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Evidence for Intrinsic Foot Muscle Training in Improving Foot Function: A Systematic Review and Meta-Analysis

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Objective: To critically assess the literature focused on strength training of the intrinsic foot muscles (IFMs) and resulting improvements in foot function.

Data Sources: A search of electronic databases (PubMed, CINAHL, Scopus, and SPORTDiscus) was completed between January 2000 and March 2022.

Study Selection: Randomized control trials with an outcome of interest and at least 2 weeks of IFM exercise intervention were included. Outcomes of interest were broadly divided into 5 categories of foot posture (navicular drop and Foot Posture Index), namely: balance, strength, patient-reported outcomes, sensory function, and motor performance. The PEDro scale was used to assess the methodologic quality of the included studies with 2 independent reviewers rating each study. Studies with a PEDro score greater than 4/10 were included.

Data Extraction: Data extracted by 2 independent reviewers were design, participant characteristics, inclusion and exclusion criteria, type of intervention, outcomes, and primary results. We performed a random-effects meta-analysis to analyze the difference between intervention and control groups for each outcome when at least 2 studies were available. Standardized mean differences (SMDs) describe effect sizes with 95% CIs (SMD ranges). When the CI crossed zero, the effect was not significant.

Data Synthesis: Thirteen studies were included, and IFM exercise interventions were associated with decreasing navicular drop (SMD range = 0.37, 1.83) and Foot Posture Index (SMD range = 1.03, 1.69) and improving balance (SMD range = 0.18, 1.86), strength (SMD range = 0.06, 1.52), and patient-reported outcomes for disability (SMD range = 0.12, 1.00), with pooled effect sizes favoring the IFM intervention over the control. The IFM exercises were not superior (SMD range = –0.15, 0.66) for reducing pain. We could not perform a meta-analysis for sensory function and motor performance, as only 1 study was available for each outcome; however, these results supported the use of IFM strength training.

Conclusions: Strength training of the IFMs was helpful for patients in improving foot and ankle outcomes.

Key Words: foot core, balance, rehabilitation, lower extremity, ankle instability

Key Points

- Intrinsic foot muscle (IFM) exercises improved balance and strength, reduced self perceived disability, and lowered navicular drop and foot posture index. Sensory and motor function was also improved with IFM exercise.
- The IFM exercises were not beneficial in improving pain. Overall, IFM exercises may help in the rehabilitation of patients with other types of lower extremity dysfunction.
- The short foot exercise appeared to be the most effective IFM exercise compared with other available IFM exercises.

The human foot is made up of complex articulations and is integral to locomotion.[1] It provides support to the human body while generating the forces needed to help us perform dynamic activities.[1] During walking, the feet support the weight of the body and continuously adjust to the surface, assist in force dissipation, and act as a propulsive lever.[1] Any disruption in foot function can jeopardize the function of all lower extremity structures.[1] A deeper understanding of normal foot function is essential for clinicians to effectively manage patients with any foot dysfunction.

Similar to the lumbopelvic complex, the foot skeleton is also supported by local and global stabilizers that comprise the *foot core*.[2] The intrinsic foot muscles (IFMs) are the principal stabilizers of the medal longitudinal arch and are essential to the passive, active, and neural subsystems that form the core musculature of the foot.[2] They also provide muscular support to the structures that form the base of support during postural stability,[2,3] help dissipate forces during loading,[2,4] and generate the propulsive forces needed for locomotion.[2,4] Weakness of the IFMs is associated with several musculoskeletal conditions, including plantar fasciitis, pes planus, posteromedial shin pain, and chronic ankle instability (CAI).[5–7] Weakness of the IFMs is also associated with surgical conditions such as first metatarsophalangeal

Table 1. Search Strategy Used

Search Term	Limiters
1. (((((((intrinsic foot muscles) OR intrinsic foot musculature) OR intrinsic foot flexor) OR intrinsic planter muscles) OR intrinsic plantar muscles)) AND	• Full-text English articles • Published in peer-reviewed journals
2. (((((((Strength) OR strengthening) OR training) OR therapy) OR "Toe Yoga") OR "Short Foot Exercise") OR "Short Foot Exercises")) AND ((((((((Function) OR "foot function") OR "motor performance") OR foot) OR "dynamic balance") OR "balance") OR "static balance") OR "postural control" OR "functional status" OR "motor function")	• Published between January 2000 and March 2022

(MTP) joint arthrodesis[8] and systemic conditions such as diabetes mellitus.[9,10] In addition, IFM weakness is often associated with balance problems, increased navicular drop (ND), decreased strength, and biomechanical abnormalities that eventually result in limitation of activity and negatively affect patient function.[2,8,11]

Strengthening of the IFMs has been recommended to treat foot and ankle conditions such as CAI, first MTP joint arthrodesis, patellofemoral pain (PFP), pes planus, and plantar fasciitis.[5,12] Incorporating IFM exercises into lower extremity injury rehabilitation protocols may improve functional outcomes such as balance, strength, sensory activity, and motor performance and the subjective measures of pain and disability in clinical groups.[2,11] However, whether IFM exercises improve functional outcomes has not been studied extensively.[11] Therefore, the aim of our review was to critically and holistically evaluate the effect of IFM strengthening on functional outcomes. The evaluation and synthesis of current evidence associated with IFM strength training have implications for assessment, diagnosis, targeted therapies, and avenues for future research in the treatment of foot and ankle injuries.

METHODS

Search Strategy

A health sciences librarian assisted in the systematic search of electronic data bases (PubMed, CINAHL, Scopus, and SPORTDiscus), and we performed manual searches of reference lists. The search strategy is outlined in Table 1. Next, we completed the database searches, screened the literature and extracted the data. The final literature search was performed on March 15, 2022. This systematic review with meta-analysis was registered with the International Prospective Register of Systematic Reviews (No. CRD42020170470). Two reviewers independently screened all relevant articles and abstracts and were blinded to the authors and journals. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines when conducting the systematic review and meta-analyses.

Study Selection Criteria

The screening of the literature began with the removal of duplicate articles. The remaining articles were then screened based on the title and abstract using the following criteria: (1) research specific to the IFMs, (2) randomized controlled trials (RCTs) with at least 2 weeks of IFM training administered, and (3) at least 1 desired functional outcome of interest (Figure 1).

Assessment of Methodologic Quality

We evaluated the methodologic quality of the included studies using the PEDro scale, a 10-item instrument, with a score of 10 representing the *highest quality* and 0, the *lowest quality*.[13] Two examiners independently scored the selected articles, with any disagreement resolved by reaching consensus after discussion. Any study with a PEDro score of $<$4 was considered lower quality and excluded.[14] Details of the methodologic quality assessment are provided in Table 2.

Data Extraction

The study design, population, experimental and comparison interventions, preintervention and postintervention time points, sample sizes, sets, repetitions, progression of the interventions, and main findings for the desired functional outcomes were extracted for every reported time point in the included studies (Table 3). When the relevant data were published in a graph, we contacted the corresponding author for more information. Means, SDs, and *P* values for the outcomes of interest are detailed in Table 4.

Measures of Treatment Effect

Because of diverse IFM therapies, we used a random-effects model to assess Cohen *d* effect sizes (ES) measured as the standardized mean difference (SMD) with associated 95% CIs to perform a statistical analysis.[26] Data were extracted from all of the RCTs to determine SMD between-groups differences with 95% CIs (Tables 3 and 4). The SMD between the intervention and control groups calculated was based on the change score (postintervention baseline) and SDs. If an SD was missing, the value was estimated using a formula proposed by the Cochrane handbook.[27]

Because we pooled outcome measures assessed on difference scales to determine the effects of the IFM exercises, we used SMDs for the analysis instead of mean differences. Forest plots were generated to illustrate the SMDs and associated 95% CIs between the treatment and control groups. The ESs (calculated as SMDs) were interpreted using the scheme recommended by Cohen et al,[26] as follows: $<$0.2 as *trivial*, 0.2 to 0.49 as *small*, 0.5 to 0.79 as *moderate*, and $>$0.8 as *large*. When the 95% CI for the point estimates of the treatment effect did not cross zero, it was interpreted as conclusively advantageous. To measure the overall effect, the z-test significance level was set at $P < .05$.

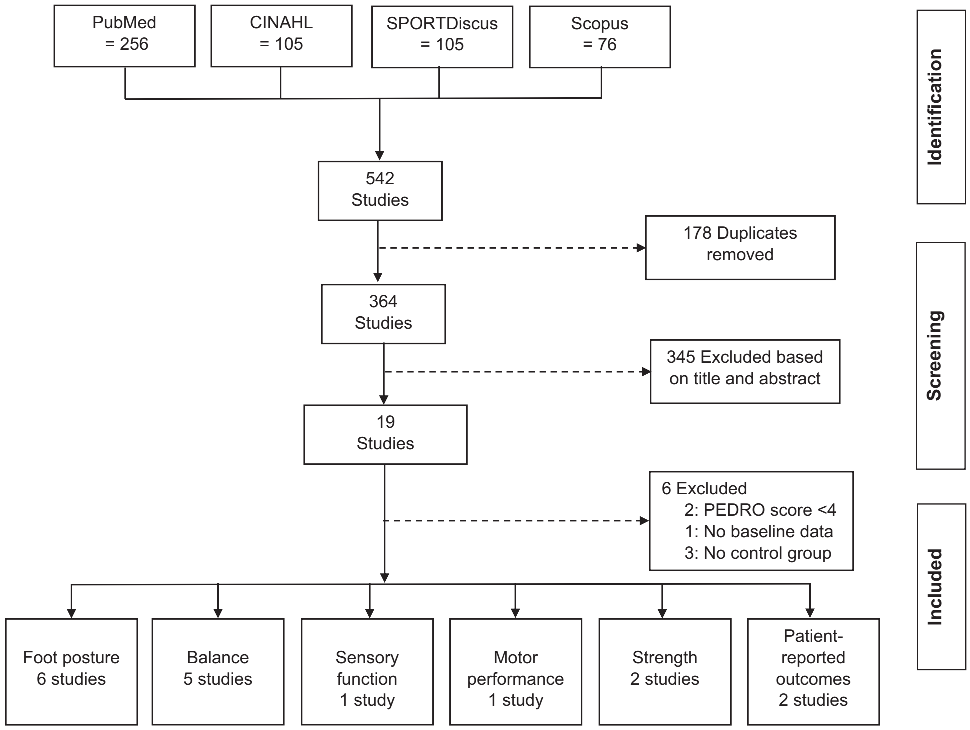

Figure 1. Study selection process and search results with outcome measure of interest.

Assessment of Heterogeneity

If the authors of at least 2 studies reported on the same outcome measure, a meta-analysis was deemed possible. We were able to perform the meta-analyses on balance, strength, ND (ND and FPI), and the patient-reported outcomes (PROs) of pain and disability.

Heterogeneity among the studies was analyzed using I^2 test statistics, as suggested by the *Cochrane Handbook for Systematic Reviews of Interventions*.[28] The I^2 statistic was interpreted using the following guideline: 0% to 40%, *heterogeneity might not be important;* 30% to 60%, *moderate heterogeneity;* 50% to 90%, *substantial heterogeneity;* and 75% to 100%, *considerable heterogeneity*.[28] We used the meta package in RStudio (version 1.2.5001) to perform the meta-analysis when the researchers of more than 1 study investigated the same outcome of interest.

Outcome Variables

Outcomes of interest were divided into the following 5 broad categories: foot posture, balance, strength, PROs, and sensory function and motor performance. Foot posture consisted of the measures of ND and FPI. The *ND* is measured as the difference between the seated and standing navicular positions. The *FPI* categorizes foot posture during standing based on talar head palpation, curvature of the medial and lateral malleoli, position of the calcaneus in the frontal plane, prominence of the talonavicular joint, congruence of the medial longitudinal arch, and position of the forefoot on rearfoot from a posterior view.[29] The balance measure was dynamic balance, and the strength measure was force dynamometry. The PROs were pain and disability. Changes in sensory function (vibratory sense) and motor performance reported by the authors of 2 studies were also outcomes of interest.[12,24] We could not conduct meta-analysis on sensory function and motor performance because only 1 study provided each outcome. Details of the study outcomes are given in Table 4.

RESULTS

The first search resulted in 542 studies (Figure 1). After removing the duplicates and excluding articles based on irrelevant titles and screening the abstracts, we noted that 19 articles remained (Figure 1). An additional 6 articles were removed.[30–32] Two[30,31] articles were removed because they had PEDro scores lower than 4, and the study by Saikia et al[32] was removed because the authors did not report baseline data. The other 3 articles[33–35] were removed because they were intervention studies with no control group. Based on the inclusion criteria, 13 RCT studies evaluated the outcomes of IFM training on foot function (Table 2). Individual study characteristics are supplied in Table 2. Meta-analyses could not be performed on the outcomes of sensory function and motor performance because each outcome was measured in only 1 study.[12,24]

Foot Posture

In 5 studies, foot posture was primarily measured as the decrease in ND.[3,15,19,21,23] The pooled analysis showed that the IFM exercise intervention reduced ND ($P < .01$) with an effect size of SMD = 1.10 (0.37, 1.83) and $I^2 = 80\%$ compared with the control group (Figure 2A).

In 4 studies, researchers also reported FPI as an outcome.[15,17,19,23] The individual SMD point estimates (Figure 2B) of all studies suggested a benefit favoring the IFM exercise intervention groups in the RCTs in which the researchers reported FPI. The pooled analysis showed that the IFM exercise intervention decreased FPI ($P < .01$) with

Table 2. PEDro Scoring for Studies Included in the Analysis

	Kisacik et al (2021)[15]	Lee (2019)[16]	Sánchez-Rodriguez et al (2020)[17]	Fraser and Hertel (2019)[12]	Kamonseki et al (2016)[18]	Unver et al (2019)[19]	Jung et al (2011)[20]	Kim and Kim (2016)[21]	Lynn et al (2012)[3]	Day and Hahn (2019)[22]	Pabón-Carrasco et al (2020)[23]	Lee and Choi (2019)[24]	Okamura et al (2020)[25]
1. Eligibility criteria?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Random allocation?	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y
3. Allocation concealed?	Y	N	N	Y	Y	N	Y	N	N	N	N	N	N
4. Groups similar?	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
5. Participant blinding?	Y	N	N	N	N	N	N	N	N	N	Y	N	N
6. Therapist blinding?	N	N	N	N	N	N	N	N	Y	N	N	N	N
7. Assessor blinding?	N	Y	N	Y	Y	Y	Y	N	Y	N	Y	N	N
8. 85% of Participants completed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
9. Allocation maintained or intention to treat?	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	Y
10. Between-groups statistical comparisons?	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
11. Point and variability measures reported?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PEDro score	8	7	6	8	8	5	8	5	6	5	8	4	5

Abbreviation: N, no; Y, yes.

an effect size of SMD = 1.36 (1.03, 1.60) and $I^2 = 0\%$ compared with the control group (Figure 2B).

Balance

Researchers of 5 out of 13 included studies described balance as an outcome measure.[3,16,18,21,24] Lynn et al[3] reported both static and dynamic balance changes, whereas the authors of all other studies measured changes in dynamic balance. Lee et al[16] used a postural stability program involving Biodex software (version 950-302; Biodex Medical Systems) that measures longitudinal and lateral motions of the body as dependent measures of balance. Kamonseki et al,[18] Kim and Kim,[21] Lynn et al,[3] and Lee and Choi[24] used the Star Excursion Balance Test to measure changes in dynamic balance. The participant characteristics, treatments given, and assessment time points are summarized in Tables 3 and 4.

The pooled meta-analysis showed that the IFM exercise intervention improved balance ($P < .01$) with an effect size of SMD = 1.02 (0.18, 1.86) and $I^2 = 83\%$ compared with the control group (Figure 2C). Individually, we observed that although most of the intervention groups displayed moderate to large effect sizes in balance improvement after the intervention, Kamonseki et al[18] and Lee et al[16] did not show any improvement in balance compared with the control groups (Figure 2C). Okamura et al[25] also used balance as an outcome measure, but we could not include it in the meta-analyses as both groups performed IFM exercises and the experimental group also received biofeedback. No improvement in balance was observed in the biofeedback group compared with that of the control group.

Strength

In 2 RCTs[20,22] included in this study, investigators evaluated dynamometric strength. Jung et al[20] used a fixed digital dynamometer with a stable wooden board, whereas Day and Hahn[22] used a Biodex dynamometer. The participant characteristics, treatment administered, and assessment time points are provided in Table 3. The pooled meta-analysis showed that the IFM exercise intervention ($P < .01$) improved toe flexion strength with SMD = 0.79 (0.06, 1.26) and $I^2 = 21\%$ compared with the control group (Figure 2D). We found a trend toward improved dynamometric strength in both studies, with a moderate to large effect size. However, the individual effect sizes for the work of Jung et al[20] crossed zero. Okamura et al[25] also had strength as an outcome, but we did not include it in the meta-analyses because both the experimental and control group performed IFM exercises. The experimental group also received biofeedback and demonstrated greater strength improvement (SMD = 0.82 [0.17, 1.91]) than the control group (SMD = 0.25 [–1.21, 0.70]).

Sensory Function and Motor Performance

Fraser and Hertel[12] reported motor performance and Lee et al[16] reported sensory function as an outcome after IFM exercise training. Both studies were RCTs. Fraser and Hertel[12] used clinician-assessed motor performance (4-point scale: 0 = *does not initiate movement*, 3 = *performs exercise in standard pattern*) to assess improvement in motor

Table 3. Summary of the 13 Studies Included Continued on Next Page

Author (Year)	Sample Population	Inclusion Criteria	Group(s) and Intervention(s)	Outcome Measure(s)	Results
Lee et al (2019)[16]	Adults with ankle sprains (n = 30; 15 F, 15 M)	History of first ankle sprain >1 y before trial; score of <24 on Cumberland Ankle Instability Tool; no ankle sprain within 6 wk of start of trial; experienced ≥2 more ankle sprains in past 2 mo	IG (n = 15) performed SFE in 4 sets of 5 minutes each, 20–25 min/d, 3x/wk x 8 wk. C (n = 15) performed PSE with same intensity, time, and frequency/wk x 8 wk.	Dynamic balance, cm; somatosensory function, μm	Improved dynamic balance in SFE group vs PSE group. Benefit of SFE over PSE for somatosensory function.
Fraser and Hertel (2019)[12]	Adults (n = 24; 12 F, 12 M)	Healthy, recreationally active (≥20 min/d x ≥3x/wk) individuals	IG (n = 12) perfromed IFM exercises. CG: No intervention.	Motor function, 4-point ordinal scale; perceived rating of difficulty, 5-point Likert scale	Improved motor function in the IG. Improved perceived level of difficulty in IG.
Kamonseki et al (2016)[18]	Adults (n = 83; 66 F, 17 M), 20–60 years of age, with diagnosis of plantar fasciitis	Pain on plantar surface of heel; insidious pain onset; pain accentuated after long periods of upright activities or after rest, such as first morning step; reduced pain after light activities	3IGs: SAEG, FEG, and FHEG. Total intervention = 8 wk. SAEG: Stretching only. FHEG: Stretching + foot strengthening exercises. FHEG: Stretching + foot strengthening + hip abductor, lateral rotator strengthening.	Dynamic balance, cm; pain and quality of life measures taken from FOAS	All measures improved in all groups. No significant group-by-time interaction.
Unver et al (2019)[19]	Adults (n = 41; 25 F, 16 M)	Age = 18–25 y Bilateral pes planus per ND and FPI	SFEG: SFE x 6 wk. CG: No intervention.	ND, mm; FPI, scale from –2 to +2; pain and disability from FFI	SFEG: Reduced ND, FPI, pain, disability. CG: No change. SFEG: Increased lateral midfoot force. CG: No change.
Jung et al (2011)[20]	Adults (n = 28) with bilateral pes planus	Resting calcaneal stance position with ≥4° eversion, ND > 13 mm	Participants randomly assigned to FO or FOSF group for 8-wk intervention. Both groups wore orthosis, but FOSF group also performed SFE: 5 reps x 3 sets for each foot.	Toe flexor strength, kgf	Improved in both groups, FOSF > FO.
Lynn et al (2012)[3]	Adults (n = 30; 15 F, 15 M)	Healthy participants with no history of major lower limb injury or balance impairment	Participants randomly assigned to SFE, a TCE, or a CG. SFE and TCE groups instructed to perform 100 reps of prescribed exercise daily basis x 4 wk. In the first and second week, participants performed these exercises in the sitting position, and in the third and fourth weeks, participants performed these exercises in the standing position.	ND, mm; dynamic balance, cm	No change in ND in any group. Improved dynamic balance in exercise groups, SFE > TCE.
Day and Hahn (2019)[22]	Adults (n = 23; 8 F, 15 M)	Healthy participants with no history of lower limb injury or balance impairment	Participants randomly assigned to IG (IFM training) or the CG. IG performed isometric, concentric, and eccentric exercises (SFE, band curls, foot curls) 1x/d, 3 d/wk x 10 wk. CG: No exercise.	Strength, N/kg	IG: Improved. CG: No change.

Table 3. Continued From Previous Page

Author (Year)	Sample Population	Inclusion Criteria	Group(s) and Intervention(s)	Outcome Measure(s)	Results
Pabón-Carrasco et al (2020)[23]	Adults (n = 90; 48 F, 42 M) with bilateral pes planus	Healthy participants with bilateral asymptomatic pronated feet (FPI > 6)	Participants randomly assigned to IG (SFE 1x/d x 4 wk) or CG (active flexion-extension 1x/d x 4 wk).	ND, mm; FPI	No difference in foot posture or ND between groups, but individual pre-post intervention differences were observed in each group.
Lee and Choi (2019)[24]	Adults (n = 30; 20 F, 10 M) with history of chronic ankle instability	History of >1 ankle sprain, with first 1 y ago; Cumberland Ankle Instability Tool score > 24	Participants randomly assigned to IG (IFM exercises [first toe extension, toes spread out, second-fifth toe extension] 3x/wk x 6 wk, supervised) or CG (no exercise).	Dynamic balance, cm	Improved in IG vs CG.
Okamura et al (2020)[25]	Older adults (n = 17; 1 F, 16 M)	Community-dwelling older adults (age > 65 y) participating in day-care rehabilitation service	Participants randomly assigned to electromyographic biofeedback group or CG. Both groups performed IFM exercises including SFE and toes spread out, 3 sets of 10 reps (5 s each) 2x/wk x 6 wk. Three sets of 10 repetitions (5 s each) were performed. Biofeedback group: Feedback while performing exercises.	Toe flexor strength, %BW; balance measures with time up and go, s; functional reach test, mm	Toe flexor strength: Both groups improved on dominant side, biofeedback group improved on nondominant side. Balance: Neither group improved.
Kısacık et al (2021)[15]	Adults (n = 30; 27 F, 3 M)	History of patellofemoral pain with continuing knee pain ≥6 mo without trauma FPI > 6 = weak, pronated foot	Participants randomly assigned to SFEG or the CG. Both groups performed supervised training sessions 2x/wk x 6 wk. CG: Standard hip, knee strengthening exercises. SFEG: Added SFE.	ND, mm; FPI	Improved ND and FPI, SFEG > CG.
Sánchez-Rodriguez et al (2020)[17]	Adults (n = 36; 21 F, 15 M)	Healthy participants with pronated feet	Participants randomly assigned to IG (strengthening including IGM exercises: two 40-min sessions/wk x 9 wk) or CG (no exercises).	FPI	Improved FPI, IG > CG.
Kim and Kim (2016)[21]	Adults (n = 14; 4 F, 10 M)	Healthy participants with pronated feet	Participants assigned to an SFE (n = 7 each) or ASI (n = 7 each).	NDT, mm; dynamic balance, %	More NDT and dynamic balance improvement in the IG than the CG.

Abbreviations: ASI, arch support insoles; BW, body weight; CG, control group; COP, center of pressure; F, female; FEG, foot exercise group; FFI, foot function index; FHEG, foot and hip exercise group; FO, foot orthosis; FOAS, Foot and Ankle Outcome score; FOSF, foot orthosis short foot; FPI, foot postural index; IG, intervention group; IFM, intrinsic foot muscles; kgf, kilogram force; M, male; ND, navicular drop; NDT, navicular drop test; PSE, proprioceptive sensory exercise; rep, repetition; SAEG, stretching alone exercise group; SFE, short foot exercise; SFEG, short foot exercise group; TCE, towel-curl exercise.

Table 4. Descriptive Point Estimate Statistics for the Selected Outcome Measure of the Included Studies[a]

		Group Point Measures, Mean ± SD			
		Intervention, Postintervention		Control, Preintervention	
Author (Year)	Outcome Measure(s)	Baseline	Posttreatment	Baseline	Posttreatment
Lee et al (2019)[16]	Dynamic balance, cm	4.27 ± 1.58	2.15 ± 0.85	3.62 ± 1.36	2.57 ± 0.99
	Somatosensory function, μm	4.29 ± 0.98	2.50 ± 0.79	3.73 ± 1.14	2.87 ± 1.24
Fraser and Hertel (2019)[12]	Motor function (4-point ordinal scale)	1.9 ± 0.5	2.6 ± 0.5	2.0 ± 0.6	2.0 ± 0.7
Kamonseki et al (2016)[18]	Dynamic balance, cm	73.7 ± 19.0	77.7 ± 18.0	76.5 ± 24.0	82.7 ± 24.0
	Pain taken from FAOS	56.3 ± 17.0	73.9 ± 16.0	56.9 ± 17.0	71.2 ± 22.0
	Quality of life measures taken from FAOS	34.2 ± 22.0	50.9 ± 25.0	29.2 ± 21.0	52.2 ± 23.0
Unver et al (2019)[19]	ND, mm	16.47 ± 5.45	10.85 ± 5.92	17.25 ± 5.31	16.90 ± 5.90
	FPI (scale from –2 to +2)	8.95 ± 1.46	7.33 ± 2.15	8.40 ± 1.95	8.50 ± 2.03
	Pain and from FFI	12.23 ± 11.96	7.85 ± 8.78	7.20 ± 10.34	5.00 ± 6.31
	Disability from FFI	7.80 ± 6.91	3.95 ± 4.52	4.05 ± 7.52	3.55 ± 5.73
Jung et al (2011)[20]	Toe flexor strength, kgf	6.35 ± 2.98	8.14 ± 3.17	6.38 ± 3.53	7.26 ± 3.24
Lynn et al (2012)[3]	ND, mm	45.9 ± 3.4	44.6 ± 2.5	42.8 ± 5.4	42.5 ± 4.3
	Dynamic balance, cm	52.4 ± 4.5	43.1 ± 5.1	47.8 ± 7.8	48.1 ± 5.5
Day and Hahn (2019)[22]	Toe flexor strength, N/kg	2.6 ± 0.7	3.3 ± 1.0	2.6 ± 0.6	2.7 ± 0.9
Pabón-Carrasco et al (2020)[23]	ND, mm	0.79 ± 0.08	0.63 ± 0.06	0.67 ± 0.06	0.59 ± 0.54
	FPI	6.77 ± 0.62	5.37 ± 0.63	6.35 ± 0.31	5.43 ± 0.44
Lee and Choi (2019)[24]	Dynamic balance, cm	66.79 ± 9.64	70.94 ± 8.74	65.44 ± 8.67	66.74 ± 9.09
Okamura et al (2020)[25]	Toe flexor strength, %BW				
	Dominant side	12.2 ± 4.2	13.8 ± 3.8	13.1 ± 4.5	14.4 ± 5.4
	Nondominant side	9.8 ± 3.1	13.1 ± 4.9	9.6 ± 4.6	10.7 ± 4.1
	TUG, s	10.1 ± 3.2	9.4 ± 2.8	9.7 ± 2.1	9.2 ± 2.3
	Functional reach, mm	276.5 ± 43.8	278.6 ± 66.5	274.3 ± 60.6	278.6 ± 66.5
Kısacık et al (2021)[15]	ND, mm	11.19 ± 3.48	8.21 ± 2.95	8.61 ± 3.12	8.74 ± 2.65
	FPI	6.13 ± 3.04	4.0 ± 2.87	6.53 ± 3.77	6.53 ± 3.77
Sánchez-Rodriguez et al (2020)[17]	FPI	8.0 ± 1.5	6.4 ± 2.1	8.0 ± 1.2	8.0 ± 1.2
Kim and Kim (2016)[21]	NDT	11.4 ± 1.6	7.7 ± 1.1	12.2 ± 1.8	10.5 ± 1.7
	Dynamic balance, %	74.3 ± 8.3	82.4 ± 7.4	72.4 ± 7.1	74.2 ± 7.2

Abbreviations: BW, body weight; FFI, foot function index; FOAS, Foot and Ankle Outcome score; FPI, foot posture index; ND, navicular drop; NDT, navicular drop test; TUG, Time Up and Go.

[a] All studies were randomized control led trials.

performance. The authors found greater improvement on the motor performance in the intervention group (SMD = 1.40 [0.77, 2.03]) than in the control group (SMD = 0.00 [–0.63, 0.63]).[12] Lee et al[16] measured vibration using a Neurosensory Analyzer-II (Vibratory Sensory Analyzer-II; Medoc) as an outcome measure. Based on individual assessments of the magnitude changes, Lee et al[16] observed a greater improvement in sensory function in the intervention group with a strong effect (SMD = 2.27 [1.35, 3.19]) than in the control group (SMD = 0.69 [–0.05, 1.43]). Additional details of the participant characteristics, treatment administered, and assessment time points are summarized in Table 3. We could not perform meta-analyses on these data, as only 1 study was available for each outcome of interest.

Patient-Reported Outcomes

Pain and disability were the outcomes of interest among PROs and were measured by researchers of 2 RCTs.[18,19,32] Kamonseki et al[18] characterized quality of life and activities of daily living using the Foot and Ankle Outcome Score. An increase in score indicated improvement in pain and disability. Unver et al[19] used the pain and disability subscales (each with 9 items) of the Foot Function Index. The level of foot pain in different situations and the difficulty performing daily living activities because of foot problems were rated via visual analogue scales. Decreases in scores indicated improvements in pain and disability. The details of the participant characteristics, treatment administered, and assessment time points are supplied in Table 3. The SMD point estimates and 95% CIs for comparisons of the pain and disability PROs are given in Figure 3A. The pooled meta-analysis between the intervention and control groups revealed an improvement ($P = .01$) in disability (SMD = 0.56 [0.12, 1.00], $I^2 = 0\%$) favoring the IFM exercise intervention group. Interestingly, the pooled meta-analysis for pain did not demonstrate any improvement ($P = .22$; SMD = 0.25 [–0.15, 0.66], $I^2 = 0\%$) after the IFM training program compared with the control (Figure 3B).

DISCUSSION

In this review and meta-analysis, we studied the effects of IFM exercises systematically and holistically on both objective and subjective patient outcomes. The superiority of IFM interventions was seen in all outcomes compared with control groups for the pooled effect sizes except pain, for which we did not observe any preferential improvement from the IFM intervention. However, the effect sizes for some individual study intervention groups did cross zero. These meta-analyses may provide clinicians an opportunity to assess IFMs and choose the exercise interventions that are most effective for their patients' care.

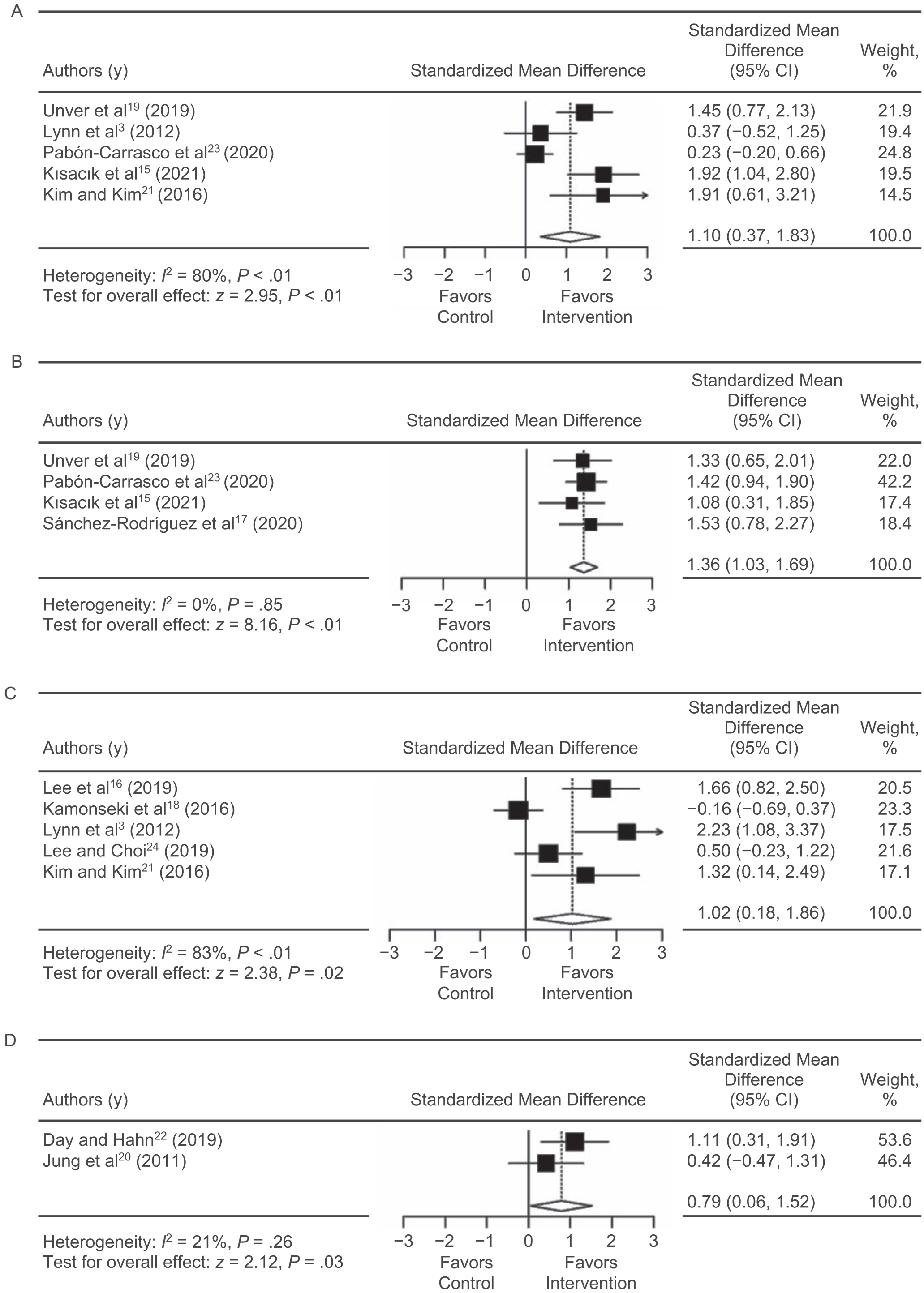

Figure 2. Forest plot and meta-analysis of intrinsic foot muscle (IFM) exercise intervention treatment compared with the control group for A, navicular drop; B, foot posture index; C, balance; D, strength.

Groups that received IFM exercise interventions generally had greater improvement in ND, balance, strength, sensorimotor function, and PROs. The pooled effect size favored the implementation of IFM exercises (Figures 2A–2D and 3A and 3B). For broad lower extremity rehabilitation programs, clinicians should consider incorporating IFM exercises because of the improvements seen in both objective and subjective functional outcomes. In this review and meta-analysis, we compared the effectiveness of IFM exercises between intervention and control groups.

Short Foot Exercise

The most commonly used IFM exercise in the included studies was the short foot exercise (SFE). The SFE also appeared to be the most effective intervention for strengthening the IFMs and improving both subjective and objective outcomes. The SFE involves contraction of the midfoot, moving the metatarsal heads posteriorly toward the calcaneus without flexing the toes.[33] This maneuver targets activation of the IFMs and increases the medial longitudinal arch height.[33] The SFE is thought to selectively

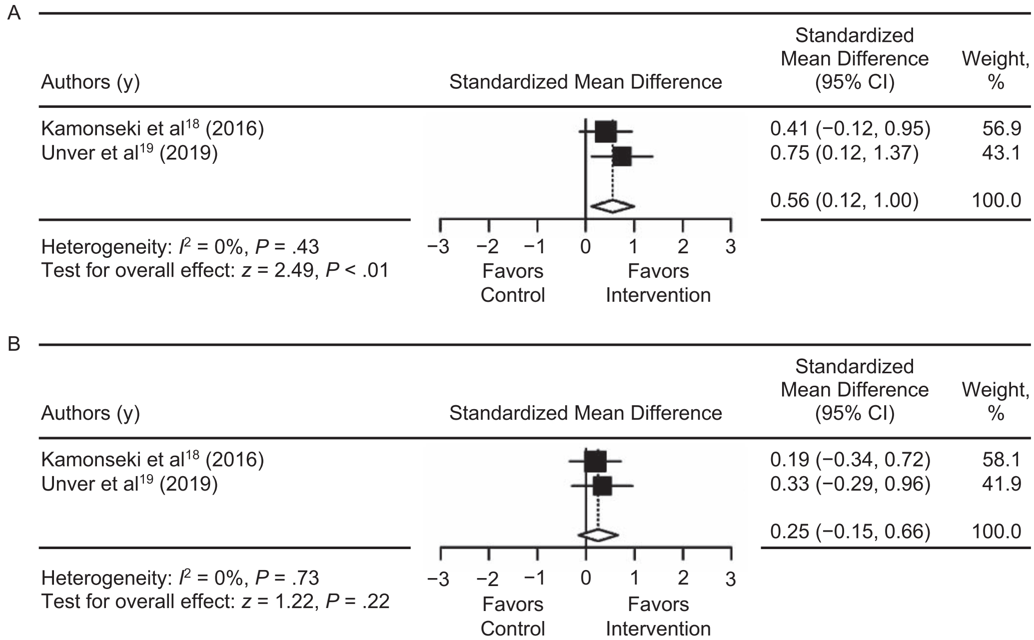

Figure 3. Forest plot and meta-analysis of intrinsic foot muscle (IFM) exercise intervention treatment compared with the control group for A, pain and B, disability.

activate the IFMs without activating the extrinsic foot muscles.[33] In this review and meta-analysis, it was used in isolation or integrated with other treatment interventions and was proven superior to control groups in all studies[3,12,15,16,18–23,25] except those of Kamonseki et al[18] and Pabón-Carrasco et al,[23] who found no improvement. Lee et al[16] noted improved dynamic balance for the SFE group compared with the proprioceptive sensory exercise group. They also observed improvement with a large effect size of 2.27 in the foot vibratory sense after the intervention, whereas the effect size of the control group was moderate at 0.69.

Similarly, Lynn et al[3] described superiority of the SFE in improving balance compared with the towel exercise or control group. Unver et al[19] used the SFE for 6 weeks in patients with a history of pes planus; pain and disability decreased and ND improved compared with the control group (Figures 2A, 2B, and 3A). Jung et al[20] studied IFM strength in 2 groups of adults with bilateral pes planus (Figure 2D). Similarly, Day and Hahn[22] reported strength gains when IFM exercises, including the SFE, were performed by healthy participants versus the control group (Figure 2D). Okamura et al[25] had both groups perform IFM exercises, including the SFE, but the experimental group also received biofeedback. Greater IFM strength gains were seen in the experimental group than in the control group with no biofeedback. Overall, the pooled effect of the current evidence delineated a decrease in ND, increase in IFM strength, enhanced sensory function and motor performance, and improved PROs in the groups with the SFE intervention.

Researchers in 2 studies[17,24] did not incorporate the SFE in their intervention protocol. Lee and Choi[24] used IFM exercises consisting of first toes extension, toe spread out, and second to fifth toe extension. The intervention group performed IFM exercises for 6 weeks, and the control group did not perform any exercise. Dynamic balance improved in the intervention group compared with the control group. Sánchez-Rodriguez et al[17] added marble-picking exercises for IFM training to the experimental group and observed a decrease in FPI after 9 weeks. It is difficult to ascertain if this change in FPI was due to the IFM exercises because extrinsic muscle exercises were also performed.

Clinical Groups

Our review and meta-analysis further substantiates the use of IFM exercises in patients with a variety of foot and ankle problems. Some of the clinical groups studied were those with pes planus, CAI, PFP, or plantar fasciitis.[15,16,18–20,32]

Pes Planus. Pes planus is a condition involving lowering of the medial longitudinal arch, which alters the load distribution in the lower extremity, causing excessive stresses on the foot, ankle, and knee joints and compensatory increased internal rotation at the hip joint.[19] In 3 studies,[17,19,21] authors showed decreased ND, FPI, pain, and disability in a pes planus group that performed IFM exercises compared with the control group that did not receive any such training. Pes planus is associated with a number of lower limb conditions, such as hallux valgus, plantar fasciitis, tarsal tunnel syndrome, anterior cruciate ligament injuries, and PFP.[19] Incorporating IFM exercises into rehabilitation programs may be beneficial for reducing pain and disability in individuals with these conditions. In another investigation,[20] the group that performed IFM exercises and used a foot orthosis displayed greater improvements in strength than the group that only used the foot orthosis. However, other researchers[23] identified no benefit in the experimental group that received IFM exercises versus the control group.[23] Whether IFM exercises can improve strength is unclear, and more work is needed in this area. Future researchers should also further investigate the effects of IFM strengthening in populations with pes planus.

Plantar Fasciitis. Kamonseki et al[18] examined the effects of foot exercises in patients with plantar fasciitis (characterized by pain on the plantar surface of the heel[18]) by comparing them with a group that received stretching-only exercises. Both groups improved in dynamic balance and subjective pain and disability. The lack of differences between groups could reflect the many exercises used in combination, thereby reducing the focus and time spent on the SFE, which was a more effective intervention than other exercises, such as towel curls, in activating the IFMs.[3] Multimodel rehabilitation programs are more clinically applicable, but they make it difficult to determine the effectiveness of IFM exercises alone. Therefore, more evaluations of different treatment protocols are needed to understand the effectiveness of IFM exercises in plantar fasciitis.

Chronic Ankle Instability. Lee et al[16] tested the SFE in individuals with CAI. This condition is associated with decreased function, especially postural control, due to recurrent ankle sprains.[36] Lee et al[16] noted improvements in dynamic balance and sensory function among individuals who performed SFEs compared with the group that performed proprioceptive sensory exercises. Very large effect sizes were present for both dynamic balance and sensory function in the intervention group versus the control group. Similar improvements in dynamic balance were observed in another study,[24] yet the effect size was smaller (Figure 2C).[24] A lateral ankle sprain can damage the tibial nerve and cause IFM weakness and decreased sensory feedback on the plantar surface of the foot.[37] Large deficits in IFM size have been seen in patients with CAI.[5] However, less emphasis is typically placed on IFM training during these interventions. More investigators should address the effectiveness of IFM exercises for improving balance, strength, and sensory motor function in patients with CAI.

Patellofemoral Pain. Baellow et al[29] recently found large deficits in IFM size using ultrasound imaging in individuals with PFP and recommended strengthening of IFM exercises be incorporated into their rehabilitation. Only 1 set of authors applied IFM exercises in patients with PFP and assessed our outcomes of interest.[15] Compared with the control group, the intervention group showed decreases in ND and FPI (Figures 2A and 2B). Comparative superiority of the IFM training group was also evident in the knee-related symptoms of the PFP group. It is possible that the decreased ND in people with PFP may result in postural corrections at the knee and hip, potentially improving pain. Nonetheless, because we focused on outcomes related to the foot, we did not include information related to the knee and hip in this review.

Healthy Groups. The primary purpose of this systematic review and meta-analysis was to determine the effectiveness of IFM exercises in clinical populations; however, understanding the effectiveness of IFM exercises in a healthy population may help further contextualize the results in clinical populations. Tests of IFM exercises in healthy participants revealed improved ND, balance, strength, and subjective function.[3,12,22] These results are promising for determining the effects of the IFM exercises. The literature regarding IFM function, deficits, and treatment is still developing. Contextualizing the results from the included studies can be critically important for clinical decision making while treating patients with lower extremity injuries.

LIMITATIONS

Certain limitations occurred in this analysis. Our primary objective was to investigate the effects of IFM exercises, so we pooled the healthy and clinical groups. Another review of the literature in which researchers study specific clinical groups is warranted once enough intervention studies of IFM exercises are available. We found positive results of administering IFM exercises for clinical groups, such as those with pes planus, plantar fasciitis, or CAI. Yet, we still do not know whether these exercises can work for other clinical groups with IFM atrophy or deficits, such as patients with diabetes[9,10] or a history of first MTP joint arthrodesis.[8] Another limitation of this study was the variety of intervention approaches, exercises, and times; however, the random-effects analysis and use of SMDs in the meta-analysis accounted for such diversity.

CONCLUSIONS

This is the first comprehensive review of the effectiveness of IFM strengthening for improving foot function. We outlined the usefulness of IFM strengthening in clinical populations. The clinical and functional benefits of using IFM exercises in rehabilitation of the lower extremities include improving balance, strength, and somatosensory function and decreasing ND, pain, and disability. Implementation of IFM exercises has also been shown to improve PROs. Therefore, we recommend that clinicians use IFM exercises either in isolation or integrated in comprehensive rehabilitation programs to improve patient outcomes.

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