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Strength training for plantar fasciitis and the intrinsic foot musculature: A systematic review

Dean Huffer ^{a,1}, Wayne Hing ^{b,*}, Richard Newton ^c, Mike Clair ^d

^a South Yarra Spine & Sports Medicine / Glenferrie Sports & Spinal Clinic, VIC / Bond University, QLD, Australia

^b Bond University, Australia

^c Pindara Physiotherapy & Sports Medicine / Sports Super Centre Runaway Bay / Bond University, QLD, Australia

^d Active Physiotherapy, Katherine N.T. / Bond University, QLD, Australia

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ABSTRACT

The aim was to critically evaluate the literature investigating strength training interventions in the treatment of plantar fasciitis and improving intrinsic foot musculature strength.

A search of PubMed, CINAHL, Web of Science, SPORTSDiscus, EBSCO Academic Search Complete and PEDRO using the search terms plantar fasciitis, strength, strengthening, resistance training, intrinsic flexor foot, resistance training.

Seven articles met the eligibility criteria. Methodological quality was assessed using the modified Downs and Black checklist. All articles showed moderate to high quality, however external validity was low.

A comparison of the interventions highlights significant differences in strength training approaches to treating plantar fasciitis and improving intrinsic strength. It was not possible to identify the extent to which strengthening interventions for intrinsic musculature may benefit symptomatic or at risk populations to plantar fasciitis. There is limited external validity that foot exercises, toe flexion against resistance and minimalist running shoes may contribute to improved intrinsic foot musculature function. Despite no plantar fascia thickness changes being observed through high-load plantar fascia resistance training there are indications that it may aid in a reduction of pain and improvements in function.

Further research should use standardised outcome measures to assess intrinsic foot musculature strength and plantar fasciitis symptoms.

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1. Introduction

Plantar fasciitis is one of the most common musculoskeletal disorders of the foot (McPoil et al., 2008; Young, 2012) treated in primary care (Thing, Maruthappu, & Rogers, 2012). It is thought to result from chronic overload either from lifestyle or exercise and affects both elderly and athletic populations (Schwartz, 2014).

The plantar fascia is an aponeurosis that originates from the medial tubercle of the calcaneus and extends distally to the phalanges (Bolgia, & Malone, 2004). The Windlass Mechanism is a term

used to describe how the plantar aponeurosis acts like a pulley (Hicks, 1954), developing tension during dorsiflexion of the great toe. This shortens the distance between the calcaneus and the metatarsals, as the aponeurosis winds around the metatarsal head resulting in elevation the medial longitudinal arch (Bolgia, & Malone, 2004). Together with the intrinsic foot muscles the plantar aponeurosis stabilises the arch and provides dynamic sensory and motor control to the foot (McKeon & Fouchet, 2015).

In addition to sedentary middle aged patients (Radford, Landorf, Buchbinder, & Cook, 2006), plantar fasciitis is particularly prevalent in running and dancing activities that require maximal plantar-flexion of the ankle and dorsiflexion of the metatarsophalangeal joint (Brukner & Khan, 2012). Symptoms are characterised by pain radiating the medial aspect of the heel into the arch of foot. Pain is often most intense with the first steps of the day or after rest or warming up with activity (Thing et al., 2012). As the condition progresses these symptoms can become more debilitating reducing

* Corresponding author.

E-mail addresses: dean@syssm.com.au (D. Huffer), whing@bond.edu.au (W. Hing), rmnewton@bigpond.net.au (R. Newton), mclair.physio@gmail.com (M. Clair).

¹ Contact address: Faculty of Health Sciences & Medicine, Bond University, QLD 4229, Australia.

the patient's ability to weight bear. Recent literature proposes that the condition should be termed a fasciosis as the pathology more closely resembles that of tendinosis (Brukner & Khan, 2012; Schwartz, 2014).

Brukner and Khan (2012) state that despite plantar fasciitis being the most common cause of rear foot (inferior heel pain) differential diagnosis should not overlook other common conditions such as fat pad contusion, and less common conditions such as calcaneal stress and traumatic fractures, medial calcaneal nerve entrapment, lateral plantar nerve entrapment, tarsal tunnel syndrome, talar stress fracture, retrocalcaneal bursitis, along with not to be missed pathologies such as spondyloarthropathies, osteoid osteoma and post knee or ankle injury complex pain syndrome (CRPS Type 1). McPoil et al. (2008) include a similar list of differentials, but with the addition of Sever's disease (calcaneal apophysitis) a common cause of heel pain in pediatric patients typically aged 7–14 years old (Marchick, Young, & Ryan, 2015).

Treatments for plantar fasciitis have been varied, with conflicting evidence (McPoil et al., 2008). Until recently exercise therapy reviews have highlighted the effectiveness of plantar fascia-specific stretching and have indicated it may have limited benefits (Almubarak, 2012; Schwartz, 2014). However, a recent a systematic

review found that there is a significant association between intrinsic foot muscle weakness and painful foot pathologies such as plantar fasciitis (Latey, Burns, Hiller, & Nightingale, 2014). Therefore, the aim of this review is to critically evaluate the literature investigating strength training interventions in the treatment of plantar fasciitis and improving intrinsic foot musculature strength.

2. Methodology

2.1. Search strategy

The systematic review "Strength training for plantar fasciitis and the intrinsic foot musculature" was registered with PROSPERO (No. CRD42016036302). The following bibliographic databases were searched to identify potentially relevant articles: PubMed, CINHAL, Web of Science, SPORTSDiscus, EBSCO Academic Search Complete and PEDRO or all articles up until March 23, 2016.

The database search, literature screening and data extraction was completed by a single researcher (DH). The database search consisted of using the search terms: ("plantar fasciitis") AND ("strength" OR "strengthening" OR "resistance training") and then repeated with the search terms ("intrinsic foot muscle" OR

<p>REPORTING: "Yes=1," "No=0"</p> <ol style="list-style-type: none"> 1. Is the hypothesis / aim / objective of the study clearly described? 2. Are the main outcomes to be measured clearly described in the Introduction or Methods section 3. Are the characteristics of the patients / samples included in the study clearly described? 4. Are the interventions of interest clearly described? 5. Are the distributions of principal confounders in each group of subjects to be compared clearly described? "Yes=2," "Partially=1," "No=0" 6. Are the main findings of the study clearly described? 7. Does the study provide estimates of the random variability in the data for the main outcomes? 8. Have all important adverse events that may be a consequence of the intervention been reported? 9. Have the characteristics of patients lost to follow-up been described? 10. Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001? 11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited? <p>EXTERNAL VALIDITY: "Yes=1," "No=0," "Unable to determine=0"</p> <ol style="list-style-type: none"> 12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited? 13. Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive? <p>INTERNAL VALIDITY - BIAS: "Yes=1," "No=0," "Unable to determine=0"</p> <ol style="list-style-type: none"> 14. Was an attempt made to blind study subjects to the intervention they have received? 15. Was an attempt made to blind those measuring the main outcomes of the intervention? 16. If any of the results of the study were based on "data dredging" was this made clear? 17. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls? 18. Were the statistical tests used to assess the main outcomes appropriate? 19. Was compliance with the intervention/s reliable? 20. Were the main outcome measures used accurate (valid and reliable)? <p>INTERNAL VALIDITY - CONFOUNDING (Selection Bias): "Yes=1," "No=0," "Unable to determine=0"</p> <ol style="list-style-type: none"> 21. Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population? 22. Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time? 23. Were study subjects randomised to intervention groups? 24. Was the randomized intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable? 25. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn? 26. Were losses of patients to follow-up taken into account? <p>POWER</p> <ol style="list-style-type: none"> 27. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?
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Fig. 1. Modified Downs & Black Checklist (Deschpande et al., 2008).

“intrinsic flexor foot”) AND (“strength” OR “strengthening” OR “resistance training”).

2.2. Study selection

The screening process began with the removal of duplicate articles, before screening articles based on title and abstract against the search terms. The remaining articles were then reviewed as full texts against the following criteria: (i) a specific isolated plantar/IFM strength intervention, and (ii) pre-test and post-test measures to assess the effectiveness of intervention being the only study design requirement.

2.3. Data extraction

Data extraction was performed by using a pre-defined data-abstraction sheet. The following data were extracted: (i) Author (year), (ii) country, (iii) study design, (iv) participants i.e. sample size, demographics, male/female ratio, (v) interventions i.e. intervention groups, exercise prescription (sets/repetitions); (vi) outcome measures; and (vii) main findings (results).

2.4. Quality evaluation

Study quality was independently assessed by two examiners (MC, DH), with disagreements resolved by consensus. In the case of continued disagreement, a third reviewer was available for arbitration (WH). Quality was assessed using the “Checklist for Measuring Quality” (Downs & Black, 1998) (Re: Fig. 1). The 27 question checklist has been used previously in systematic reviews including various study designs (Crow, Pizzari, & Buttifant, 2011), and has been shown to have good intra-rater ($r = 0.88$) and inter-

rater ($r = 0.75$) reliability (Downs & Black, 1998). The last item of the checklist examining the power of results was simplified to a score of 0 (no sample size calculation) or 1 (sample size calculation reported) (Deshpande, Khoja, & McKibbin, 2008). Therefore, a maximum score of 28 could be achieved for randomised studies and 25 for non-randomised studies.

2.5. Data analysis

Due to the heterogeneous nature of the included studies (i.e. varying study designs, interventions, outcome measures, and quality of data), a quantitative analysis was unfeasible. The following cut-off points have been reported to categorise studies by quality: excellent (26–28), good (20–25), fair (15–19) and poor (≤ 14) (Chudyk, Jutai, Petrella, & Speechley, 2009).

3. Results

Combined searches literature searches produced a total of 226 articles, and once duplicates were removed (94 excluded) this was reduced to 132 eligible articles. Articles were then screened by title (92 excluded), abstract (11 excluded), and then 29 articles full text articles were obtained for review against the inclusion criteria “(i) specific isolated plantar/IFM strength intervention, and (ii) pre-test and post-test measures to assess the effectiveness of intervention” with a further 22 articles being excluded. A total of seven clinical trials published in peer-reviewed journals were retained for review at the completion of the literature screening process.

3.1. Methodological quality

All seven articles were assessed against the Down’s and Black

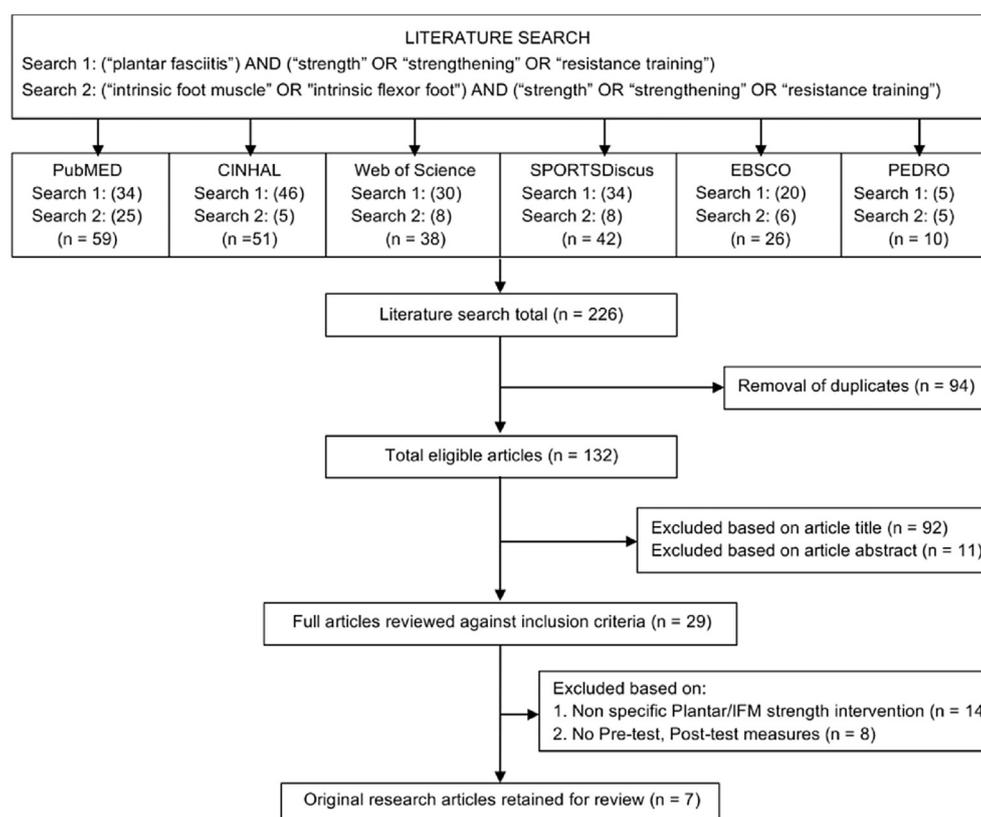


Fig. 2. Flow diagram of literature screening process.

Table 1
Categorisation of total methodological scores with Downs & Black checklist.

Quality Index	Percentage	Methodological quality score
Strong	75%+	21+
Moderate	50–74%	14–20
Limited	25–49%	7–13
Poor	<25%	<7

Adapted from (Hartling, Brison, Crumley, Klassen, & Pickett, 2004).

checklist and attained a score of either moderate or high quality. Four of the seven articles were deemed to be high quality articles (score > 21). The other three articles were deemed to be of moderate quality (score >14). The main areas of weakness in all seven studies was their external validity and power analysis of the Modified Downs and Black checklist. Internal validity of all seven articles was fairly poor as well. Additionally, only five of the seven articles attempted to blind those measuring the main outcomes of the intervention (Re: Table 1).

3.2. Study characteristics

The studies included four randomised control trials (RCTs) (Johnson, Myrer, Mitchell, Hunter, & Ridge, 2015; Lynn, Padilla, & Tsang, 2012; Miller, Whitcome, Lieberman, Norton, & Dyer, 2014; Rathleff et al., 2014) and three pre/post-test designs (Hashimoto & Sakuraba, 2014; Mulligan & Cook, 2013; Skou, Rathleff, Moelgaard, Rasmussen, & Olesen, 2012).

All studies had substantial differences in their strengthening interventions for plantar heel pain and the intrinsic foot musculature from their approach, exercise prescription/progression and timeframe. In broad terms the eight articles could be grouped into three interventional approach categories: 1. Minimalist running shoe IFM strengthening (Johnson et al., 2015; Miller et al., 2014.), 2. IFM foot exercises (Hashimoto & Sakuraba, 2014; Lynn et al., 2012; Mulligan & Cook, 2013), and 3. Plantar aponeurosis loading (Rathleff et al., 2014; Skou et al., 2012). Four of these seven studies stipulated loading progressions for the intervention over the duration of the study.

3.2.1. Minimalist running shoe IFM strengthening

The differences in minimalist running shoes interventions (Johnson et al., 2015; Miller et al., 2014.) included minimal running shoe allocation, mileage prescription and intervention duration. Miller et al. (2014) provided a range of minimal running with a 4mm heel-to-toe offset or less. It also stipulated a precise 30miles (48km) per week running total volume over 12-weeks. In comparison the Johnson et al. (2015) prescribed a specific 0 mm heel-to-toe offset minimal running shoe model (Vibram Five Fingers), and a mileage range 15–30miles (24–48km) over its 10-week duration.

3.2.2. IFM foot exercises

The IFM strengthening in response to a foot exercises load included three exercise interventions (Hashimoto & Sakuraba, 2014), towel curl exercises (Lynn et al., 2012) short foot exercises (SFE) (Lynn et al., 2012; Mulligan & Cook, 2013). The SFE, along with the heel raise variations in the (Rathleff et al., 2014; Skou et al., 2012) were the only exercises appearing in more than a single study. The SFE intervention consisted of shortening the foot without curling the toes to elevate the arch, with care to avoid engaging the long toe flexors. The intervention was submaximal exercise that relied on technique for IFM activation rather than power (Mulligan & Cook, 2013).

3.2.3. Plantar aponeurosis loading

The plantar aponeurosis loading interventions (Rathleff et al., 2014; Skou et al., 2012) exercise consisted of a single leg heel raise protocol, with toes dorsiflexed under cloth (Skou et al., 2012) and towel (Rathleff et al., 2014). This loading approach was inspired by the Carlson, Fleming, and Hutton, (2000) research into the biomechanical relationship between the tendoachilles, plantar fascia and metatarsophalangeal joint dorsiflexion angle. However, Rathleff et al. (2014) was a longer duration study with one, two, three and 12-month follow-ups and was progressed with loading a backpack with books. While the Skou et al. (2012) was only a time-of-day intervention.

Therefore, all seven studies were clinically and therapeutically heterogeneous, necessitating a qualitative analysis for summarizing the results. Table 2 provides a summary of the included studies.

3.3. Sample characteristics

All together the seven studies included a total of 185 participants with a slightly higher female portion reported (51.6%). Hashimoto & Sakuraba (2014) was the only gender specific study (12 males). Rathleff et al. (2014) differed from the other studies with an older (mean age 46years \pm 8.0) and symptomatic plantar fasciitis sample population with greater body mass indexes (BMI's) 27.1kg/m² (\pm 8.9). In contrast the other studies all had young (mean ages between 23.0 and 31.2 years) healthy - BMI between 18.50 and 24.99 (World Health Organization, 2015) asymptomatic patients (no history of plantar fasciitis/heel pain). The sample sizes of the studies were small and ranged from 12 to 48 participants, therefore reducing the validity of the studies' statistical conclusions. Table 3 contains details of the sample population characteristics.

3.4. Outcome measures

A total of 18 outcome measures were identified across the eight reviewed studies. Toe dynamometry (Toe flexor strength) was the only direct strength measure with excellent inter-rater reliability (ICC value of 0.98) reported by Hashimoto & Sakuraba (2014).

Indirect IFM functional measures included Intrinsic Foot Musculature Test (Mulligan & Cook, 2013), Navicular height in standing (Lynn et al., 2012), Navicular drop (Mulligan & Cook, 2013), Arch Height Index (Mulligan & Cook, 2013), Arch rigidity index (Mulligan & Cook, 2013), Relative arch deformation (Miller et al., 2014), Lower limb physical performance tests: Star excursion balance test (Mulligan & Cook, 2013), The modified Star Excursion (Y-Balance) Test (Lynn et al., 2012), Single legged long jump (Hashimoto & Sakuraba, 2014), Vertical jump (Hashimoto & Sakuraba, 2014) and 50-m dash (Hashimoto & Sakuraba, 2014).

Ultrasonographic Imaging (USI) and Magnetic Resonance Imaging (MRI) were the other two objective measures implemented across the studies with different objectives. USI to measure plantar fascia thickness (Rathleff et al., 2014; Skou et al., 2012) and cross sectional areas of IFM (Johnson et al. 2015). MRI was used to measure cross sectional areas of IFM (Miller et al., 2014) and employed by Johnson et al. (2015) to calculate Bone Marrow Oedema scores (BMES), a four point radiology scale (0 = no oedema, 1 = remodeling, 2 = stress reaction, 3 = stress fracture and 4 = full fracture).

Rathleff et al. (2014) implemented the only subjective measure, the Functional Foot Index (FFI). The FFI is a self-report questionnaire that assesses multiple dimensions of foot function (Budiman-Mak, Conrad, & Roach, 1991). The FFI consists of 23 items divided into three subscales that quantify the impact of foot pathology on pain, disability, and activity limitation. The scores range from 0 to

Table 2
Summary of included studies.

Author (Year) Study design D&B score	Sample size	Intervention Group (IG)	Comparison Group (CG)	Outcome measures	Results
Hashimoto & Sakuraba (2014) Pre/post 15/28	n = 12	Toe flexion Interphalangeal/ Metatarsophalangeal joints 3 kg load. 8wks 3 day/wk 200reps/day	–	<ul style="list-style-type: none"> Digital grip dynamometer Foot arch measurements (longitudinal and horizontal planes) during static standing using the Berkemann footprint. Dynamic test items: single leg long jump, vertical jump, and 50 m dash. Ultrasonography measurements of abductor hallucis (ABDH), flexor digitorum drevus (FDB), flexor hallucis brevis (FHB), extensor digitorum brevis (EDB) thickness Magnetic resonance imaging (MRI) of Bone Marrow Oedema scores (BME) 	<ul style="list-style-type: none"> Significant changes observed for intrinsic foot flexor strength scores, foot arches, vertical jumping, single leg long jumping, and 50 m dash time.
Johnson et al. (2015) RCT 23/28	n = 37	n = 18 Transitioned to Vibram Five Fingers (VFF) (0 mm heel-to-toe offset) 10wks: 24–48 km running/wk	n = 19 Ran in preferred traditional running shoes (12 mm heel-to-toe offset) 10wks: 24–48 km running/wk	<ul style="list-style-type: none"> Total range of movement of the center of pressure in mediolateral direction for a static-balance test and a dynamic balance test on a force plate Navicular height in weight-bearing 	<ul style="list-style-type: none"> Significant increase in ABDH cross sectional area in the Vibram Five Fingers (minimalist running shoe) group ($p = 0.01$) No significant changes in the other muscles measured ($p > 0.05$). Bone marrow oedema developed primarily in females who has significantly smaller size in all muscles ($p \leq 0.05$). Static-balance test and navicular-height test were not affected by training the intrinsic form muscles (IFM). Dominant limb: Small improvement in performance for all 3 groups during the second testing. Non-dominant limb, dynamic-balance test performance only improved in the 2 exercise groups. Short foot exercise (SFE) group improved much more than the Towel curl exercise (TCE) group. CG: Foot strike pattern did not change IG: Shifted to a more mid-foot strike or fore-foot strike pattern. FDB became larger in both groups: CG = 11% IG = 21% ABDM became larger in minimally shod runners. IG = 22% Significantly increased longitudinal arch stiffness (60%) in minimally shod runners.
Lynn et al. (2012) RCT 19/28	n = 24	Short Foot Exercise (SFE) n = 8 Towel Curl Exercises (TCE) n = 8 4wks: 100reps/day for both groups	n = 8	<ul style="list-style-type: none"> Running kinematics – captured on a standard treadmill using an eight-camera Vicon MX T10 3D motion capture system. Arch height index in sitting and standing to calculate relative arch deformation $\frac{AH_{sit}-AH_{std}}{AF_{sit}} \times \left(\frac{10^4}{BW}\right)$ MRI to measure cross-sectional area and muscle volumes of abductor hallucis (ADH), flexor digitorum brevis (FLDB), and abductor digiti minimi (ABDM) Navicular drop (ND) difference between the seated and standing navicular positions Arch Height Index (AHI) calculated by dividing the dorsum foot height by the truncated length of the foot to form a ratio in both the seated and standing positions Intrinsic Foot Musculature Test 	<ul style="list-style-type: none"> CG: Foot strike pattern did not change IG: Shifted to a more mid-foot strike or fore-foot strike pattern. FDB became larger in both groups: CG = 11% IG = 21% ABDM became larger in minimally shod runners. IG = 22% Significantly increased longitudinal arch stiffness (60%) in minimally shod runners. Subject ND decreased by a mean of 1.8 mm at 4wks and 2.2 mm at 8wks ($p < 0.05$) AHI increased from 28 to 29% ($p < 0.05$) Intrinsic foot muscle performance during a static unilateral balancing activity improved from a grade of fair to good ($p < 0.001$)
Miller et al. (2014) RCT 22/28	n = 33	n = 17 Transitioned to running in minimal shoes (4 mm or less heel-to-toe offset) 12wks: 30miles (48km) running/wk	n = 16 Ran in traditional running shoes 12wks: 30miles running/wk	<ul style="list-style-type: none"> Running kinematics – captured on a standard treadmill using an eight-camera Vicon MX T10 3D motion capture system. Arch height index in sitting and standing to calculate relative arch deformation $\frac{AH_{sit}-AH_{std}}{AF_{sit}} \times \left(\frac{10^4}{BW}\right)$ MRI to measure cross-sectional area and muscle volumes of abductor hallucis (ADH), flexor digitorum brevis (FLDB), and abductor digiti minimi (ABDM) Navicular drop (ND) difference between the seated and standing navicular positions Arch Height Index (AHI) calculated by dividing the dorsum foot height by the truncated length of the foot to form a ratio in both the seated and standing positions Intrinsic Foot Musculature Test 	<ul style="list-style-type: none"> CG: Foot strike pattern did not change IG: Shifted to a more mid-foot strike or fore-foot strike pattern. FDB became larger in both groups: CG = 11% IG = 21% ABDM became larger in minimally shod runners. IG = 22% Significantly increased longitudinal arch stiffness (60%) in minimally shod runners. Subject ND decreased by a mean of 1.8 mm at 4wks and 2.2 mm at 8wks ($p < 0.05$) AHI increased from 28 to 29% ($p < 0.05$) Intrinsic foot muscle performance during a static unilateral balancing activity improved from a grade of fair to good ($p < 0.001$)
Mulligan & Cook (2013) Pre/post 25/28	n = 21	Short Foot Exercises (SFE) 4wks: 5sec holds up to 3 min holds day for approximately 30reps/day. Progressed: from sitting to double limb stance (DLS) to single limb stance (SLS) when 3 min obtained.	–	<ul style="list-style-type: none"> Running kinematics – captured on a standard treadmill using an eight-camera Vicon MX T10 3D motion capture system. Arch height index in sitting and standing to calculate relative arch deformation $\frac{AH_{sit}-AH_{std}}{AF_{sit}} \times \left(\frac{10^4}{BW}\right)$ MRI to measure cross-sectional area and muscle volumes of abductor hallucis (ADH), flexor digitorum brevis (FLDB), and abductor digiti minimi (ABDM) Navicular drop (ND) difference between the seated and standing navicular positions Arch Height Index (AHI) calculated by dividing the dorsum foot height by the truncated length of the foot to form a ratio in both the seated and standing positions Intrinsic Foot Musculature Test 	<ul style="list-style-type: none"> CG: Foot strike pattern did not change IG: Shifted to a more mid-foot strike or fore-foot strike pattern. FDB became larger in both groups: CG = 11% IG = 21% ABDM became larger in minimally shod runners. IG = 22% Significantly increased longitudinal arch stiffness (60%) in minimally shod runners. Subject ND decreased by a mean of 1.8 mm at 4wks and 2.2 mm at 8wks ($p < 0.05$) AHI increased from 28 to 29% ($p < 0.05$) Intrinsic foot muscle performance during a static unilateral balancing activity improved from a grade of fair to good ($p < 0.001$)

(continued on next page)

Table 2 (continued)

Author (Year) Study design D&B score	Sample size	Intervention Group (IG)	Comparison Group (CG)	Outcome measures	Results
Rathleiff et al. (2014) RCT 23/28	n = 48	Strength: n = 24 Follow-up: n = 22 1mth: n = 22 3mths: n = 18, 6mths: n = 17, 12mths: n = 18 Strength group (shoe inserts and high-load strength training) Every 2nd day: 3sets of 12reps (3sec concentric heel raise, 3sec eccentric heel down phase). 2wks: Load increased (backpack/books) for 4sets of 10, then at 4wks: 5sets of 8. Sub-study 2: Unilateral heel raise with toes dorsiflexed by placing a folded dishcloth under toes. 12 reps (3sec concentric heel raise, 3 s eccentric heel down phase) approx. 90sec per set with 3 sets, and 2 min recovery between sets.	Stretch: n = 24 Follow-ups: 1mth: n = 23, 3mths: n = 2, 6mths: n = 20 12mths: n = 20) Stretch group (shoe inserts and plantar fascia stretching) 3 × day (10 × 10sec) stretch	<ul style="list-style-type: none"> Arch rigidity index (ARI), represents the structural mobility of the MLA. This ratio is calculated by dividing the standing AHI by the sitting AHI Star excursion balance test Primary Outcome: Foot Function Index (FFI) Self report questionnaire Secondary Outcomes: Ultrasonography measurements of plantar fascia thickness at 1, 3 and 6mths, FFI: Item 1 (foot pain at worst) and Item 2 (foot pain during first step in the morning). 	<ul style="list-style-type: none"> Significant improvement during a functional balance and reach task in all directions with the exception of an anterior reach ($p < 0.05$) At the primary endpoint the strength group had a FFI that was 29-points lower ($p.0.05$) compared with the stretch group. There were no differences in any of the secondary outcomes.
Skou et al. (2012) Pre/post-test 20/28	n = 10		–	Sub-study 2: Ultrasonography measurements of plantar fascia thickness prior, immediately after, and 3 h post-exercise.	Plantar fascia thickness did not change in relation to Sub-study 2: high-load strength training.

Note: n = participants, sec = seconds, mins = minutes, hrs = hours, wks = weeks, mth(s) = month(s), reps = repetitions, mm = millimetres, m = metres, km = kilometres, kg = kilograms, RCT = randomised control trial IG = Intervention Group, CG = Control Group.

Table 3
Sample population characteristics.

Author/Country	Sample population	Sample mean (standard deviation)				
		Gender (M:F)	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m ²)
Hashimoto & Sakuraba (2014) Japan	Healthy males without motor system disease or sport history.	12:0	29.0(±5.0)	172.5 (±7.3)	64.9 (±12.8)	21.5
Johnson et al. (2015) U.S.A.	Recreational runners completing an average of 24–48 km/wk running for 6mths prior. Exclusion criteria: Previous use of minimal running shoes or a lower extremity injury that prevented running for >3 day/wk during the previous 6mths. Healthy university-age volunteers with no history of major lower limb pathology or balance impairment.	10:8*	26 (±6)	174 (±1)	70 (±13)	23.1
Lynn et al. (2012) U.S.A.	Healthy runners running an average 30miles(48miles)/wk running in a standard running shoe for more than 12mths prior.	10:14	23.0(±1.6)	172.0	68.2 (±9.8)	23.2
Miller et al. (2014) U.S.A.	Asymptomatic to foot pain, PFPs, tibialis anterior or posterior dysfunction or neurological disease within past 3mths.	17:16	30.2	177.1	69.8	22.3
Mulligan & Cook (2013) U.S.A.	Average weekly training days 5.94days per/wk Over 18yrs, non-pregnant with: (i) history of heel pain for at least 3mths prior (ii) pain on palpation of the medial calcaneal tubercle or the proximal plantar fascia. (iii) >4 mm plantar fascia thickness.	3:18	26.1 (±5.0)	168.4 (±7.1)	69.3 (±13.5)	24.4
Rathleff et al. (2014) Denmark	No history of systemic diseases, prior heel surgery, corticosteroid injections into plantar fascia (within 6mths). No history of aponeurosis plantaris pedis pain.	16:32	46.0 (±8.0)	172.1 (±8.9)	79.6 (±12.8)	27.1 (±8.9)
Skou et al. (2012) Denmark		5:5	31.2 (±6.5)	–	–	22.2 (±6.5)

Note: M = male, F = female, wks = weeks, mths = months, yrs = years, mm = millimetres, m = metres, km = kilometres, kg = kilograms, PFPs = patellofemoral pain.

230, with 0 reflecting no pain, disability, or activity limitations (Budiman-Mak et al., 1991). The minimal important change is 7-points for the total scale (Landorf & Radford, 2008).

3.5. Clinical benefits

Five of the seven studies found evidence of IFM strengthening gains in response to the strengthening interventions (Hashimoto & Sakuraba, 2014; Johnson et al., 2015; Lynn et al., 2012; Miller et al., 2014; Mulligan & Cook, 2013).

In respect to plantar fasciitis/heel pain Rathleff et al. (2014) found a 29-point improvement on the strengthening intervention group on the FFI compared to stretching group at the primary study endpoint at three months. Skou et al. (2012) found no change in USI measurements of plantar fascia thickness immediately after, while Rathleff et al. (2014) found no significant changes between the stretching and strengthening intervention groups plantar fascia thickness.

4. Discussion

A comparison of the interventions presented in the reviewed studies highlights significant differences in strength training approaches to treating plantar fasciitis and improving intrinsic foot musculature strength. Lately et al. (2014) documented a link between intrinsic foot muscle weakness and painful foot pathologies such as plantar fasciitis. However, Rathleff et al. (2014) was the only study that examined a symptomatic population. It was also of particular significance given that high-load strength training that causes high tensile loads across the tendon has shown promising results on degenerative tendon disorders such as achilles and patellar tendinopathy (Cook & Purdam, 2009; Malliaras, Barton, Reeves, & Langberg, 2013).

The external validity of the studies is limited due to the non-sampling of at risk populations for plantar fasciitis. Riddle, Pulisic, Pidcoe, and Johnson (2003) described the main risk factors for plantar fasciitis as reduced ankle dorsiflexion, obesity (BMI >30 kg/m²) and work-related weight-bearing. Despite Riddle et al. (2003) concluding that reduced ankle dorsiflexion appears to be the most important risk factor, Rathleff et al. (2014) reported a greater reduction on the FFI symptoms from a strengthening intervention at the primary study endpoint (3 months) in comparison to stretching interventions. There were no significant differences in any of the secondary outcomes in Rathleff et al. (2014) study including USI of plantar fascia thickness at one, three and six months and FFI: Item 1 (foot pain at worst) and Item 2 (foot pain during first step in the morning).

In terms of athletic populations, it has been found that the relative risk of injury increases significantly in males and females running greater 40miles (64 km) per week (Macera, 1989) which is still considered low-mileage in distance running terms. Both Miller et al. (2014) 30miles (48km) and Johnson et al. (2015) 15–20miles (24–48 km) prescribed much lower weekly volumes and therefore reducing the validity of their results to distance runners. The studies did show promising results in hypertrophy of abductor hallucis (Johnson et al. 2015), flexor digitorum brevis muscles, abductor digiti minimi and significantly increased longitudinal arch stiffness (Miller et al., 2014). It should be acknowledged that Johnson et al., 2015 documented that pre IFM strength was also a factor in a safe transition to minimal running shoes, with some participants (primarily woman with smaller IFM) developing bone marrow oedema in response to the intervention.

Knapik, Orr, Pope, and Grier (2016) recently reported that despite impact forces generally being lower in minimally shod

shoes that the findings were inconclusive in regard to impact forces, loading and injury rates. Along with the lack of research into the safety and effectiveness of minimal running shoes in symptomatic populations with IFM weakness related pathologies such as plantar fasciitis, the duration of these studies was also limited for a condition that may debilitate for months on end.

The main limitation of a systematic review of the effectiveness of the strengthening interventions for IFM and plantar fasciitis/heel pain is the variance in outcome measures. There is a focus on not only assessing strength of the IFM muscles but also their function in the literature with a number of outcome measures. Unfortunately, these are not uniform across the studies. Rathleff et al. (2014) was the only study to implement an outcome measure that took into account the effect of pain that is often described as the most debilitating component of plantar fasciitis (McPoil et al., 2008).

The narrative article by (McKeon & Fourchet, 2015), propose a new paradigm by which to view foot function, assessment, and treatment as one. McKeon & Fourchet (2015) claim that methods of assessing toe flexion strength are inherently limited by the inability to conclusively separate the contributions of intrinsic and extrinsic toe flexor muscles.

There is a strong need for future studies regarding investigating strength training interventions in the treatment of plantar fasciitis and the improving intrinsic foot musculature strength to use consistent outcome measures and to examine at risk populations. Study outcome measures should address the following: (i) objective: functional performance, (ii) subjective: functional performance (i.e. pain/limiting factors) and (iii) intrinsic foot muscle strength. Future research into strength training interventions in the treatment of plantar fasciitis and the improving intrinsic foot musculature strength should target symptomatic and at risk populations.

5. Summary

Based on the studies reviewed it was not possible to identify the extent to which strengthening interventions that improve intrinsic foot musculature may benefit symptomatic or at risk populations to plantar fasciitis/heel pain.

There is limited external validity that short foot exercises (Lynn et al., 2012; Mulligan & Cook, 2013) toe flexion of all interphalangeal and metatarsophalangeal joints against resistance (Hashimoto & Sakuraba, 2014) contribute to improved intrinsic foot musculature functional performance when assessed against a variety of outcome in young healthy asymptomatic adults.

Minimal running shoes (Miller et al., 2014; Johnson et al., 2015) have also shown hypertrophic changes in IFM in asymptomatic populations. However, more research is needed for their effectiveness and safety of their prescription in symptomatic populations with foot weakness related pathologies such as plantar fasciitis.

Despite no plantar fascia thickness changes being observed through high-load plantar fascia resistance training (Rathleff et al., 2014; Skou et al., 2012) there are indications that it may aid in a quicker reduction of pain and improvements in function (Rathleff et al., 2014).

Further research should use standardised outcome measures to assess intrinsic foot musculature strength and plantar fasciitis symptoms.

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References

- Almubarak, A. (2012). Exercise therapy for plantar heel pain. *International Journal of Exercise Science*, 5(3), 276–289.
- Bolgia, L. A., & Malone, T. R. (2004). Plantar fasciitis and the windlass mechanism: A biomechanical link to clinical practice. *Journal of Athletic Training*, 39(1), 77–82.
- Brukner, P., & Khan, K. (2012). *Brukner & Khan's clinical sports medicine*. Sydney: McGraw-Hill.
- Budiman-Mak, E., Conrad, K. J., & Roach, K. E. (1991). The foot function index: A measure of foot pain and disability. *Journal of Clinical Epidemiology*, 44, 561–570.
- Carlson, R. E., Fleming, L. L., & Hutton, W. C. (2000). The biomechanical relationship between the tendoachilles, plantar fascia and metatarsophalangeal joint dorsiflexion angle. *Foot & Ankle International*, 21(1), 18–25.
- Chudyk, A., Jutai, J., Petrella, R., & Speechley, M. (2009). Systematic review of hip fracture rehabilitation practices in the elderly. *Archives of Physical Medicine and Rehabilitation*, 90(2), 246–262.
- Cook, J. L., & Purdam, C. R. (2009). Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *British Journal of Sports Medicine*, 43(6), 409–416.
- Crow, J., Pizzari, T., & Buttifant, D. (2011). Muscle onset can be improved by therapeutic exercise: A systematic review. *Physical Therapy In Sport*, 12(4), 199–209.
- Deshpande, A., Khoja, S., & McKibbin, A. (2008). *Telehealth for acute stroke management (Telestroke): Systematic review of analytic studies and environmental scan of relevant initiatives (Technology Report No. 99)*. Ottawa: Canadian Agency for Drugs and Technologies in Health.
- Downs, S. H., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomized and non-randomized studies of health care interventions. *Journal of Epidemiology & Community Health*, 52, 377–384.
- Hartling, L., Brison, R. J., Crumley, E. T., Klassen, T. P., & Pickett, W. (2004). A systematic review of interventions to prevent childhood farm injuries. *Pediatrics*, 114(4), e483–e496.
- Hashimoto, T., & Sakuraba, K. (2014). Strength training for the intrinsic flexor muscles of the foot: Effects on muscle strength, the foot arch, and dynamic parameters before and after the training. *Journal of Physical Therapy Science*, 26(3), 373.
- Hicks, J. H. (1954). The mechanics of the foot, ii: The plantar aponeurosis and the arch. *Journal of Anatomy*, 88, 25–30.
- Johnson, A., Myrer, J., Mitchell, U., Hunter, I., & Ridge, S. (2015). The effects of a transition to minimalist shoe running on intrinsic foot muscle size. *International Journal of Sports Medicine*, 37(02).
- Knapik, J., Orr, R., Pope, R., & Grier, T. (2016). Injuries and footwear (Part 2): Minimalist running shoes. *Journal of Special Operations Medicine*, 16(1), 89–96.
- Landorf, K. B., & Radford, J. A. (2008). Minimal important difference: Values for the foot health status questionnaire, foot function index and visual analogue scale. *The Foot*, 18, 15–19.
- Latey, P. J., Burns, J., Hiller, C., & Nightingale, E. J. (2014). Relationship between intrinsic foot muscle weakness and pain: A systematic review. *Journal of Foot and Ankle Research*, 7(1), A51.
- Lynn, S. K., Padilla, R. A., & Tsang, K. K. (2012). Differences in static- and dynamic-balance task performance after 4 weeks of intrinsic-foot-muscle training: The short-foot exercise versus the towel-curl exercise. *Journal of Sport Rehabilitation*, 21(4), 327–333. Nov.
- Macera, C. (1989). Predicting lower-extremity injuries among habitual runners. *Archives of Internal Medicine*, 149(11), 2565–2568.
- Malliaras, P., Barton, C. J., Reeves, N. D., & Langberg, H. (2013). Achilles and patellar tendinopathy loading programmes. *Sports Medicine*, 43(4), 267–286.
- Marchick, M., Young, H., & Ryan, M. (2015). Sever's disease: An underdiagnosed foot injury in the pediatric emergency department. *Open Journal of Emergency Medicine*, 03(04), 38–40.
- McKeon, P., & Fourchet, F. (2015). Freeing the foot. *Clinics in Sports Medicine*, 34(2), 347–361.
- McPoil, T., Martin, R., Cornwall, M., Wukich, D., Irrgang, J., & Godges, J. (2008). Heel pain - Plantar fasciitis. *Journal Orthopedic & Sports Physical Therapy*, 38(4), A1–A18.
- Miller, E., Whitcome, K., Lieberman, D., Norton, H., & Dyer, R. (2014). The effect of minimal shoes on arch structure and intrinsic foot muscle strength. *Journal of Sport and Health Science*, 3(2), 74–85.
- Mulligan, E. P., & Cook, P. G. (2013). Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Manual Therapy*, 18(5), 425–430.
- Radford, J., Landorf, K., Buchbinder, R., & Cook, C. (2006). Effectiveness of low-dye taping for the short-term treatment of plantar heel pain: A randomised trial. *BMC Musculoskeletal Disorders*, 7(1).
- Rathleff, M., Mølgaard, C., Fredberg, U., Kaalund, S., Andersen, K., Jensen, T., et al. (2014). High-load strength training improves outcome in patients with plantar fasciitis: A randomized controlled trial with 12-month follow-up. *Scandinavian Journal of Medicine & Science in Sports*, 25(3), e292–e300.
- Riddle, D. L., Pulisic, M., Pidcoe, P., & Johnson, R. E. (2003). Risk factors for plantar fasciitis: A matched case-control study. *Journal of Bone & Joint Surgery of America*, 85(5), 872–877. May.
- Schwartz, E. (2014). Plantar fasciitis: A concise review. *The Permanente Journal*, e105–e107.

- Skou, S. T., Rathleff, M. S., Moelgaard, C. M., Rasmussen, S., & Olesen, J. L. (2012). The influence of time-of-day variation and loading on the aponeurosis plantaris pedis: An ultrasonographic study. *Journal of Sports Medicine and Physical Fitness*, *52*(5), 506–512. Oct.
- Thing, J., Maruthappu, M., & Rogers, J. (2012). Diagnosis and management of plantar fasciitis in primary care. *British Journal of General Practitioners*, *62*(601), 443–444.
- World Health Organization. (2015). *WHO: Global database on body mass index*. Retrieved 4 December 2015, from http://apps.who.int/bmi/index.jsp?introPage=intro_3.html.
- Young, C. (2012). Plantar fasciitis. *Annals of Internal Medicine*, *156*(1).