligibility criteria

This review considered randomised controlled trials (RCTs) only for eligibility for inclusion. To be considered for inclusion, RCTs must have investigated a primary resistance training intervention, either in isolation or combined with another treatment in adults with lower limb tendinopathy. Specific tendinopathies included patellar, Achilles, and gluteal tendinopathy, posterior tibial tendon dysfunction and plantar heel pain. Studies published in peer-reviewed journals and in English language were considered for inclusion.

Data sources

Scientific databases were searched in November 2020 and included Medline, CINAHL, AMED, Sportsdiscus. Search terms related to the included lower limb tendinopathies and resistance training were entered in different combinations as Medical Subject Heading (MESH) terms and keywords where appropriate. All terms were applied and modified specifically to each database. Manual searches of reference lists from other systematic reviews of resistance training interventions for lower limb tendinopathy were conducted to retrieve any additional articles. Databases were searched from 2000 to 2020. The year 2000 was chosen to ensure seminal work is not missed as clinical research in this area began around this time. Including findings from studies published more than 20 years ago may not be relevant due to advances in both research methodologies and clinical practice for tendinopathy. Studies published in a language other than English were only included if a translation was available as translation services are not available to the authors.

Article selection

Two reviewers independently screened the title and abstracts of every citation found in the literature search to decide eligibility, with any disagreements resolved through discussion. Identified articles considered relevant were obtained in full-text and independently assessed against the eligibility criteria by both reviewers. Any disagreements were resolved through discussion and consensus with an independent third reviewer if required. The search results are reported in accordance with the PRISMA guidelines and are presented in figure 1, which outlines the results of the comprehensive searches.

Data extraction

Relevant data from included studies were systematically extracted into pre-determined templates under the following headings: population, tendinopathy diagnosed, sample size, outcome measures, outcomes (table 3), and details on

resistance training principles and the training interventions used (table 4). The relevant details from each study were independently extracted and rated by both reviewers according to the definitions of each resistance training principle, as outlined in tables 1 and 2. Appropriate inclusion and reporting of a training principle were assigned a 'Y', with 'NR' assigned if the principle was not reported in the study. If it was unclear whether a training principle was appropriately included, 'UC' was assigned to the principle. Characteristics of each training intervention according to the FITT principles of frequency, intensity, time and type of exercise, together with details on specific exercises used, prescribed repetitions and sets were also extracted. An overview of extracted details on the description of components of training interventions and their principles is provided in table 4. Each study was assigned a separate score rating for each of the key resistance training principles and adherence, based on application of the principle within the study design and for adequate reporting of the principle within the study. Appropriate application of each principle was assigned a score of 1, and 0 was applied for inadequate description of the principle or if it was not used in the study. A total score for the resistance training principles and adherence was obtained for each study in the review, with a maximum score of 10 available per study. Details of the scoring criteria are provided in table 2.

Risk of bias

Included studies were critically appraised by two independent reviewers at study level for methodological quality in the review using the standardized Cochrane risk of bias tool on Covidence. Any disagreements that arose between the reviewers were resolved through discussion or with a third reviewer. The results of critical appraisal are reported in narrative form, and in a graph. All studies meeting the inclusion criteria, regardless of their methodological quality, underwent data extraction and synthesis and were included in the review. Seven criteria were appraised for RCTs. Item three which pertained to blinding was included but not considered highly relevant in final scoring and grading of recommendations, given that interventions could not be blinded. Therefore, a maximum high-quality score of 6 or 7 could be achieved, with all included studies scoring at least 4/7, which was considered a moderate quality score (figure 2).

Table 1: Resistance training principles and training intervention criteria assessed

Principle	Criteria for this review
Specificity: Training and desired adaptations should be specific to the tendinopathy and relevant to desired outcomes	Appropriate population targeted and intervention designed to improve primary outcome
Progression: to allow for continuous adaptations, resistance or load must be increased providing a greater stress to the body	Training intervention was stated to be progressive with gradual increases in frequency, sets, repetitions, resistance or loading throughout intervention
Overload: for the intervention to improve strength, greater than normal stress and training volume must occur above current training levels	Interventions included baseline strength testing or rationale that intervention was of sufficient intensity and volume relative to baseline capacity
Individualisation: Training is tailored to the individual to allow for consideration of individual factors and training response	Training intervention considered methods to individually tailor exercises stimulus based on an individual's own factors or training response
Component of training	Description
Frequency	How many times per week or day
Intensity	Measurement method: RM, %RM, RPE, pain level
Time	Duration of session
Sets	How many sets of each exercise
Repetitions	How many repetitions of each exercise or target number of repetitions
Exercise selection	Outline and description of specific exercises used in intervention
Adherence	Was adherence to the training intervention monitored and reported?

Table 2: Scoring of the application and reporting of key training principles

Principle/ criterion	Description		Score
Specificity	Design: have the authors designed the intervention to achieve desired outcomes? 1/10	Reporting: have the authors adequately described the intervention specificity? 1/10	2/10
Overload	Design: have the authors appropriately manipulated training variables to achieve desired outcomes? 1/10	Reporting: have the authors adequately described the intervention training variables? 1/10	2/10
Progression	Design: have the authors appropriately manipulated training variables to adequately progress the intervention? 1/10	Reporting: have the authors adequately described how intervention progression was achieved and assured? 1/10	2/10
Individualisation	Design: have the authors appropriately manipulated training variables to adequately individually tailor the intervention? 1/10	Reporting: have the authors adequately described how individually tailoring the intervention was achieved and assured? 1/10	2/10
Adherence	Design: have the authors appropriately designed and described methods for monitoring adherence? 1/10	Reporting: have the authors adequately reported individual adherence to training and training dose achieved? 1/10	2/10

Figure 1: PRISMA study flow diagram

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed100009

Figure 2: Risk of bias summary

	Risk of bias							Overall
	D1	D2	D3	D4	D5	D6	D7	
Beyer et al. 2015	+	+	×	+	-	+	+	+
Kongsgaard et al. 2009	+	+	×	-	+	+	+	+
Riel et al. 2019	+	+	×	×	+	+	+	+
Stevens & Tan 2014	+	+	×	+	-	+	+	+
Da Cunha et al. 2012	+	-	×	-	+	+	-	-
Kulig et al. 2009	-	-	×	-	+	+	×	×
Bahr et al. 2006	+	+	×	-	-	+	-	-
Lee et al. 2017	-	-	×	-	-	+	+	×
Frohm et al. 2007	+	+	×	-	+	+	-	-
Silbernagel et al. 2001	-	-	×	-	-	+	+	×
Balius et al. 2016	+	-	×	-	+	+	+	-
Mafi et al. 2001	+	-	×	-	+	+	+	-
Norregaard et al. 2007	+	+	×	-	-	+	+	-
Stasinopoulos et al. 2004	+	-	×	+	+	+	-	-
De Vos et al. 2007	+	+	×	+	-	+	+	+
Johannsen et al. 2019	+	+	×	+	+	+	+	+
MacDonald et al. 2019	+	-	×	-	-	+	-	×
Gatz et al. 2020	+	-	×	-	-	+	-	-
Ganderton et al. 2018	+	+	×	+	-	+	+	+
Silbernagel et al. 2007	+	+	×	+	+	+	+	+
Clifford et al. 2019	+	×	×	×	-	+	-	×
Stergioulas et al. 2008	-	-	×	+	-	+	+	-
Rompe et al. 2008	+	+	×	+	+	+	+	+
Mellor et al. 2018	+	+	×	+	+	+	+	+
Van Ark et al. 2016	+	+	×	-	-	+	-	-
Roos et al. 2004	+	-	×	-	-	+	-	×

D1: Random sequence generation (selection bias)
D2: Allocation concealment (selection bias)
D3: Blinding of participants and personnel (performance bias)
D4: Blinding of outcome assessment (detection bias)
D5: Incomplete outcome data (attrition bias)
D6: Selective reporting (reporting bias)
D7: Other bias

Judgement
 High
 Unclear
 Low

	Risk of bias							Overall
	D1	D2	D3	D4	D5	D6	D7	
Chester et al. 2008	+	-	×	-	+	+	-	-
Rompe et al. 2007	+	+	×	+	+	+	+	+
Thijs et al. 2017	+	+	×	-	-	+	+	-
Horstmann et al. 2011	+	+	×	-	+	+	-	-
Alfredson et al. 1998	×	×	×	×	+	+	-	+
Alvarez et al. 2006	+	×	×	-	-	+	+	-
Kearney et al. 2013	+	+	×	+	+	+	-	+
Tumilty et al. 2012	+	+	+	+	-	+	+	+
Yelland et al. 2011	+	+	×	+	+	+	-	+
McCormack et al. 2016	+	+	×	-	-	+	-	-
Tumilty et al. 2016	+	+	+	+	-	+	+	+
Cannell et al. 2001	+	-	×	-	+	+	-	-
Jonsson et al. 2005	-	-	×	-	-	+	-	×
Kedia et al. 2014	+	+	×	-	+	+	+	+
Herrington et al. 2007	+	-	×	+	+	+	-	-
Houck et al. 2015	+	+	×	-	+	+	+	+
Dimitrios et al. 2012	-	-	×	-	+	+	+	-
Petersen et al. 2007	+	-	×	-	-	+	+	-
Steunebrink et al. 2013	+	+	×	-	+	+	+	+
Rompe et al. 2009	+	+	×	+	-	+	+	+
Young et al. 2005	+	-	×	-	+	+	-	-
De Jonge et al. 2010	+	+	×	+	-	+	+	+
Praet et al. 2019	+	+	×	+	+	+	-	+
Rathleff et al. 2015	+	-	×	-	-	+	+	-
Knobloch et al. 2008	+	+	×	-	-	+	+	-
Wheeler et al. 2017	+	+	×	-	+	+	+	+

Study

D1: Random sequence generation (selection bias)
D2: Allocation concealment (selection bias)
D3: Blinding of participants and personnel (performance bias)
D4: Blinding of outcome assessment (detection bias)
D5: Incomplete outcome data (attrition bias)
D6: Selective reporting (reporting bias)
D7: Other bias

Judgement
× High
- Unclear
+ Low

Figure 3: Risk of bias graph

Data synthesis

The results from extraction are presented in a narrative synthesis and a summary of findings was tabulated (table 3) and included study characteristics, sample size, duration and outcomes together with a summary of the key training principles. The application of training components such as specific exercises, repetitions, sets and intensity is included in table 4. The total number of studies that applied each training principle and reported intervention components was calculated into percentages based on the proportion of studies reporting a principle relative to the total number of included studies.

RESULTS

Study characteristics

An outline of the characteristics of included studies, such as intervention groups, sample size and outcomes are presented in table 3, with resistance training principles presented in table 4. A total of 6188 records were identified in the comprehensive literature search, with 188 selected for full-text review (figure 1). A total of 52 RCTs involving 2487 participants met the review inclusion criteria,

with 136 studies being excluded due to wrong study design, mainly not being RCTs. Achilles tendinopathy was the most common tendinopathy investigated (26 studies), followed by patellar (16), plantar heel (4), gluteal (3), and tibialis posterior (3). All studies investigated a resistance training intervention, with most doing so in isolation, while 4 studies investigated resistance training combined with another intervention, either corticosteroid injection or orthoses. Eccentric resistance training (40 studies) was the most common resistance training type investigated, with concentric (3), isometric (3), isotonic (3) heavy slow resistance (7) and combined or general training approaches (4) also investigated. The duration of training interventions ranged from 4 to 26 weeks, with 44 studies (85%) using a 12-week intervention. All studies adopted outcome measures which assessed pain and function outcomes of the interventions, with other measures including quality of life and tendon structure through ultrasonography. Pain was measured by VAS scales in 26 studies, and NRS in 3 studies. The VIS-A was used to measure function in 18 studies, VISA-P in 10 studies and the FFI in 5 studies. Cochrane risk of bias scores ranged from 1-6, with no studies achieving a maximum score of 7. This was largely since resistance training interventions cannot be blinded, therefore all studies had high risk of bias for this criterion. Therefore, if a score of 6 was considered the maximum score, only 7 of 52 studies achieved this score, highlighting the high risk of bias throughout many included studies.

Application of key principles

An overview of the application of key resistance training principles within included studies is presented in table 4. All studies (100%) appropriately implemented the principle of specificity by targeting the resistance training to the pathological tendon with the aim of improving pain and function. The principle of overload was appropriately applied in 48/52 studies (92%), in the form of progressively increasing resistance throughout the intervention. The principle of progression was implemented in 48/52 studies (92%), however only 19 studies (37%) appropriately described how this progression in resistance was achieved and with what load, most commonly with small increases in external weight. Increased

resistance was applied by using a progressively loaded backpack in 31 studies (60%), with 5 studies (10%) reporting using weight machines, and 4 studies using resistance bands (8%). Incremental increases in resistance ranged from 0.9-5kg, with 5kg being the most common as reported in 12 studies (23%). The principle of individualisation through individually tailoring training was applied in 46/52 studies (88%), with 39 studies tailoring training based on pain response, four on exercise technique, two on as much volume as possible per session and one study used a BORG scale to tailor intensity. Of the studies that considered individualisation, only 18 studies (35%) reported specific instruction on how this was applied, such as by following pain scales to a certain level before adjusting resistance. Adherence was considered in 27 studies (52%), most commonly in the form of an exercise adherence diary. However, only 17 studies (33%) reported the levels of adherence to the prescribed training intervention. In the scoring criteria, a maximum score of 8 was possible for application and reporting of resistance training principles only, and a total score of 10 with adherence included. Only 5 studies (10%) achieved a total maximum score of 10, with 17 studies (33%) achieving a maximum score of 8 for implementing and reporting the principles of specificity, overload, progression and individualisation.

Reporting of resistance training components

All but one study failed to report the frequency of training sessions (98%). Frequency ranged from 2 to 7 days per week, and 2 to 14 sessions per week. All but two studies (96%) failed to report the intensity of the prescribed training intervention. Intensity was prescribed either using a percentage of 1 repetition maximum (RM) or most commonly as a target RM for a session, such as 10-15 RM. Although the duration of the entire intervention was reported in all studies (100%), the duration of each session was only reported in 7 studies (13%). All, but two studies (96%) reported the number of sets and repetitions of exercise. Sets ranged from 1-12, with one study including as many sets as possible (Riel et al. 2019), and repetitions per set ranged from 3-30, with one study including as many repetitions as possible (Stevens and Tan 2014). All studies reported the specific exercises used, with eccentric or isotonic heel raises being implemented

in 33 studies (63%), with 13 studies using eccentric decline squats (25%). The most reported resistance training prescription throughout the interventions was the parameters of the 'Alfredson' protocol, with 25 studies (48%) using the original protocol or slight modifications from it. The parameters of the Alfredson protocol include training twice per day, seven days per week, with 6 sets of 15 repetitions, totalling 180 repetitions per day, progressed with increased resistance by adding weight to a backpack as able. The protocol involves two variations of a standing heel raise exercise performed on a step, one performed with the knee straight to target the gastrocnemius and the other with the knee flexed to target the soleus muscles (Alfredson 1998).

Discussion

The primary purpose of this systematic review was to examine the current literature on resistance training interventions for lower limb tendinopathies and evaluate the proportion of studies that implemented key resistance training principles (specificity, progression, overload, individualisation) and reported relevant prescription components (frequency, intensity, sets, repetitions) and reported adherence. A total of 52 RCTs investigating resistance training in five different lower limb tendinopathies were included. The principles of specificity, overload, progression and individualisation were applied and reported to varying degrees throughout studies, along with consideration of exercise adherence. Although most studies considered the principles of progression (92%) and individualisation (88%), only 19 studies (37%) appropriately described how this progression in resistance was achieved, and only 18 studies (35%) reported specific instruction on how individualisation was applied. Adherence was considered in 27 studies (52%), with only 17 studies (33%) reporting the levels of adherence to the prescribed training intervention, which raises significant concerns regarding the levels of exercise dosage achieved within studies. In the scoring criteria, only 5 studies (10%) achieved a total maximum score of 10, with 17 studies (33%) achieving a maximum score of 8 for implementing and reporting the principles of specificity, overload, progression and individualisation. There is therefore meaningful variability and methodological concerns regarding the

application and reporting of resistance training principles, particularly progression and individualisation, along with intervention adherence throughout studies. Collectively, these findings have important implications for the prescription of current resistance training interventions, including the design and implementation of future interventions for populations with lower limb tendinopathies.

Since the publication of the Alfredson eccentric protocol for Achilles tendinopathy in 1998, eccentric resistance training has become the dominant conservative intervention strategy for lower limb tendinopathies over the last two decades (Malliaras et al. 2013). The Alfredson protocol has also been modified for patellar tendinopathy in several studies, in the form of an eccentric decline squat protocol (Visnes et al. 2007; Young et al. 2005). Although eccentric training has positive effects in treating tendinopathies, there is currently no strong evidence to suggest that decreasing or eliminating concentric actions from the stretch-shortening cycle is appropriate when treating chronic tendinopathies (Couppé et al. 2015; Malliaras et. 2013). However, eccentric only training has shown better results when compared with concentric only, for Achilles (Mafi et al. 2001), and patellar tendinopathy (Jonsson and Alfredson 2005). Systematic reviews have evaluated the evidence for eccentric resistance training, concluding that high-quality evidence is lacking despite positive clinical outcomes in lower limb tendinopathies (Mendonca et al. 2020; Girgis et al. 2020; Murphy et al. 2019; Lim and Wong, 2018). Despite Alfredson's initial high success rate with an athletic cohort, it is apparent from the evidence that not all patients have positive clinical outcomes from isolated eccentric training. Sayana et al. (2007) found that 45% of patients were considered to have failed treatment with eccentric training based on pain and function outcomes, indicating that it may not be suitable for all patients.

More recently, Heavy Slow Resistance Training (HSRT) with heavy-load concentric-eccentric contractions, has become more widespread in research and clinical practice (Couppe et al. 2015). This method was first successfully implemented in patellar tendinopathy (Kongsgaard et al. 2009) and later investigated with positive outcomes in Achilles tendinopathy (Beyer et al. 2015) and Plantar heel pain (PHP) (Rathleff et al. 2015) based on the same loading

principles and volume progression. Whereas the Alfredson eccentric protocol stipulates a strict protocol of 180 repetitions daily, HSRT adheres more to scientific training principles, such as progressive increases in load and volume and increased rest periods. Recent evidence suggests that HSRT may have superior clinical outcomes compared to isolated eccentric training interventions and leads to greater patient satisfaction in treating lower limb tendinopathies (Murphy et al. 2019; Beyer et al. 2015; Kongsgaard et al. 2009). Despite this, evidence suggests that even HSRT protocols do not reach intended dosage levels and may require better loading and progression methods and a more individualised approach rather than a standardised protocol (Riel et al. 2019).

The finding from this review that almost half of studies (48%) adopted the parameters of the Alfredson protocol, which involves training twice per day, seven days per week, with 6 sets of 15 repetitions, totalling 180 repetitions per day, is particularly concerning. Training twice per day with such a high volume does not follow current scientific resistance training recommendations, to achieve optimal exercise dosage, recovery, tendon and physiological adaptations required to improve clinical outcomes. The overload principle speaks to the necessity to stress biological tissues beyond their current thresholds to increase tolerance to subsequent stresses and avoid future injuries. Greater load tolerance can be achieved by training at higher loads, which also has positive effects on remodeling of the degenerated tendon (Kulig 2009). However, the Alfredson protocol for example involves training twice daily for 12 weeks, meaning it is unlikely high loads are being achieved. It is recommended that no more than 3 high-intensity training sessions should be undertaken within a week in the recovering tendon, to allow adequate recovery and collagen synthesis (Malliaras et al. 2015; Magnussen et al. 2009). Adequate rest periods are required in training protocols for tendon adaptation in relation to anabolic and catabolic processes involved in tendon remodelling (Waugh 2018). Resistance training for longer than 12-weeks may also be necessary, in order to gain sufficient adaptation and positive results for lower limb tendinopathies (Sussmilch-Leitch et al. 2012). The dosage (e.g., number of repetitions, days per week and duration of a contraction) and type of exercise are important characteristics of an exercise program, with loads as high as 80% of 1 repetition maximum (RM) having been used for isometric (80% 1RM) and isotonic

exercises (80% 8RM) (Van Ark et al. 2016). Beneficial effects from rehabilitation for tendons require high load per repetition. Furthermore, a high percentage of RM in leg extension exercises has been shown to improve muscle strength and neural activation. However the precise mechanism of effect, optimal dosage and loading strategy has not yet been determined and further research is required (Van Ark et al. 2016).

There is currently little consensus regarding which variables might influence the outcome of training, including whether training should be painful, home- versus clinic-based training, the speed of the exercise, training duration, and progression methods (Rompe et al. 2009). Large randomized controlled trials that consider these parameters and include blinded assessors and extended follow-up periods are warranted. Resistance training at a high intensity level of training, with gradual increases in loading, are required to create positive effects on both the muscle and tendon. Although the importance of mechanical loading through exercise in patients with tendinopathy is well established, the optimal exercise protocol contents and loading dosages require further investigation and may include aspects of motor control, proprioception, strength, malalignment, flexibility, kinetic chain and plyometric strength (Silbernagel 2007). The effects of different loading strategies need to be investigated in tendinopathy before they can be recommended in clinical practice, and findings in one type of tendinopathy may not necessarily be generalisable to others (Riel 2018). As previous research on lower limb tendinopathies has not found superiority of one specific resistance training type, the long-term effects of different loading programs in tendinopathy remain to be investigated (Riel 2018).

As recognised by Purdam et al. (2004) there is a question of whether most of the published studies are offering strength training, or may they be better described as active stretching with relative low intensity eccentric actions (Abat et al. 2017). It seems that published works on eccentric protocols do not offer true strength training and it might be that only HSRT develops the minimum level of load and tension to identify them as strength training based on scientific training principles. Recent evidence suggests that an intensity threshold above 70% of maximum is

required to cause adaptations in tendon properties, including mechanical, material and morphological tendon changes (Arampatzis et al. 2020; Bohm et al. 2015). However, with the high repetition volume and inadequate loading in current protocols, it is unlikely this intensity is being achieved, which may be related to poor outcomes. Performing very slow repetitions (often 6-8 seconds) at a high repetition volume, may also lead to reduced intensity. Perhaps a better approach may be to perform less repetitions at a higher load with increased sets while maintaining the slow tempo implemented in HSRT, such as the approach known as 'cluster training' which could help maintain sufficient intensity and volume (Davies et al. 2020). In conjunction with decreased repetitions and increased loading intensity, autoregulation or self-selection of within-session load may also account better for the principle of individualisation and allow for better individual outcomes, by tailoring the training load to an individual's response (Mann et al. 2010, Helms et al. 2018; Rauch et al. 2020). Two studies included in this review (Riel et al. 2019; Stevens and Tan 2014), found that allowing patients to self-select or autoregulate their training load was no less effective than following a standardised protocol, suggesting that autoregulation may provide a method for individually tailoring training loads to account for individual factors.

Limitations

The purpose of this systematic review was not to determine outcomes or effectiveness of resistance training interventions in lower limb tendinopathies, rather to report on the application of resistance training principles and adherence of interventions. Determining the proportion of previous studies that have implemented and reported key resistance training principles is a critical step in advancing the knowledge and application of resistance training as treatment in tendinopathy, as outcomes of current interventions have inadequate long-term outcomes. While the authors believe the findings present meaningful implications for future training interventions in tendinopathy, the review has several limitations. The review is unable to present any meaningful estimation of the effectiveness or dose response of resistance training on clinical outcomes such as pain and function in lower limb tendinopathies. Although there have been previous

systematic reviews investigating effectiveness, conclusions are often limited and inconclusive, due to the significant heterogeneity in methodological approaches in resistance training interventions for tendinopathies. This includes inconsistencies in the application and reporting of key resistance training principles and levels of adherence to the interventions, preventing any meaningful and accurate conclusions on outcomes. Another limitation of current RCTs on resistance training is the lack of blinding in studies, which introduces potential bias, as evidenced in this review. Although blinding may be difficult to implement in resistance training interventions, blinded allocation may help minimise the potential for bias in studies.

The importance of determining if the application of resistance training principles impacts on improved outcomes for tendinopathy patients is an essential requirement. As future RCTs addressing the methodological limitations identified in this review and implementing and applying the correct scientific principles of resistance training emerge in the literature, future systematic reviews will be in a better position and more justified in using methods to determine true effectiveness on clinical outcomes with meta-analysis techniques. Most studies in this review were conducted on Achilles and patellar tendinopathy (42/52), highlighting the paucity of resistance training studies conducted on other lower limb tendinopathies to date, despite progressive resistance training being widely recognised as the gold standard treatment for lower limb tendinopathies. Therefore, the generalisability of the review findings across all lower limb tendinopathies is limited. Further research on resistance training in other lower limb tendinopathies is warranted, and its emergence would allow for expansion of the resistance training recommendations highlighted in this review.

Conclusion

This review has highlighted the meaningful variability and methodological diversity that exists across studies which have implemented resistance training interventions as treatment for lower limb tendinopathies. Although the principles

of specificity and overload are adequately described and reported in resistance training studies, there is significant methodological shortcomings when it comes to the application and reporting of progression and individualisation principles, along with inadequate implementation and reporting of intervention adherence. Although the components of resistance training prescription are generally well reported throughout studies, the extent to which the modification of load and volume are modified to allow adequate overload and progression are poorly reported in current studies. Many studies also fail to prescribe resistance training within recommended scientific guidelines, with almost half of the studies adopting a twice daily eccentric training protocol, which does not allow for basic components of scientific training, such as recovery and progressive overload. Although many studies have shown positive clinical outcomes of various types of resistance training for lower limb tendinopathies, such as improved short-term pain and function, long-term outcomes may be considered inadequate, with up to half of patients being symptomatic at one-year follow up in several studies. This indicates that better resistance training interventions are warranted, with improvement of the implementation of resistance training principles, following scientific recommendations, being a potential avenue for improving outcomes. However, until the application of scientific resistance training principles is consistently reached in the tendinopathy literature, proper scientific appraisal and determining effectiveness through meta-analysis techniques cannot appropriately and conclusively be achieved. Future research evaluating the effects of resistance training on clinical outcomes for tendinopathies that is scientifically designed with accurate reporting of intervention adherence is urgently warranted to better elucidate the optimal treatment approach for this burdensome condition which has a significant global morbidity.

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Table 3: Study characteristics

Author	Tendinopathy	Intervention groups	Sample size	Intervention duration (wks)	Outcomes + measures	Follow-up length (weeks)	Outcomes/ results	Quality score
Beyer et al. 2015	Achilles	1. HSRT 2. ECCT	58	12	Pain (VAS), Function (VISA-A), Ultrasound	52	Both interventions were effective, with HSRT having greater patient satisfaction at 12 but not 52 weeks.	5
Kongsgaard et al. 2009	Patellar	1. CSI 2. HSRT 3. ECCT	37	12	Pain (VAS), Function (VISA-P), Ultrasound	26	All groups improved, with only exercise groups maintaining improvements at 6 months. HSRT has good short- and long-term clinical effects.	5
Riel et al. 2019	Plantar heel	1. fixed HSRT 2. Self-dosed HSRT	70	12	Function (FHSQ), Pain (self-efficacy), ultrasound	12	Both groups improved pain and function, with no significant differences between groups.	5
Stevens & Tan 2014	Achilles	1. fixed ECCT 2. Self-dosed ECCT	28	6	Pain (VAS), Function (VISA-A)	6	Both groups improved pain and function, with no significant differences between groups.	5
Da Cunha et al. 2012	Patellar	1. ECCT pain 2. ECCT no pain	17	12	Pain (VAS), Function (VISA-P)	12	No difference between groups, both groups improved pain and function.	3
Kulig et al. 2009	Posterior tibial	1. ECCT 2. CONCT 3. Orthoses	36	12	Pain (VAS), function (FFI)	12	Eccentric program was more effective than concentric or orthoses alone.	2
Bahr et al. 2006	Patellar	1. ECCT 2. surgery	35	12	Pain, function (VISA-P)	12	Both groups improved, no significant difference between groups. Trend favouring ECCT.	3
Lee et al. 2020	Patellar	1. ECCT 2. ECCT + ESWT	34	12	Pain (VAS), function (VISA-P), ultrasound	12	Combining exercise and ESWT could not been shown to be more effective than exercise alone	2
Frohm et al. 2007	Patellar	1. Standard ECCT 2. Overload ECCT	20	12	Pain (VAS), function (VISA-P)	12	Both treatment groups improved in the short term, with no significant difference between groups.	4

Silbernagel et al. 2001	Achilles	1. Overload ECCT 2. control	40	12	Pain (VAS), function, task performance	52	No significant difference between groups, at 1-year ECCT group more satisfied with outcomes.	2
Balius et al. 2016	Achilles	1. ECCT 2. ECCT + supplement 3. Supplement + stretching	59	12	Pain (VAS), function (VISA-A), ultrasound	12	Reduction in pain at rest was greater in the groups who took the supplement than in the ECCT alone group	4
Mafi et al. 2001	Achilles	1. ECCT 2. CONCT	44	12	Pain (VAS), function	12	The results after treatment with eccentric training was significantly better ($P<0.002$) than after concentric training.	4
Norregaard et al. 2007	Achilles	1. ECCT 2. Stretching	45	12	Manually tested Pain, function	52	Marked improvement in symptoms and findings could be gradually observed in both groups during the 1-year follow-up period.	4
Stasinopolous et al. 2004	Patellar	1. ECCT 2. Ultrasound 3. MT	30	4	Pain	4	ECCT was statistically significantly better than the other two treatments at the end of treatment.	4
De Vos et al. 2007	Achilles	1. ECCT 2. ECCT +night splint	70	12	Pain, function (VISA-A)	12	Both groups improved pain and function, with no significant difference between groups	5
Johannsen et al. 2019	Plantar Heel	1. HSRT 2. CSI 3. HSRT + CSI	90	12	Pain (VAS), function (FFI), ultrasound	26	Combined treatment is superior both in the short- and in the long-term.	6
MacDonald et al. 2019	Patellar	1. ECCT 2. ECCT + hip exercises	41	12	Pain, function (VISA-P, LEFS)	24	Favourable effects were demonstrated with combined treatment of eccentric squat and hip muscle strengthening or squat only	2
Gatz et al. 2020	Achilles	1. ECCT 2. ECCT + isometric	42	12	Pain, function (VISA-A), shear wave elastography	12	Isometric exercises do not have additional benefit when combined with eccentric exercises, as assessed over a 3-month intervention period.	3
Ganderton et al. 2018	Gluteal	1. Ex 2. Sham Ex	94	12	Pain, function (VISA-G)	52	Lack of treatment effect was found with the addition of an exercise program to education	5

Silbernagel et al. 2007	Achilles	1. Rehab with continued sports 2. Control	38	12	Pain (VAS), function (VISA-A)	26	Significant improvement and no negative effects demonstrated from continuing Achilles tendon-loading activity, such as running and jumping, with the use of a pain-monitoring model, during treatment.	6
Clifford et al. 2019	Gluteal	1. isometric Ex 2. Isotonic Ex	30	12	Pain (NRS), function (VISA-G), QoL	12	Both groups effective in reducing pain and improving function, no difference between groups.	2
Stergioulas et al. 2008	Achilles	1. ECCT + LLLT 2. ECCT	52	8	Pain (VAS), function (VISA-A)	12	LLLT accelerates clinical recovery when added to ECCT	3
Rompe et al. 2008	Achilles	1. ECCT 2. ESWT	50	12	Pain, function (VISA-A)	16	ESWT superior to ECCT at 16 weeks.	6
Mellor et al. 2018	Gluteal	1. Ex, education 2. CSI 3. control	204	8	Pain (NRS), function (VISA-G), QoL (EQ5D), GROG	52	At 52-week follow-up, education plus exercise led to better global improvement than corticosteroid injection use, but no difference in pain intensity	6
Van Ark et al. 2016	Patellar	1. isotonic Ex 2. Isometric Ex	29	4	Pain (NRS), function (SLDS)	4	Both isometric and isotonic exercise programs improved pain and function	3
Roos et al. 2004	Achilles	1. ECCT 2. ECCT + night splint 3. Night splint	44	6	Pain, function (FAOS)	52	ECCT more effective than night splint for improving pain and function	2
Chester et al. 2008	Achilles	1. ECCT 2. Ultrasound	16	12	Pain (VAS), function (FILLA), QoL (EQ5D)	12	There were no significant differences between groups or clear trends over time. Both interventions proved acceptable with no adverse effects.	3
Rompe et al. 2007	Achilles	1. ECCT 2. ESWT 3. Control	75	12	Pain, function (VISA-A)	16	ECCT and ESWT showed comparable positive results. The wait-and-see strategy was ineffective.	6
Thijs et al. 2017	Patellar	1. ECCT + ESWT 2. ECCT	52	12	Pain, function (VISA-P)	12	No additional effect of ESWT to ECCT for pain and function improvement.	4
Horstmann et al. 2013	Achilles	1. ECCT 2. Vibration	58	12	Pain (VAS), function,	24	Pain improvements were greatest in the eccentric group.	4

		training 3. control			tendon structure			
Alfredson et al. 1998	Achilles	1. ECCT 2. CT control	30	12	Pain (VAS)	12	Significant improvement with ECCT	2
Alvarez et al. 2006	Posterior tibial	1. Strength Ex + orthoses 2. Stretching + orthoses	39	12	Pain, function (FFI)	12	Both groups significantly improved in pain and function over the 12-week trial period. The self-report measures showed minimal differences between the treatment groups.	3
Kearney et al. 2013	Achilles	1. ECCT 2. PRP injection	20	12	Pain (VAS), function (VISA-A)	26	Both interventions effective, with PRP having better outcomes, however there was no significant difference.	5
Tumilty et al. 2012	Achilles	1. ECCT 2. ECCT + LLLT	40	12	Pain (VAS), function (VISA-A)	52	There was no statistically significant difference in VISA-A scores between groups.	6
Yelland et al. 2011	Achilles	1. ECCT 2. ECCT + prolotherapy 3. prolotherapy	43	12	Pain (VAS), function (VISA-A), costs	52	prolotherapy and particularly ECCT combined with prolotherapy give more rapid improvements in symptoms than ECT alone but long-term VISA-A scores are similar.	5
McCormack et al. 2016	Achilles	1. ECCT 2. ECCT + MT	16	12	Pain (NPRS), function (VISA-A)	52	ECCT + MT more effective than ECCT only at improving function during both short- and long-term follow-up	3
Tumilty et al. 2016	Achilles	1. ECCT 1 2. ECCT 1 + LLLT 3. ECCT 2 4. ECCT 2 + LLLT	80	12	Pain, function (VISA-A)	12	Twice-daily exercise sessions are not necessary as equivalent results can be obtained with two exercise sessions per week. The addition of LLLT can bring added benefit.	6
Cannell et al. 2001	Patellar	1. ECCT 2. Isotonic Ex	19	12	Pain (VAS), return to sport	12	Progressive drop squats and leg extension/curl exercises both reduced pain and enable return to sport	3
Jonsson et al. 2005	Patellar	1. ECCT 2, CONCT	19	12	Pain (VAS), function, (VISA-P)	12	eccentric, but not concentric, quadriceps training on a decline board, seems to reduce pain in PT	1
Kedia et al. 2014	Achilles	1. CT 2. ECCT + CT	36	12	Pain (VAS), function (SF36)	12	No significant differences between groups. CT and ECCT both effective.	5

Herrington et al. 2007	Achilles	1. ECCT + CT 2. CT	25	12	Pain, function (VISA-A)	12	ECCT + CT was more effective than CT alone for pain and function.	4
Houck et al. 2015	Posterior tibial	1. Orthosis + stretching 2. + strength Ex	39	12	Pain, function (FFI)	12	Both groups significantly improved in pain and function over the 12-week trial period. minimal differences between the treatment groups.	5
Dimitrios et al. 2012	Patellar	1. ECCT 2. ECCT + stretching	43	4	Pain, function (VISA-P)	24	ECCT and static stretching exercises is superior to ECCT alone to reduce pain and improve function	3
Petersen et al. 2007	Achilles	1. ECCT 2. Brace 3. ECCT + brace	100	12	Pain (VAS), function (AOFAS), QoL (SF-36)	54	The VAS score for pain, AOFAS score, and SF-36 improved significantly in all 3 groups at all 3 follow-ups, no significant difference between groups	3
Steunebrink et al. 2013	Patellar	1. ECCT + GTN 2. ECCT	33	12	Pain, function (VISA-P)	24	GTN + ECCT does not improve clinical outcome compared to placebo patches + ECCT	5
Rompe et al. 2009	Achilles	1. ECCT + ESWT 2. ECCT	68	12	Pain, function (VISA-A)	52	Combined ECCT + ESWT more effective at 4 months follow-up	5
Young et al. 2005	Patellar	1. ECCT step 2. ECCT decline	17	12	Pain (VAS), function (VISA-P)	52	Both groups improved pain and sporting function at 12 months. Decline squat more effective.	3
De Jonge et al. 2010	Achilles	1. ECCT 2. ECCT + night splint	58	12	Pain, function (VISA-A)	52	ECCT with or without a night splint improved functional outcome at 1-year. no significant difference in clinical outcome between groups.	5
Praet et al. 2019	Achilles	1. ECCT + collagen peptides	20	26	Pain, function (VISA-A)	26	Oral supplementation of collagen peptides may accelerate the clinical benefits of ECCT.	5
Rathleff et al. 2015	Plantar heel	1. HSRT 2. stretching	48	12	Pain, function (FFI)	52	HSRT superior to plantar fascia stretching for pain and function	3
Knobloch et al. 2008	Achilles	1. ECCT + brace 2. ECCT	116	12	Pain (VAS), function (FAOS)	12	No additional effect of heel brace to ECCT alone.	4
Wheeler et al. 2017	Plantar heel	1. General Ex 2. Ex + night splint	40	12	Pain (VAS), Function (FFI, FAAM)	12	Improvement in both groups, with no significant differences between groups.	5

Table 4: Application of resistance training principles

Author	Specificity	Overload	Progression + method	Individualised + method	Frequency (d/wk)	Intensity	Time (min)	Sets	Reps	Exercise mode/type	Adherence	RTP, Total score /10
Beyer et al. 2015	Y	Y	Y, increase resistance/load	Y, pain response 4-5/10	3	15RM – 6RM	107 x wk (HSRT) 308 x wk (ECCT)	3-4	15-6	Heel raises, with external weights	Y, diary	7, 9
Kongsgaard et al. 2009	Y	Y	Y, increase resistance	NR	3	15RM – 6RM	NR	3-4	15-6	DSL squats, squat, leg press, hack squat, with external weights	NR	5, 5
Riel et al. 2019	Y	Y	Y, increase resistance or volume	Y, as many sets as possible	3	8RM – 12RM	tut	3-5, AMAP	8-12	Heel raises, loaded backpack	Y, diary, 20 not returned	7, 9
Stevens & Tan 2014	Y	Y	Y, increase resistance or volume	Y, as many reps as possible	7, 2xd	15RM	NR	2 x 6 (12)	15 (180 total)	Heel raises (straight leg & bent knee), loaded backpack	Y, diary	7, 9
Da Cunha et al. 2012	Y	Y	Y, increase resistance (5kg inc)	Y, pain response	3	15RM	NR	3	15	Eccentric decline squat	NR	8, 8
Kulig et al. 2009	Y	Y	Y, increase resistance (0.9kg conforce spring)	Y, increase isokinetic resistance as able	7, 2xd	15RM	NR	2 x 3 (6)	15 (180)	Isokinetic resisted horizontal adduction with plantar flexion	Y, diary, 68% (39-98)	8, 10
Bahr et al. 2006	Y	Y	Y, increase resistance (5kg inc)	Y, pain response less 3/10, increase 5kg	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	DSL squat, loaded backpack	NR	8, 8
Lee et al. 2020	Y	Y	Y, increase resistance (5kg inc)	Y, pain response	7, 2Xd	15RM	NR	2 X 3 (6)	15 (180)	DSL squat, loaded backpack	Y, diary	8, 10

				4/10, increase 5kg								
Frohm et al. 2007	Y	Y	Y, increase resistance (5kg inc)	Y, pain response 5/10, increase 5kg	1.2 2. 7, 2xd	15-16RM	70 mins x session	3-4	15-16	1. The Bromsman eccentric overload training device 2. DSL squat, loaded backpack	NR	8,8
Silbernagel et al. 2001	Y	Y	Y, increase resistance, volume, speed & difficulty	Y, pain response 5/10	7	5-15RM	NR	3	5-15	Double and single leg Slow Heel raises, fast rebounding heel raises	Y, diary	7, 9
Balius et al. 2016	Y	UC	UC	UC	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	Alfredson heel raises, straight & bent knee	PT recorded; 70% minimum allowed	2, 4
Mafi et al. 2001	Y	Y	Y, increase resistance	Y, pain response	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	Alfredson heel raises, straight & bent knee, loaded with backpack or weight machines	NR	7, 7
Norregaard et al. 2007	Y	Y	Y, increase resistance (5kg inc)	Y, pain response, increase 5kg	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	Alfredson heel raises, straight & bent knee, loaded with backpack	Y. diary, results NR	8, 9
Stasinopolous et al. 2004	Y	Y	Y, increase resistance	Y, pain response	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	DSL squat, handheld external weights	NR	8, 8
De Vos et al. 2007	Y	Y	Y, increase resistance	Y, pain response	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	Alfredson heel raises, straight & bent knee, loaded with backpack or weight machines	Y, diary	7, 9
Johannsen et al. 2019	Y	UC	UC	NR	3	NR	NR	NR	NR	(1) heel-rises, (2) flexion of the first toe against elastic band. (3) Inversion of the	NR	2, 2

										foot against elastic band		
MacDonald et al. 2019	Y	Y	Y, increase resistance (5kg inc)	Y, pain response 5/10, increase 5kg, correct technique	7, 2xd	15RM	NR	2 X 3 (6)	15 (180)	DSL squat eccentric protocol with addition of isotonic hip exercise, loaded backpack	Y, diary, 42.5% full	8, 10
Gatz et al. 2020	Y	Y	Y, increase resistance	Y, pain response	7, 2 X D	15RM	NR	2 X 3 (6)	15 (180)	Alfredson eccentric heel raise protocol + isometric exercise	Y, verbal, NR	7, 8
Ganderton et al. 2018	Y	Y	Y, increase difficulty	Y, individual ability determined progression	7, 2 x d	5-15RM	30MIN X D	2-4	5-15	isometric loading of gluteals, and kinetic chain strength exercises	Y, diary	6, 8
Silbernagel et al. 2007	Y	Y	Y, Increase resistance, volume and speed of exercises	Y, Increased resistance, volume and speed guided by Pain response	7	10-20RM	NR	3	10-20	2-legged, 1-legged, eccentric, and fast rebounding toe raises, plyometric exercise. Loaded with backpack or weight machine	Y, diary	7, 9
Clifford et al. 2019	Y	Y	Y, increase resistance band strength	Y, pain response 5/10	7	6-10RM	6min TUT x d	3-6	6-10	Isotonic & isometric hip abduction, loaded with bands	Y, diary	7, 9
Stergioulas et al. 2008	Y	Y	Y, increase resistance (4kg inc)	Y, pain response 5/10	4	12RM	NR	12	12	Eccentric heel raise, knee straight & flexed, loaded backpack	Y, NR	8, 9
Rompe et al. 2008	Y	Y	Y, increase resistance (5kg inc)	Y, pain response, increase 5kg	7, 2 X D	10-15RM	NR	3 X 2 (6)	10-15 (180)	Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	Y, verbal, NR	8, 9
Van Ark et al. 2016	Y	Y	Y, increase resistance 2.5% per week	Y, pain response, correct technique,	4	isometric (80% 1RM) isotonic	NR	4-5	5-8	Leg extension machine, external weight. Audio used for speed tempo	NR	8, 8

				2.5% increase		(80% 8RM)						
Roos et al. 2004	Y	Y	Y, increase resistance	Y, pain response	7, 2 X D	15RM	NR	1-3	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	7, 7
Chester et al. 2008	Y	Y	Y, increase resistance	Y, pain response	7	15RM	NR	3 X 2 (6)	15 (90)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	7, 7
Rompe et al. 2007	Y	Y	Y, increase resistance (5kg inc)	Y, pain response, increase 5kg	7, 2 X D	10-15RM	NR	3 X 2 (6)	10-15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	8, 8
Thijs et al. 2017	Y	Y	Y, increase resistance	Y, pain response, 4/10	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	DSL eccentric squat, loaded backpack	NR	7, 7
Horstmann et al. 2013	Y	Y	Y, increase resistance + volume, based on fatigue	Y, increase resistance + volume, based on fatigue	7	15RM	NR	3-4	15	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	7, 7
Alfredson et al. 1998	Y	Y	Y, increase resistance	Y, pain response	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack or weight machine	NR	7, 7
Alvarez et al. 2006	Y	Y	Y, increase resistance (elastic bands) and volume	Y, increase resistance based on pain response + correct technique	7, 2 X D	30RM	NR	3	30	Isotonic exercise with elastic bands, increased resistance (elastic bands strength) 1. Bilateral heel raises 2. Ankle plantar flexion with adduction and	Y, diary	7, 9

										Inversion. 3. Unilateral heel raises (standing)		
Kearney et al. 2013	Y	Y	Y, progress from DL to SL with increased resistance	Y, pain response, progress from DL to SL with increased load	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack, DL progressing to SL	NR	7, 7
Tumilty et al. 2012	Y	Y	Y, increase resistance	Y, pain response	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	7, 7
Yelland et al. 2011	Y	Y	Y, increase resistance	Y, pain response 4/10	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	Y, diary	7, 9
McCormack et al. 2016	Y	Y	Y, increase resistance	NR	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	5, 5
Tumilty et al. 2016	Y	Y	Y, increase resistance	Y, pain response, 4/10	2	15RM	NR	3 X 2 (180)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack. 2Xwk V D	Y, diary, 46 returned	7, 9
Cannell et al. 2001	Y	Y	Y, increase resistance with fixed loading protocol & external weight	Y, pain response	5	10-20RM	NR	3	10-20	Progressive drop squats and leg extension/curl exercises, fixed loading protocol, external weights	NR	8, 8
Jonsson et al. 2005	Y	Y	Y, increase resistance	Y, self-acceptable	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	Eccentric v concentric DSL	NR	7, 7

				pain response						squat, loaded backpack		
Mellor et al. 2018	Y	Y	Y, increase difficulty/ intensity (BORG)	Y, pain response 5/10, BORG scale (13-17 target)	7	BORG (13-17)	30 min x session	1-2	3-15	Comprehensive progressive exercise program targeting hip muscles, monitored by pain response and BORG scale. External load NR. Spring resistance for hip abduction	Y, diary, 80%	8, 10
Kedia et al. 2014	Y	Y	Y, increase resistance	Y, exercise difficulty, increase resistance	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	Y, diary, NR	7, 8
Herrington et al. 2007	Y	Y	Y, increase speed and resistance	Y, increase speed and resistance based on pain response	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	Y, diary, NR	7, 8
Houck et al. 2015	Y	Y	Y, increase resistance – elastic bands strength	Y, increase resistance based on pain response & Ex technique	7, 2 X D	30RM	30 min x session	3 X 2 (6)	30 X 3 X 3 (180)	Bilateral & unilateral heel raises, ankle plantarflexion with adduction & inversion. Resistance bands	Y, diary	7, 9
Dimitrios et al. 2012	Y	Y	Y, increase resistance with handheld weights	Y, pain response	5	15RM	NR	3	15	Eccentric DSL squat, handheld weights	Y, diary, NR	7, 8
Petersen et al. 2007	Y	Y	Y, increase resistance	Y, pain response	7, 3 x D	15RM	NR	3 X 3 (9)	15 (270)	Modified Alfredson eccentric heel raise, knee	Y, diary, NR	7, 8

										straight & flexed, loaded backpack		
Steunebrink et al. 2013	Y	Y	Y, increase resistance (5kg inc)	Y, pain response, 3/10 = increase load	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson - Eccentric DSL squat	NR	8, 8
Rompe et al. 2009	Y	Y	Y, increase resistance (5kg inc)	Y, pain response	7, 2 X D	15RM	NR	3 X 2 (6)	10-15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	NR	8, 8
Young et al. 2005	Y	Y	Y, increase speed, then resistance (5kg inc)	Y, pain response	7. 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson DSL squat, loaded backpack	Y, diary	8, 10
De Jonge et al. 2010	Y	Y	Y, increase resistance	Y, pain response	7, 2 x d	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack or weight machine	Y, diary	7, 9
Praet et al. 2019	Y	Y	Y, increase speed, then resistance (5kg inc until max 60kg)	Y, pain response	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed, loaded backpack	Y, diary, NR	8, 9
Rathleff et al. 2015	Y	Y	Y, increase resistance	NR	3	12-8RM	NR	3-5	12-8	Heel raise on step with toes maximally dorsiflexed on towel	NR	5, 5
Knobloch et al. 2008	Y	NR	NR	NR	7, 2 X D	15RM	NR	3 X 2 (6)	15 (180)	Modified Alfredson eccentric heel raise, knee straight & flexed,	NR	2, 2
Wheeler et al. 2017	Y	NR	NR	NR	NR	NR	NR	NR	NR	stretching, calf & foot muscle strengthening and balance exercises.	NR	2, 2