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Structural Foot Characteristics in People With Midfoot Osteoarthritis: Cross-Sectional Findings From the Clinical Assessment Study of the Foot

Merridy J. Lithgow,[1] Andrew K. Buldt,[1] Shannon E. Munteanu,[1] Michelle Marshall,[2] Martin J. Thomas,[2,3] George Peat,[2,4] Edward Roddy,[2,3] and Hylton B. Menz[1,2]

Objective. This study compared radiographic measures of foot structure between people with and without symptomatic radiographic midfoot osteoarthritis (OA).

Methods. This was a cross-sectional study of adults aged 50 years and older registered with four UK general practices who reported foot pain in the past year. Bilateral weightbearing dorsoplantar and lateral radiographs were obtained. Symptomatic radiographic midfoot OA was defined as midfoot pain in the last 4 weeks, combined with radiographic OA in one or more midfoot joints (first cuneometatarsal, second cuneometatarsal, navicular-first cuneiform, and talonavicular). Midfoot OA cases were matched 1:1 for sex and age to controls with a 5-year age tolerance. Eleven radiographic measures were extracted and compared between the groups using independent sample *t*-tests and effect sizes (Cohen's *d*).

Results. We identified 63 midfoot OA cases (mean ± SD age was 66.8 ± 8.0 years, with 32 male and 31 female participants) and matched these to 63 controls (mean ± SD age was 65.9 ± 7.8 years). There were no differences in metatarsal lengths between the groups. However, those with midfoot OA had a higher calcaneal-first metatarsal angle ($d = 0.43$, small effect size, $P = 0.018$) and lower calcaneal inclination angle ($d = 0.46$, small effect size, $P = 0.011$) compared with controls.

Conclusions. People with midfoot OA have a flatter foot posture compared with controls. Although caution is required when inferring causation from cross-sectional data, these findings are consistent with a pathomechanical pathway linking foot structure to the development of midfoot OA. Prospective studies are required to determine the temporal relationships between foot structure, function, and the development of this common and disabling condition.

INTRODUCTION

Midfoot osteoarthritis (OA) is a common cause of foot pain, affecting one in eight people aged over 50 years, with three-quarters of these people reporting disabling pain.[1] The joint-specific prevalence of symptomatic radiographic midfoot OA has been shown to be 3.9% in the first cuneometatarsal joint, 6.8% in the second cuneometatarsal joint, 5.2% in the navicular-first cuneiform joint, and 5.8% in the talonavicular joint.[2] People with midfoot OA experience higher levels of pain and disability compared with people without,[3] with the midfoot being the most disabling location of foot OA.[4] Person-level risk factors for midfoot OA include female sex, age, obesity, manual occupations, and previous injury.[1]

The views expressed herein are those of the authors and do not necessarily represent those of the NHS, the NIHR, Health Education England, or the Department of Health and Social Care.

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[1]Merridy J. Lithgow, MSc, Andrew K. Buldt, PhD, Shannon E. Munteanu, PhD, Hylton B. Menz, DSc School of Allied Health, Human Services and Sport, La Trobe University, Melbourne, Victoria, Australia; [2]Michelle Marshall, PhD, Martin J. Thomas, PhD, George Peat, PhD, Edward Roddy, DM, Hylton B. Menz, DSc: Primary Care Centre Versus Arthritis, School of Medicine, Keele University, Keele, Staffordshire, UK; [3]Martin J. Thomas, PhD, Edward Roddy, DM: Haywood Academic Rheumatology Centre, Midlands Partnership University National Health Service Foundation Trust, Haywood Hospital, Burslem, Staffordshire, UK; [4]George Peat, PhD: Centre for Applied Health and Social Care (CARe), Sheffield Hallam University, Sheffield, UK.

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Address correspondence via email to Merridy J. Lithgow, MSc, at Merridy.lithgow@latrobe.edu.au.

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SIGNIFICANCE & INNOVATIONS

- This is the most detailed study to investigate the differences in structural foot characteristics in people with midfoot osteoarthritis (OA).
- Participants with midfoot OA had a higher calcaneal-first metatarsal angle and lower calcaneal inclination angle.
- The findings of a flatter foot posture may indicate a possible mechanical cause of midfoot OA.

Given that malalignment and altered loading are associated with the development of OA in other weightbearing joints,[5,6] it is plausible that structural foot characteristics could also be associated with the development of midfoot OA. A recent systematic review examining foot structure and lower limb function found that those with midfoot OA had a more pronated foot posture, greater first ray mobility, less range of motion in the subtalar joint and first metatarsophalangeal joints, longer central metatarsals, and elevated plantar pressures during walking.[7] However, radiographic measures of foot structure or alignment were only investigated in four studies from this review.[8–11] Furthermore, these studies were conducted in clinical populations rather than representative samples, used a range of different case definitions, and incorporated structural measures using a range of different techniques that may not be directly comparable.

Understanding how foot structure differs between people with and without midfoot OA may provide insights into the possible mechanisms responsible for its development. Therefore, the objective of this cross-sectional study was to compare foot structure between people with and without symptomatic radiographic midfoot OA using clear case definitions and a wide range of reliable radiographic measures in a population-based cohort.

PATIENTS AND METHODS

Study design. This study uses baseline data from a population-based prospective observational cohort study, the Clinical Assessment Study of the Foot. The study protocol is described in detail elsewhere.[12] Adults aged 50 years and older registered with four general practices in Staffordshire, United Kingdom, were invited to participate. All eligible participants were mailed a health survey questionnaire to gather information on demographic and social characteristics and general health. In the United Kingdom, over 95% of people are registered with general practices, thus providing a convenient general population sample.[13] Those who reported pain in and around the foot in the past 12 months and provided written consent to further contact were invited to attend a research clinic in which weightbearing, dorsoplantar, and lateral radiographs of both feet were obtained. The location of foot pain in the last 4 weeks was ascertained from shading a foot manikin (©The University of Manchester 2000. All rights reserved).[14] The period of 4 weeks was used because this was a part of the validated instrument to ensure it was recent midfoot pain. Ethical approval was obtained from Coventry Research Ethics Committee (reference number: 10/H1210/5). Participants provided written informed consent to participate and were asked to consent to review of their medical records by the research team.

Midfoot OA case definition. Symptomatic, radiographic midfoot OA was defined as (1) a radiographic score of 2 or more for osteophytes or joint space narrowing on either weightbearing dorsoplantar or lateral views in one or more midfoot joints (first cuneometatarsal, second cuneometatarsal, navicular-first cuneiform, and talonavicular) using the La Trobe Foot Atlas,[15] combined with (2) pain located in the midfoot region in the last 4 weeks in the same foot.[1] For bilateral cases, the index foot was randomly selected. Symptomatic, radiographic midfoot OA cases were then sex and age matched to controls with a 5-year tolerance for age. Controls had (1) no radiographic midfoot OA according to the La Trobe Foot Atlas case definition (ie, all midfoot joint radiographic scores were higher than 2) and (2) no pain in the midfoot. The control index foot was matched to the case index foot. For both cases and controls, we excluded those with hallux valgus (measured using a validated line drawing instrument)[16,17] and inflammatory arthritis.

Radiographic measurements. The radiographic measures were selected based on measures commonly used to evaluate foot structure from the literature. A description of each of these measures is provided in Supplementary Table 1. A pilot study was first undertaken to determine which radiographic measures demonstrated acceptable reliability, which was prespecified as an intraclass correlation coefficient (ICC) of greater than 0.90.[18] The primary author (MJL) performed 21 radiographic measures using graphical illustration software (Canvas 11 software, ACD Systems of America) on 25 randomly selected participants and repeated the process 2 weeks later, blinded to previous measurements and to all other participant information.

Statistical analysis. Statistical analysis was undertaken in four stages using IBM SPSS Statistics version 26.0 (IBM). First, the case-control matching function was used to match symptomatic radiographic midfoot OA cases to controls. Second, the normal distribution of all radiographic variables was confirmed using a combination of graphical outputs (histograms, box plots, P–P plots, and Q–Q plots) and statistical tests (Shapiro–Wilk test, Kolmogorov–Smirnov test, skewness, and kurtosis). Third, the test–retest reliability of the radiographic measurements was calculated using two-way mixed effect ICCs[1,2] and 95% confidence intervals (95% CIs), with values less than 0.50 being indicative of poor reliability, values between 0.50 and 0.75 moderate reliability, values between 0.75 and 0.90 good reliability, and values greater than 0.90 excellent reliability.[18] Fourth, differences between midfoot OA cases and controls were calculated using independent sample *t*-tests, and adjustment for differences in body mass index (BMI) was conducted using a general linear model with BMI as a covariate. Effect sizes for between-group comparisons were calculated using Cohen's *d* and were interpreted as follows: less than 0.1 as tiny, 0.1 to 0.2 as very small, 0.2 to 0.5 as small, 0.5 to 0.8 as medium, 0.8 to 1.2 as large, 1.2 to 2 as very large, and greater than 2 as huge.[19] Adjustment for multiple testing was not deemed necessary.[20–23]

RESULTS

Study population. As previously reported, 5,109 completed health survey questionnaires were received (adjusted response 56%).[2] Of these, 1,635 individuals who reported pain in and around the foot in the past 12 months and provided consent to further contact were invited to the research assessment clinic, and 560 attended. Those with hallux valgus (measured using a validated line drawing instrument)[16,17] (n = 230), inflammatory arthritis (n = 24), or incomplete data (n = 11) were excluded, leaving 295 participants (63 with symptomatic radiographic midfoot OA and 232 without). Of the 232 participants without symptomatic radiographic midfoot OA, 110 were excluded because of midfoot pain (n = 55) or radiographic midfoot OA (n = 55), leaving 122 potential control matches, from which 63 were matched (Supplementary Figure 1). The characteristics of participants with symptomatic radiographic midfoot OA and the sex- and age-matched controls are provided in Table 1. Those with midfoot OA had a higher BMI compared with controls ($P < 0.001$) and were less likely to have completed higher education ($P < 0.05$). The joint-specific prevalence of radiographic OA in the midfoot OA group was as follows: first cuneometatarsal (n = 10, 15.9%), second cuneometatarsal (n = 32, 50.8%), navicular-first cuneiform (n = 14, 22.2%), and talonavicular (n = 25, 39.7%) joints. The total number of joints affected in the index foot in those with midfoot OA was as follows: one (n = 47, 74.6%), two (n = 14, 22.2%), and three (n = 2, 3.2%).

Table 1. Participant characteristics*

Characteristic	Midfoot OA (n = 63)	No midfoot OA (n = 63)
Age, y, mean (±SD)	66.8 (8.0)	65.9 (7.8)
Sex, n (%) female	31 (49.2)	31 (49.2)
Body mass index, kg/m^2, mean (±SD)[a]	33.2 (5.1)	29.9 (5.4)
Manual occupation, n (%)	32 (51.0)	27 (42.9)
Attended higher education, n (%)[b]	8 (12.6)	21 (33.3)

* OA = osteoarthritis.
a $P < 0.001$.
b $P < 0.05$.

Reliability of radiographic measurements. The test–retest reliability of the radiographic measures is provided in Supplementary Table 2. Overall, most measures demonstrated good to excellent reliability except for the lateral Meary's angle (ICC 0.667, 95% CI 0.376–0.838), tibiotalar angle (ICC 0.709, 95% CI 0.443–0.861), and lateral talonavicular angle (ICC 0.552, 95% CI 0.209–0.774). These three measurements were therefore excluded from subsequent analysis. We also excluded the anteroposterior Meary's angle (because this is conceptually similar to the talonavicular coverage angle, which is more commonly reported in the literature) and the relative lengths of metatarsals 1 to 4 (because the Maestro technique of measuring metatarsal lengths was slightly more reliable). Thus, 11 measures were retained for the comparisons between midfoot OA cases and controls (Figures 1 and 2).

Differences in radiographic measures between midfoot OA cases and controls. Differences in radiographic measures between midfoot OA cases and controls are shown in Table 2. Those with midfoot OA had a higher calcaneal-first metatarsal angle ($d = 0.43$, small effect size, $P = 0.018$) and lower calcaneal inclination angle ($d = 0.46$, small effect size, $P = 0.011$) compared with controls. Adjusting for BMI slightly attenuated these differences, but the effect size categories for these variables remained largely unchanged (Supplementary Table 3).

DISCUSSION

The objective of this study was to compare radiographic measures of foot structure between people with and without symptomatic radiographic midfoot OA. Understanding the differences in structural foot alignment between cases and controls could potentially provide insights into the development of the condition. We found that people with midfoot OA had a higher calcaneal-first metatarsal angle and lower calcaneal inclination angle.

The calcaneal-first metatarsal angle and calcaneal inclination angle are both sagittal plane measures of foot posture, and our findings are indicative of a flatter foot posture in those with midfoot OA. This is consistent with Menz et al,[9] who reported higher calcaneal-first metatarsal angles and lower calcaneal inclination angles in older people with OA affecting the talonavicular and navicular-first cuneiform joints, and Rao et al,[24] who reported higher calcaneal-first metatarsal angles and lower calcaneal inclination angles in people with midfoot OA. These results provide some insight into the potential mechanism behind midfoot OA. It has been previously suggested that a more pronated foot posture may result in increased joint compressive forces in the medial midfoot,[9] which is consistent with cadaver models demonstrating increased dorsal compression with a flattening of the arch.[25–27] Arch lowering associated with foot pronation may render the second cuneometatarsal joint particularly susceptible to dorsal

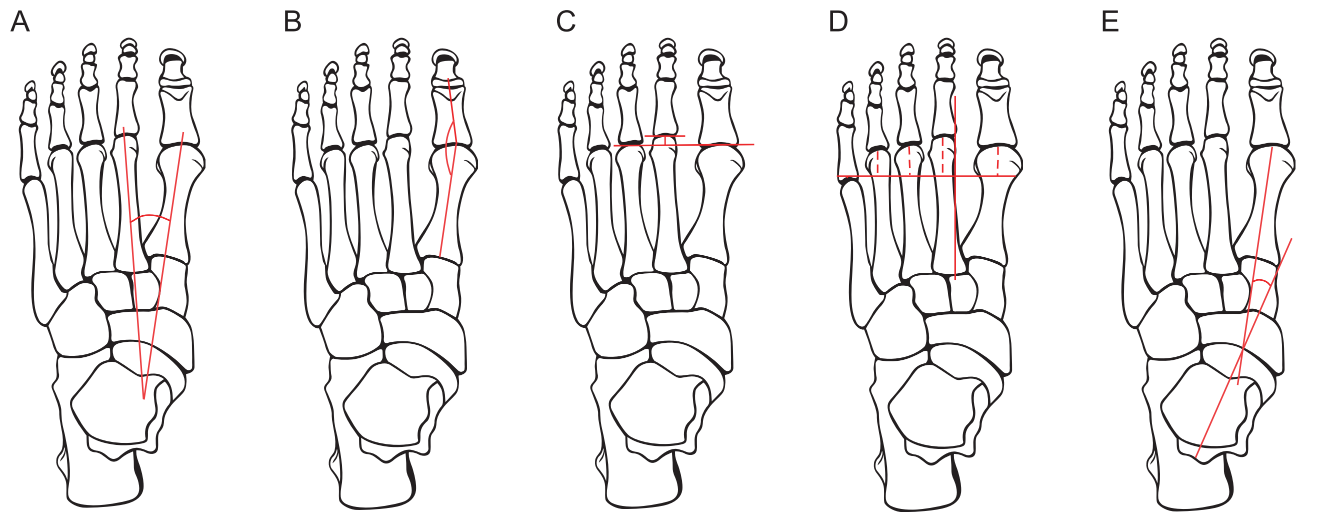

Figure 1. Measurements were taken from dorsoplantar radiographs: (**A**) first–second intermetatarsal angle, (**B**) hallux valgus angle, (**C**) functional second metatarsal length (Coughlin technique), (**D**) functional metatarsal lengths (Maestro technique), and (**E**) talonavicular coverage angle.

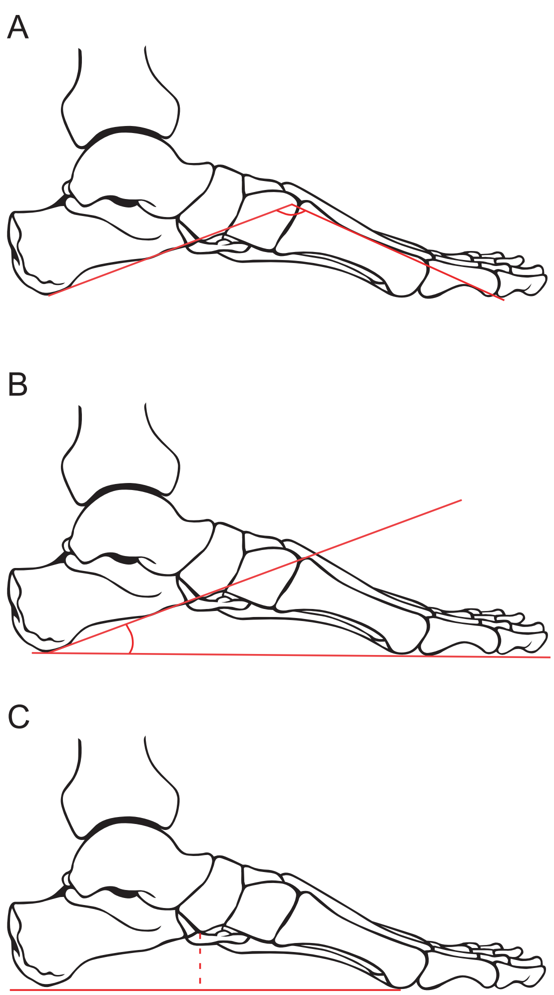

Figure 2. Measurements were taken from lateral radiographs: (**A**) calcaneal-first metatarsal angle, (**B**) calcaneal inclination angle, and (**C**) navicular height (adjusted for truncated foot length).

compression because the base of the second metatarsal is firmly wedged between the three cuneiforms[27] and undergoes the least motion during walking of the tarsometatarsal articulations.[28] Although this study does not allow temporal relationships to be inferred, it does suggest that having a flatter foot could contribute to midfoot OA and potentially explain why the second cuneometatarsal joint is most commonly affected.[1]

It has been previously suggested that a longer second metatarsal (or relatively short first metatarsal) may lead to larger retrograde forces being applied to the second cuneometatarsal joint during gait, thereby predisposing it to joint compression and development of OA.[29] Therefore, to measure the functional lengths of metatarsals, we used two different measures, one described by Maestro et al[30] and another by Coughlin.[31] Both approaches quantify the difference in metatarsal protrusion relative to a longitudinal axis. For the Maestro technique, the longitudinal axis is the second metatarsal shaft, and for the Coughlin[31] technique, an axis between metatarsals 1 and 3. For both measures, we found no statistically significant differences between those with and without midfoot OA. This finding is inconsistent with Davitt et al,[8] who previously found that people with midfoot OA had a longer actual and functional second metatarsal length. These disparate findings could be attributed to differences in midfoot OA case definitions, variations in the reference axis location, lack of adjustment for foot length, and small sample size (n = 9) in the Davitt et al[8] study. Furthermore, we excluded participants with hallux valgus, which in theory could influence the measure of the second metatarsal length. To understand the role of metatarsal length in the development of midfoot OA, more research is required that measures both actual and functional metatarsal lengths with the adjustment for foot length. Further research that could be of interest is not only measuring the distal protrusion of

Table 2. Radiographic measures of foot structure in participants with and without midfoot OA*

Radiographic measure	Midfoot OA (n = 63)	No midfoot OA (n = 63)	Mean difference (95% CI)	*P* value	Effect size[a]	
First–second intermetatarsal angle	8.12 (3.30)	8.25 (3.18)	−0.13 (−1.27 to 1.02)	0.826	0.04	Tiny
Hallux valgus angle	9.65 (6.49)	9.62 (5.43)	0.03 (−2.08 to 2.14)	0.977	0.01	Tiny
Functional second metatarsal length[b,c]	0.215 (0.082)	0.220 (0.097)	−0.005 (−0.036 to 0.027)	0.762	0.05	Tiny
Maestro 1 relative to 2[c,d]	89.59 (20.75)	90.92 (20.44)	−1.33 (−8.59 to 5.94)	0.718	0.06	Tiny
Maestro 3 relative to 2[c,d]	68.03 (14.80)	68.37 (17.01)	−0.34 (−5.96 to 5.28)	0.905	0.02	Tiny
Maestro 4 relative to 2[c,d]	6.67 (32.52)	7.75 (30.58)	−1.08 (−12.21 to 10.05)	0.848	0.03	Tiny
Maestro 5 relative to 2[c,d]	-84.57 (56.48)	-80.13 (45.37)	−4.44 (−22.51 to 13.63)	0.627	0.09	Tiny
Talonavicular coverage angle	12.43 (10.06)	13.05 (7.11)	−0.63 (−3.70 to 2.45)	0.688	0.07	Tiny
Calcaneal-first metatarsal angle	135.09 (9.58)	130.95 (9.85)	4.14 (0.71 to 7.57)	0.018	0.43	Small
Calcaneal inclination angle	19.41 (5.87)	22.36 (6.89)	−2.95 (−5.21 to −0.69)	0.011	0.46	Small
Navicular height[c]	0.206 (0.050)	0.213 (0.044)	−0.007 (−0.024 to 0.010)	0.414	0.15	Very small

* Values are mean (±SD) unless otherwise indicated. 95% CI = 95% confidence interval; OA = osteoarthritis.
a Cohen's *d* interpretation is as follows: <0.1 = tiny, 0.1–0.2 = very small, 0.2–0.5 = small, 0.5–0.8 = medium, 0.8–1.2 = large, 1.2–2 = very large, and *d* > 2 = huge.[19]
b Technique is described by Coughlin.[31]
c This is adjusted for truncated foot length.
d Technique is described by Maestro et al (30) to measure metatarsal length relative to second metatarsal length, expressed as a percentage.

the second metatarsal but also the proximal protrusion of the second metatarsal when it articulates with the cuneiforms. However, measuring the proximal aspect and length of the second metatarsal in people with midfoot OA is inherently difficult. Because of the reduced structural integrity of the midfoot joints, it is not clear where the end point of the bone is, which makes it a less reliable measure.

The clinical implications of the findings of this study are that flatter foot posture may contribute to the onset or progression of midfoot OA and mechanical interventions such as footwear and orthoses that stabilize foot posture may be effective in the treatment of the condition.[32] Indeed, a pilot randomized trial in people with midfoot OA has demonstrated that arch-contouring foot orthoses lead to improvements in symptoms over a 12-week period.[26] The mechanism behind arch-contouring insoles has been theorized to alter the magnitude and duration of loading within the foot,[33,34] which may contribute to the development of midfoot OA. Future research with adequate sample sizes is required to better understand the potential benefits of orthoses in the treatment of midfoot OA.

There are several strengths of this study. First, in contrast to previous studies that relied on relatively small clinical samples, we analyzed data from a large representative population-based study. Second, the definition of cases was undertaken using a standardized foot manikin to identify the location of pain[35] and a reliable atlas for documenting radiographic OA.[14] Third, we performed a within-rater pilot study to ensure that the measures used to document foot structure were sufficiently reliable. Finally, we adjusted the functional metatarsal length measure for foot length to account for any errors caused by differences in radiographic magnification.

Nevertheless, there are several limitations of this study that warrant consideration. First, the study was cross-sectional in design, which does not allow us to establish temporal relationships. Although it is plausible that a flatter foot leads to midfoot OA, it is also possible that osteoarthritic changes affect the structural integrity of the midfoot joints, leading to arch lowering, or there are other person-specific factors that could lead to both midfoot OA and arch lowering. These include other potentially modifiable factors such as muscle strength[3] and elevated body mass.[36] It is important to note that, in our study, although people with midfoot OA had a greater BMI compared with controls, adjusting for this in the statistical analysis did not meaningfully change the findings. Second, although we included a wide range of radiographic measures, some were not reliable enough for inclusion in the main study. Finally, because all participants had some foot pain, this meant that the controls were not completely pain free, even though they did not have any pain in the midfoot.

Midfoot OA is associated with a higher calcaneal-first metatarsal angle and lower calcaneal inclination angle. These findings suggest that people with midfoot OA have a flatter foot posture, which could be a potential risk factor for midfoot OA. Even when controlling for BMI, the effect sizes remained largely unchanged. However, given that the study design is cross-sectional, it cannot be ruled out that the differences observed are caused by OA rather than risk factors for the development of OA. Prospective studies are required to determine the temporal relationships between foot structure, function, and the development of this common and disabling condition.

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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 published. Dr. Lithgow 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.

Study conception and design. Lithgow, Buldt, Munteanu, Marshall, Thomas, Peat, Roddy, Menz.

Acquisition of data. Lithgow, Marshall, Thomas.

Analysis and interpretation of data. Lithgow, Buldt, Munteanu, Marshall, Thomas, Peat, Roddy, Menz.

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