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Foot and Leg Muscle Weakness in People With Midfoot Osteoarthritis

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Objective. To compare foot and leg muscle strength in people with symptomatic midfoot osteoarthritis (OA) with asymptomatic controls, and to determine the association between muscle strength, foot pain, and disability.

Methods. Participants with symptomatic midfoot OA and asymptomatic controls were recruited for this cross-sectional study from general practices and community health clinics. The maximum isometric muscle strength of the ankle plantarflexors, dorsiflexors, invertors and evertors, and the hallux and lesser toe plantarflexors was measured using hand-held dynamometry. Self-reported foot pain and foot-related disability were assessed with the Manchester Foot Pain and Disability Index. Differences in muscle strength were compared between groups. Multivariable regression was used to determine the association between muscle strength, foot pain, and disability after adjusting for covariates.

Results. People with midfoot OA (n = 52) exhibited strength deficits in all muscle groups, ranging from 19% (dorsiflexors) to 30% (invertors) relative to the control group (n = 36), with effect sizes of 0.6–1.1 ($P < 0.001$). In those with midfoot OA, ankle invertor muscle strength was negatively and independently associated with foot pain (β = –0.026 [95% confidence interval (95% CI) –0.051, –0.001]; $P = 0.045$). Invertor muscle strength was negatively associated with foot-related disability, although not after adjustment for depressive symptoms (β = –0.023 [95% CI –0.063, 0.017]; $P = 0.250$).

Conclusion. People with symptomatic midfoot OA demonstrate weakness in the foot and leg muscles compared to asymptomatic controls. Preliminary indications from this study suggest that strengthening of the foot and leg muscles may offer potential to reduce pain and improve function in people with midfoot OA.

INTRODUCTION

Foot osteoarthritis (OA) is a common cause of foot pain in older adults, affecting 1 in 6 adults ages >50 years in the UK (1). One of the most frequent presentations is symptomatic midfoot OA (12%), which affects the talonavicular (5.8%), navicular-first cuneiform (5.2%), or cuneometatarsal joints (3.9–6.8%) (2). Midfoot OA is associated with significant pain (2,3) and difficulty in walking (3) and climbing stairs (4). Severe midfoot OA may cause foot deformity, changes in foot posture, and difficulty with finding suitable footwear (5). Symptoms appear to change little over time, with midfoot OA causing persistent foot pain and foot-related disability over 18 months (6).

Demonstrated risk factors for midfoot OA include female sex, age, obesity, intermediate/routine occupational class, previous foot/ankle injury, and pain in other weight-bearing joints (2). Within the foot, midfoot OA is associated with bony malalignment, resulting in reduced medial longitudinal arch height (7) and a more pronated foot posture (8). This is accompanied by reduced sagittal plane range-of-motion in the medial longitudinal arch (4) and

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SIGNIFICANCE & INNOVATIONS

- To the best of our knowledge, this study is the first investigation of foot muscle strength in people with midfoot osteoarthritis and its relationship to foot pain and foot-related disability.
- Foot and leg muscle strength is reduced in all muscle groups in people with midfoot osteoarthritis compared to asymptomatic controls.
- Muscle strength was independently and inversely related to foot pain in people with midfoot osteoarthritis.

elevated forces and pressures under the midfoot during walking (7,9). Despite a growing understanding of the clinical features and functional consequences of midfoot OA, previous studies have focused on selected structural and biomechanical components, such as radiographic alignment, foot motion, and plantar pressures. Given the importance of muscle strength for joint stability and control, and the relationship between muscle weakness and OA in other joints (10,11), understanding muscle function in midfoot OA warrants further investigation. To the best of our knowledge, however, no studies have investigated muscle strength in people with midfoot OA.

Muscle weakness is a hallmark of OA at other joints such as the hip (10), knee (12), and hand (13) and is associated with pain (14), joint instability (15), and performance-based (15) and self-reported physical function (16). Deficits in muscle strength appear early in OA (17) and, in the knee, have been associated with incident radiographic disease (18) as well as symptomatic and functional decline (11). Muscle strengthening exercises are a core component of OA management and are included in international clinical guidelines (19–21). There is, however, little research on muscle strength in people with foot OA, particularly in midfoot OA. One prior study of first metatarsophalangeal joint OA investigated the relationship between symptoms and demographic and clinical characteristics, including plantarflexion strength of the hallux (22). This study showed that hallux plantarflexion strength was negatively, although weakly, associated with first metatarsophalangeal joint pain. Whether foot and leg muscle weakness is present in people with midfoot OA has not been investigated. Furthermore, whether muscle strength is associated with patient-reported outcomes in midfoot OA, such as pain and function, has not been evaluated. Greater understanding of whether foot and leg muscle weakness is a feature of midfoot OA has potential clinical implications, as muscle strength is modifiable (23) and may be a viable target for treatment. Pain and disability are the main reasons why people with OA seek treatment (24), therefore identification of the factors associated with symptoms has the potential to improve the design of treatments for this condition.

The aims of this study were to compare foot and leg muscle strength in people with symptomatic midfoot OA with asymptomatic controls and to determine whether muscle strength was associated with self-reported pain and foot-related disability. It was hypothesised a priori that people with midfoot pain and OA would present with foot and leg muscle weakness, and that muscle strength would be negatively associated with pain and foot-related disability.

PATIENTS AND METHODS

Study design and recruitment. This was a cross-sectional study involving people with midfoot pain and OA and asymptomatic controls. Participants were recruited from the community via advertisements, general practitioners, and health clinics. Ethics approval was obtained from the Leeds East Research Ethics Committee (17/YH/0261). All participants provided written informed consent prior to their involvement.

Participants. Symptomatic participants were ages >40 years, had pain in the midfoot for >3 months with an average weekly pain severity of ≥3 of 10 on an 11-point numerical rating scale (NRS) that occurred with or worsened following weight-bearing activities. The presence of midfoot pain was confirmed by participants marking the site of pain on a foot manikin (25,26), and supplemented by clinical examination to assess whether pain was reported on palpation of the talonavicular (TNJ), naviculocuneiform (NCJ), or cuneiform-metatarsal (CMJ) joints. Weight-bearing dorsoplantar and lateral radiographs were used to grade OA in either the TNJ, NCJ, or first or second CMJ by a musculoskeletal radiologist (AJG) using the La Trobe Foot Atlas (27). An established case definition was used, where a joint was considered to have OA with a score of ≥2 for osteophytes or joint space narrowing (JSN) on either the dorsoplantar or lateral views (27). To establish intrarater reliability, scoring was repeated on 20 participants, 3 months apart, without reference to the first set of scores. Exclusion criteria were >30 minutes of early morning stiffness in the feet, inflammatory arthritis, muscle or connective tissue disease, neurologic conditions, corticosteroid injection to the foot in the past 6 months, stress fracture or history of foot surgery, or contraindications to radiographs. Concurrent knee or hip pain was permitted if the pain intensity was not greater than their midfoot pain and was quiescent (average daily pain less than midfoot pain and <2 in the past week on NRS).

Control group participants were required to be age >40 years and free from foot or lower extremity joint pain. This was verified using an 11-point NRS for foot pain and a body pain manikin. Additional exclusion criteria for controls were presence of radiographic OA (osteophytes or JSN >1 on either view in any of the midfoot joints [TNJ, NCJ, first or second CMJ]), contraindications to radiograph, inflammatory arthritis, muscle or connective tissue disease, neurologic conditions, stress fracture, or lower extremity bone or joint surgery in the past 12 months. A meaningful a priori sample size calculation was not performed due to the

lack of prior research on muscle strength in people with midfoot OA. Therefore, the sample size, including unbalanced sampling of controls, was dictated by the period of recruitment for this study (12 months) and available funding.

Muscle strength testing. The maximal isometric strength of the leg and foot muscles was measured using a CITEC handheld dynamometer (CIT Technics). The device has a range of 0–500 newtons (N) and, according to manufacturer's data, was factory-calibrated to a sensitivity of 0.1%. Testing was performed by an experienced clinician (JBA) using standardized protocols, which have well-established intrarater (intraclass correlation coefficient [ICC] 0.83–0.94) and interrater reliability (ICC 0.77–0.88) (28). All testing was performed by the same researcher, with the participants in a supine position and the lower extremity stabilized proximal to the ankle joint. The muscle groups that were evaluated included ankle plantarflexors, dorsiflexors, invertors and evertors, hallux plantarflexors, and lesser toe plantarflexors.

For plantarflexion strength, the dynamometer was positioned on the plantar surface of the foot just proximal to the first metatarsal head, and for dorsiflexion it was placed on the dorsal surface of the foot just proximal to the metatarsal heads. To prevent movement during plantarflexion strength tests, the examiner anchored the dynamometer on the anterior aspect of the participants' thigh. For inversion, the dynamometer was placed on the medial border of the foot at the midpoint of the shaft of the first metatarsal, and for eversion it was placed on the lateral border of the foot over the midpoint of the fifth metatarsal. Hallux plantarflexor strength involved positioning of the dynamometer on the plantar surface of the interphalangeal joint and on the plantar surface of the toes for lesser toe strength. To standardize joint position across feet of different sizes with the same dynamometer, both the hallux and lesser toes were dorsiflexed into the participants comfortable end range of motion, as per the original protocol (28). The ankle was also placed in a plantarflexion during testing of the hallux and lesser toe muscles to prevent co-contraction of the ankle plantarflexors.

Before testing, the required movement was passively demonstrated by the examiner. This was followed by asking the participants to perform the movement against the dynamometer to ensure the correct action could be performed. The "make" technique was used requiring participants to exert a maximum voluntary contraction (MVC) against the dynamometer. Three valid MVCs of 3–5 seconds were obtained for each muscle group, with 15 seconds rest in between each trial (29). Verbal encouragement was standardized during the contractions, with the examiner telling each participant to "go ahead-push-push-push-push and relax" (30). The mean value of 3 trials was used for analysis (28). For participants with OA, the symptomatic side was the index foot; in cases of bilateral OA, only the most painful foot was tested. For controls, the right side was tested. To account for any differences in height or weight between groups, muscle strength data (in newtons) were normalized to body mass multiplied by height (% weight × height).

Foot pain and disability assessment. Pain severity in the past week, past month, and while walking was documented with an 11-point NRS for each, ranging from 0 (no pain) to 10 (worst pain imaginable). Pain and foot-related disability were assessed using the Manchester Foot Pain and Disability Index (MFPDI) (31), a 19-item questionnaire with subscales of foot pain (5 items), disability (10 items), appearance (2 items), and work or leisure (2 items). Each item is scored from 0 (none of the time) to 2 (on most days/every day). Pain subscale scores range from 0 to 10 and function scores from 0 to 20, with higher scores indicating more pain or worse foot-related disability. The MFPDI, which has been previously used in people with midfoot OA (2,3,6), displays good construct validity and internal consistency (31). Prior to analysis, raw scores were converted to Rasch-transformed interval level scores.

Other clinical characteristics. Due to the relationship and importance of depression to the development and experience of foot pain (32,33), information on depressive symptoms was obtained by participants completing the Hospital Anxiety and Depression Scale (HADS) (34), a 14-item questionnaire with 7 of these items relating to depressive symptoms (scored 0–3) with a total subscale score ranging 0–21. The psychometric properties of the HADS have been previously established (35). Questionnaires were also administered to capture general (EuroQol 5-domain) (36) and OA-specific (OA-QoL) health-related quality of life (37). Foot posture was quantified using the 6-item version of the Foot Posture Index (FPI-6), a validated and reliable clinical measure of foot posture (38,39). Each participant's foot posture (total score for the index foot) was classified according to cut points from normative data as supinated (score <0), normal (0–5), or pronated (≥6) (40).

Statistical analysis. Descriptive statistics were generated for participant characteristics, symptoms (pain NRS and MFPDI), and muscle strength scores. Normal distributions for muscle strength, pain NRS, and MFPDI scores were determined using histograms and Shapiro-Wilks tests. Independent sample *t*-tests and chi-square tests were used to compare participant characteristics and muscle strength between the midfoot pain and OA and asymptomatic control groups. Equality of variances was confirmed with Levene's test. Consistent with previous studies in foot OA (1), for the primary analysis the case definition for absence of radiographic OA in the midfoot included JSN or osteophyte grade of <2. We also conducted a further sensitivity analysis to evaluate differences in muscle strength between the midfoot OA group and asymptomatic controls using definitions of grade 0 (n = 19) and grade >0 (n = 17) for JSN or osteophytes in the midfoot joints. Differences in muscle strength were also summarized as percentage

difference (%) and with standardized effect sizes (Cohen's *d* coefficient). Intrarater reliability of radiographic scoring of foot OA was determined using percent of agreement and weighted kappa with quadratic weights.

Pearson's correlation coefficients were used to determine the strength and direction of the univariable relationship between muscle strength and MFPDI pain and function. Multivariable linear regression was used to determine the association between muscle strength and MFPDI pain (model 1) and MFPDI function (model 2), with age, sex, and body mass index (BMI) as covariates. To avoid issues with multicollinearity of predictors in the multivariable models, only the muscle strength group that displayed the strongest univariate relationship with MFPDI pain and function scores was included in the model. Due to the relationship between depression and pain, the depressive symptoms score was also entered into each model. We also adjusted for radiographic disease severity in the midfoot, represented by the total sum score of JSN and osteophytes for the TNJ, NCJ, and first and second CMJ. Results are presented as adjusted unstandardized regression coefficients (β) with 95% confidence intervals (95% CIs). The amount of variance explained by each model was determined using the adjusted r^2. All assumptions for the regression analyses were tested and met, including linearity of relationships and independence, homoscedasticity, and normality of residuals. Statistical significance was set at *P* less than 0.05. All analyses were conducted using SPSS, version 21.

RESULTS

Descriptive characteristics. Fifty-two people with midfoot OA and 36 asymptomatic controls completed all testing (Table 1). The mean age of the midfoot OA group was 62 years (73% women), with a BMI of 29.2 kg/m^2, compared to the asymptomatic controls (mean age 63 years, 66% women, BMI 27.2 kg/m^2). There were no statistically significant differences in age, sex, or BMI between groups ($P > 0.05$).

Clinical characteristics. The midfoot OA group reported moderate levels of pain over the past 24 hours (mean ± SD 3.7 ± 2.2), with slightly higher average pain over the past week (mean ± SD 4.2 ± 32.2) and while walking (mean ± SD

Table 1. Descriptive and clinical characteristics of midfoot OA and control groups*

	Midfoot OA group (n = 52)	Control group (n = 36)	*P*
Age, years	62.2 ±11.4	63.6 ± 11.7	0.586
Female sex, %	73	66	0.517
BMI (kg/m^2)	29.2 ± 5.4	27.2 ± 4.8	0.053
Joint-specific radiographic OA, no. (%)†			
Talonavicular joint	11 (21)	–	
Navicular-first cuneiform joint	21 (40)	–	
First cuneiform-metatarsal joint	18 (35)	–	
Second cuneiform-metatarsal joint	38 (73)	–	
Foot pain and functional limitation			
Dorsal midfoot pain, no. (%)	42 (81)	–	
Plantar midfoot pain, no. (%)	10 (19)	–	
Foot pain severity			
Average in past 24 hours (0–10 NRS)	3.7 ± 2.2	–	
Average in past week (0–10 NRS)	4.2 ± 2.2	–	
On walking in past week (0–10 NRS)	5.0 ± 2.6	–	
MFPDI Rasch pain‡	5.95 ± 1.6	–	
MFPDI Rasch function‡	8.62 ± 3.0	–	
Quality of life and mental health			
OA quality of life§	5.52 ± 5.9	1.08 ± 2.5	<0.001
EQ overall health (0–100)¶	68.30 ± 20.9	86.72 ± 11.9	<0.001
HADS depression#	3.87 ± 5.4	1.94 ± 3.0	0.035
HADS anxiety#	5.31 ± 6.0	3.72 ± 3.7	0.131
Foot Posture Index**			
Supinated (<0), no. (%)	4 (8)	7 (19)	
Normal (0–5), no. (%)	19 (36)	18 (50)	
Pronated (≥6), no. (%)	29 (56)	11 (31)	0.044

* Values are the mean ± SD unless indicated otherwise. BMI = body mass index; EQ = EuroQol; HADS = Hospital Anxiety and Depression Scale; MFPDI = Manchester Foot Pain and Disability Index; NRS = numerical rating scale; OA = osteoarthritis.
† Joint-specific OA does not equal 100%, as >1 midfoot joint may have OA.
‡ Higher values indicate more foot pain or foot-related disability.
§ Higher values indicate poorer OA-related quality of life.
¶ Higher values indicate better health-related quality of life.
# Higher values indicate more depression or anxiety symptoms.
** Foot Posture Index scores are for the study foot only.

Table 2. Comparison of foot and leg muscle strength between people with midfoot pain and osteoarthritis (OA) and asymptomatic controls*

Muscle strength (% weight × height)	Midfoot OA group (n = 52)	Control group (n = 36)	% difference	Effect size (Cohen's *d*)	*P*
Ankle plantarflexion	141 ± 48†	192 ± 61	26	0.9	<0.001
Ankle dorsiflexion	88 ± 33†	109 ± 30	19	0.6	<0.001
Ankle inversion	62 ± 22‡	89 ± 28	30	1.1	<0.001
Ankle eversion	67 ± 20†	90 ± 27	26	1.0	<0.001
Lesser toes plantarflexion	62 ± 20†	79 ± 23	22	0.8	<0.001
Hallux plantarflexion	62 ± 19†	85 ± 26	27	1.0	<0.001

* Values are the mean ± SD unless indicated otherwise. Percent difference is calculated relative to asymptomatic controls.
† n = 50, as 2 participants limited by pain on movement.
‡ n = 48, as 4 participants limited by pain on movement.

5.0 ± 2.6). Most participants reported dorsally located midfoot pain (81%) compared to plantar midfoot pain (19%). Thirty participants with midfoot OA had unilateral midfoot pain (57%), and 43% had bilateral midfoot pain. Radiographic OA was most commonly present in the second CMJ (73%), followed by the NCJ (40%), first CMJ (35%), and TNJ (21%). Intrarater reliability of radiographic scoring was almost perfect (percent agreement = 92%; κ_W = 0.92 [95% CI 0.90, 0.95]). People with OA reported poorer OA-specific and general health-related quality of life, as well as a higher level of depressive symptoms, compared to asymptomatic controls. A greater proportion of people with midfoot OA had a pronated foot posture (FPI ≥6) compared to controls, with fewer in the normal and supinated categories (Table 1).

Muscle strength. People with midfoot pain and OA displayed strength deficits in all muscle groups compared to asymptomatic controls (Table 2). The magnitude of weakness ranged from 19% (dorsiflexion) to 30% (inversion), equating to effect sizes of Cohen's *d* coefficient = 0.6 to 1.1 (Figure 1). Except for ankle dorsiflexion, differences existed regardless of whether people with midfoot OA were compared to controls with grade 0 for JSN or osteophytes (n = 19) or with those with grade >0 (n = 17) (*P* < 0.001–0.079) (see Supplementary Table 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24182/abstract).

Relationship between muscle strength, pain, and function. In bivariate analyses, muscle strength was negatively correlated with pain and foot-related disability for all muscle groups (Table 3) except for hallux plantarflexion strength and MFPDI pain. Ankle invertor muscle strength was most strongly associated with both MFPDI pain (*r* = –0.320, *P* = 0.027) (Figure 2) and MFPDI function (*r* = –0.349, *P* = 0.015).

Multivariable associations between invertor muscle strength, MFPDI pain, and MFPDI function are presented in Table 4. Multivariable regression analysis revealed that ankle invertor muscle strength was independently associated with foot pain (β = –0.026 [95% CI –0.051, –0.001]; *P* = 0.045) after adjusting for age, sex, BMI, radiograph severity, and depressive symptoms (Table 4). Depressive symptoms were positively associated with pain (β = 0.127 [95% CI 0.004, 0.251]; *P* = 0.044). Invertor muscle strength was also negatively associated with foot-related disability (β = –0.023 [95% CI –0.063, 0.017]; *P* = 0.250) (Table 4), although not after adjusting for the HADS depression domain, which was positively associated with foot-related disability (β = 0.286

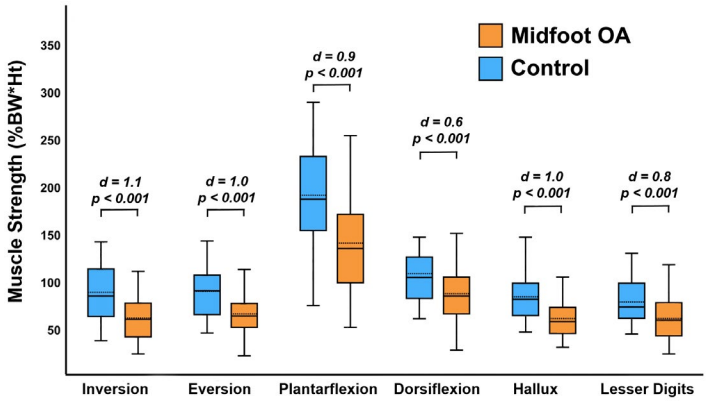

Figure 1. Box plot showing the muscle strength (% body weight [BW] × height [Ht]) for foot and leg muscle groups for midfoot osteoarthritis (OA) and control participants. Horizontal lines and error bars show the median and interquartile range. Dotted lines indicate mean value with corresponding effect size (Cohen's *d* coefficient) and *P* for differences in mean between groups for each variable.

Table 3. Univariate relationships between foot and leg isometric muscle strength variables and Manchester Foot Pain and Disability Index (MFPDI) pain and function subscales

Muscle strength (% body weight × height)	MFPDI pain		MFPDI function	
	r	*P*	*r*	*P*
Ankle plantarflexion*	−0.034	0.813	−0.221	0.122
Ankle dorsiflexion*	−0.176	0.222	−0.155	0.282
Ankle inversion†	−0.320	0.027	−0.349	0.015‡
Ankle eversion*	−0.178	0.216	−0.303	0.033‡
Lesser toes plantarflexion*	−0.279	0.053	−0.346	0.015‡
Hallux plantarflexion*	0.043	0.767	−0.125	0.387

* n = 50, as 2 participants limited by pain on movement.
† n = 48, as 4 participants limited by pain on movement.
‡ $P < 0.05$.

[95% CI 0.092, 0.480]; $P = 0.005$). As lesser toe plantarflexion and ankle eversion strength were significantly associated with foot-related disability in univariate analyses (Table 3), we substituted these variables in the multivariable analyses, and they were found not to be associated with pain or foot-related disability (data not shown). The total variance explained by the independent variables of age, sex, BMI, radiograph severity, invertor strength, and depressive symptoms was 14% for foot pain and 29% for foot-related disability.

DISCUSSION

In this study, we aimed to compare foot and leg muscle strength in people with symptomatic midfoot OA and healthy controls, and to determine whether muscle strength was associated with self-reported pain and foot-related disability. Our primary hypothesis was confirmed; we found that muscle strength was impaired in all muscle groups by 19% to 30% in people with midfoot OA. Our secondary hypothesis that muscle strength would be cross-sectionally associated with foot pain and foot-related disability was partially supported. Invertor muscle strength was independently associated with pain after adjustment for covariates. Although invertor strength was negatively associated with foot-related disability, this association was not statistically significant after adjustment for depressive symptoms.

Muscle weakness has been identified as a clinical feature of OA at other lower extremity joints, including the hip (10), knee (12), and hand (13). This is the first published study to investigate muscle strength in midfoot OA. Reductions in maximal isometric strength were observed across all foot and leg muscle groups in people with midfoot OA, with the largest differences in the ankle invertor group. This may be expected, given that radiographic midfoot OA was present in the joints along the medial arch (TNJ, NCJ, first and second CMJ) (1), where the tibialis posterior muscle (a primary hindfoot invertor) attaches to the adjacent tarsal bones and metatarsals. Deficits in intrinsic foot muscle strength were observed, including muscles that flex the lesser toes and hallux, which are responsible for stiffening the metatarsophalangeal joints to facilitate push-off during walking (41). We did not objectively quantify physical performance, but these findings suggest that muscle weakness in the foot and leg may partially explain deficits in functional ability seen in people with midfoot OA, such as difficulty walking and descending stairs (3,4).

Evidence from longitudinal studies undertaken in knee OA suggests that reduced knee extensor muscle strength is associated with incident tibiofemoral OA (18) and increased risk of symptomatic and functional decline, particularly in women (11). Although it is plausible that muscle weakness plays a role in the pathogenesis of midfoot OA, there are other factors that require consideration. For example, in hand OA, the relationship between grip strength and incident radiographic OA differed by site (metacarpal, proximal, and distal interphalangeal joints), and higher grip strength was associated with incident disease in men but not women (42). The impact of muscle weakness on structural disease in midfoot OA may also be joint specific, and the impact on prognosis may differ according to the site of foot OA, which tends to cluster in the midfoot and first metatarsophalangeal joint (3). The interaction of muscle strength and malalignment may also be important, particularly as people with midfoot OA have flatter feet than asymptomatic controls (7). As this study was cross-sectional, we were not able to determine the temporal nature of the relationship between muscle weakness and midfoot OA. Future prospective longitudinal studies in foot OA would be beneficial to clarify the nature and strength of these relationships.

The relationship between muscle weakness, foot pain, and self-reported function is complex and multifactorial. In this study, the models only explained a modest amount of variance in pain

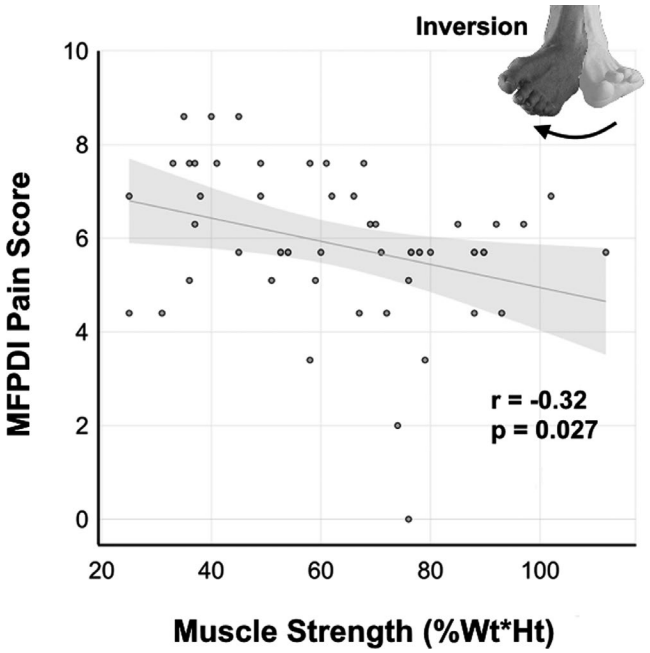

Figure 2. Relationship between invertor muscle strength (% weight [Wt] × height [Ht]) and Manchester Foot Pain and Disability Index (MFPDI) pain in people with midfoot osteoarthritis. Circles represent individual participants in the midfoot OA group.

Table 4. Relationship between invertor muscle strength and Manchester Foot Pain and Disability Index pain and function (outcomes)*

Variable	Unstandardized coefficients β	SE	95% CI	*P*
Model 1: pain				
Age	−0.012	0.027	−0.066, 0.042	0.660
Sex	0.234	0.566	−0.910, 1.378	0.682
BMI	−0.049	0.055	−0.159, 0.061	0.374
Invertor strength	−0.026	0.013	−0.051, −0.001	0.045†
Radiograph severity	0.070	0.044	−0.018, 0.159	0.117
Depressive symptoms	0.127	0.061	0.004, 0.251	0.044*
Model 2: function				
Age	0.074	0.042	−0.010, 0.159	0.081
Sex	1.030	0.886	−0.759, 2.820	0.252
BMI	0.077	0.085	−0.095, 0.250	0.370
Invertor strength	−0.023	0.020	−0.063, 0.017	0.250
Radiograph severity	−0.041	0.069	−0.180, 0.098	0.555
Depressive symptoms	0.286	0.096	0.092, 0.480	0.005*

* 95% CI = 95% confidence interval; BMI = body mass index.
† $P < 0.05$.

(14%) and foot-related disability (29%), with radiographic OA score not independently associated with either outcome. We also determined that deficits in muscle strength in people with midfoot OA existed compared to controls regardless of whether the controls demonstrated minor incidental radiographic features of midfoot OA. This suggests that pain, rather than established radiographic features, likely explained the differences in this model. These results are consistent with other sites of small-joint OA, such as the hand, where radiographic OA explains only a small amount of variance of hand pain and physical function (43,44), with pain mediating the relationship between radiographic disease and self-reported function and strength (43). Studies using magnetic resonance imaging (MRI) and ultrasound-detected OA features, which indicate OA disease activity, have revealed stronger associations between bone marrow lesions and synovitis with pain and function (45,46). Relationships between MRI-detected features of foot OA and symptoms are yet to be explored but offer an opportunity to focus on earlier disease.

Strengthening exercises are associated with moderate improvements in pain, function, physical performance, and small improvements in quality of life compared to usual care in people with hip and knee OA (47). Exercises for hand OA promoting strengthening and joint stability have shown small beneficial effects on pain, function, and joint stiffness, with few adverse events, although overall the quality of evidence is low (48). Given existing knowledge of the role of exercise for people with OA in other joints, further studies appear warranted to investigate whether muscle strengthening is a feasible and effective method to decrease pain and improve function in people with midfoot OA. Importantly, person-level psychosocial factors also influence the report of symptoms, with numerous studies identifying poorer psychological well-being to be associated with the development (49) and severity (32) of persistent foot pain. Our study in midfoot OA was able to examine the influence of depressive symptoms on pain and function and found independent associations for both outcomes, underscoring the importance of psychosocial factors in foot OA.

There are limitations to this study. Muscle strength assessment was conducted with the examiner aware of the participant's clinical status. Blinding is difficult, if not impossible, to achieve when participants have OA involving pain and deformity. To mitigate this difficulty, we used standardized, reliable protocols to obtain maximum force output from participants during testing. To be included in the control group, participants had to show grade 0 or 1 changes for JSN or osteophytes in all the midfoot joints. While this is the usual accepted criteria for absence of OA, 17 participants had grade 1 for either JSN or osteophytes in the midfoot. These participants were confirmed, however, to have no foot symptoms or history of foot injury likely to predispose them to OA. The sample size for the control group was chosen to be as large as could be practically achieved within the time and resource constraints, and consequently the control group included fewer participants than the OA group. Although we adjusted for important confounders of foot pain in the multivariable analyses, the number of participants with midfoot OA also limited the number of independent variables included in the models. Given that the amount of explained variance in pain and function in the multivariable analysis was low, other factors not investigated are likely to be associated with foot pain and foot-related disability in midfoot OA.

In conclusion, people with symptomatic midfoot OA demonstrate weakness in the foot and leg muscles compared to asymptomatic controls. In those with midfoot pain and OA, ankle invertor muscle strength was independently and negatively associated with pain after adjusting for covariates. Ankle invertor strength was also associated with foot-related disability, however, not after adjusting for depressive symptoms. Longitudinal studies are required to establish whether foot and

leg muscle weakness has implications for structural and symptomatic decline. Strengthening of the foot and leg muscles may offer potential to reduce pain and improve function in people with midfoot OA.

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AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Dr. Arnold had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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