Introduction

Foot pain is a common symptom in the general population, affecting an estimated 24% of community-dwelling older adults, and is frequently encountered in primary care. Osteoarthritis (OA) is likely to be one underlying cause of foot pain. Among adults aged 50 years and over, 17% have been estimated to have symptomatic radiographic foot OA, however, the basis for clinically diagnosing foot OA in symptomatic individuals is far from clear.

At the knee, where more research has been undertaken, the European League Against Rheumatism (EULAR) guidelines recommend the clinical diagnosis of knee OA, and highlighted the particular risk factors, clinical history and physical examination findings likely to be most informative. However, the ability to discriminate subtypes, for example patellofemoral OA, may be limited.

At the foot, diagnostic research is currently restricted to the first metatarsophalangeal joint (MTPJ). We have recently shown that polyarticular midfoot dominant OA may constitute a distinct subtype of foot OA and that symptomatic midfoot OA affects...
approximately 12% of adults aged 50 years and over, with most people reporting foot-related disability and recently utilising primary health care for foot pain10. Although often present in primary care, the ability to provide targeted treatment for the functional consequences of midfoot OA may be limited by the challenges of clinical diagnosis11.

Our aim was therefore to derive a clinically practicable multivariable diagnostic model for symptomatic midfoot OA among community-dwelling persons with midfoot pain.

Methods

Study population

Data were collected via a population-based health survey and research assessment clinic as part of the Clinical Assessment Study of the Foot (CASF)5,12. The health survey gathered information on general health, foot-specific features, demographic and socioeconomic characteristics. The research assessment clinic collected physical examination data using brief clinical assessments and plain radiography. Inclusion criteria for the present analysis were: adults aged ≥50 years who were registered with one of four general practices in North Staffordshire, United Kingdom, and who responded to a health survey, provided consent to further contact, consent to participate in a research assessment clinic and had midfoot pain in the last month. Based on self-reported shading on either dorsal or plantar views of a foot manikin in the health survey, midfoot pain was ascertained using a pre-defined regional marking template (© The University of Manchester 2000. All rights reserved)13,14.

Individuals with non-specific inflammatory arthritis, rheumatoid arthritis or psoriatic arthritis, as indicated by primary care and local hospital medical record review, or on an X-ray report by a consultant musculoskeletal radiologist, were excluded from the analyses. Ethical approval was obtained from Coventry Research Ethics Committee (REC reference number: 10/H1210/5).

Data collection

Research assessment clinic attenders underwent standardised clinical interview and physical examination performed by one of seven trained research therapists (four physiotherapists, three podiatrists). Assessors had between 1 and 35 years of post-qualification experience, reflecting the broad range of expertise found in clinical practice, and were required to satisfy pre-study training requirements and undergo quality control sessions during the study12.

During the same research assessment clinic, plain radiographs were taken of both feet from weight-bearing dorso-plantar and lateral projections. All clinical assessors were blind to participants' radiographic images and outcomes. The presence of midfoot OA was defined as a score of two or more for osteophytes or joint space narrowing at the first or second cuneometatarsal, navicular-first cuneiform or talonavicular joints on either dorso-plantar or lateral views. The included joints represent the medial midfoot as defined above).

Reliability was fair (mean unweighted \( \kappa = 0.32; 95\% \text{ CI: 0.19, 0.45, mean percentage agreement = 63\%} \)).

Reference standard for symptomatic midfoot OA

Symptomatic midfoot OA was confirmed using the atlas by Menz et al.15 and defined as the co-occurrence in the same foot of midfoot pain (ascertained from self-reported shading on a foot manikin as defined above) and the presence of radiographic OA (as defined above).

Selected predictor variables

A total of 16 predictor variables were selected from both health survey and research assessment clinic data. These were selected based on three criteria: (i) known risk factors for symptomatic OA at other joint sites, or (ii) a mechanically-driven putative link to symptomatic midfoot OA, and (iii) be clinically practicable in primary care consultations. In meeting these criteria, three variables were identified and selected as recognised independent risk factors for OA (age, gender and body mass index (BMI))16. Age and gender were ascertained from the health survey and BMI was calculated from measured height and weight. Following pre-study consensus work with a multidisciplinary team of practicing clinicians, we selected static brief clinical assessments that could detect observable deficits, which will have direct implications for both static and dynamic loading of the midfoot. These included the following:

Static foot posture

i) Arch Index: ratio of middle third area to the whole foot area, excluding toes, calculated from carbon footprints taken in relaxed bipedal standing. Higher Arch Index ratios indicate lower arch17,18.

ii) Foot Posture Index: 6-item assessment performed in relaxed bipedal standing. A summative score (range, −12 to +12) classified feet as supinated, normal or pronated19.

iii) Navicular height: height of the navicular tuberosity from the floor in relaxed bipedal standing, measured in millimetres with a ruler, and normalised for foot size by dividing by foot length20.

Range of motion (ROM)

iv) First MTPJ dorsiflexion ROM: maximum passive hallux extension, measured in degrees using a goniometer in non-weight-bearing with the ankle in a relaxed position and the first ray allowed to freely plantarflex21.

v) Subtalour joint inversion/eversion ROM: maximum passive ROM measured in degrees with a goniometer in non-weight-bearing22.

vi) Ankle dorsiflexion ROM, with the knee flexed/extended: active ROM measured in degrees with an inclinometer during a weight-bearing lunge test23,24.

Palpation and observation

vii) Midfoot exostosis: palpable presence or absence of bony prominence on the dorsum of the foot in non-weight-bearing.

viii) Plantar tenderness: palpable presence or absence of point tenderness at plantar fascia-calcaneal insertion25 and middle portion of plantar surface26 in non-weight-bearing.
ix) Lesser toe deformity: palpable presence or absence of de-
formities, in one or more lesser toes, including mallet, 
hammer and claw toe in non-weight-bearing and retracted 
toe observed in standing27.

x) Hallux valgus: ascertained using five line drawings of the 
foot progressing in severity (15° increments) using a va-
dated self-report instrument and dichotomised present or 
absent definition (three most severe vs two least severe)28.

For Arch Index, navicular height, 1st MTPj dorsiflexion, subtalar 
inverson/eversion and ankle dorsiflexion with the knee flexed/ 
extended, intra-class correlation coefficients (ICC) previously re-
ported for intra-rater reliability range from 0.82–0.9928,29,30, with 
the Foot Posture Index being slightly lower (0.61)29. Inter-rater 
reliability ICC have been documented for subtalar inverson/ever-
sion (0.73 and 0.62, respectively)29 and ankle dorsiflexion with the 
knee flexed/extended (0.97 and 0.92, respectively)29,30. For the 
dichotomised hallux valgus definition, unweighted kappa scores 
were 0.83 for intra-rater and 0.55 for inter-rater reliability29.

Statistical analysis

All feet with midfoot pain were entered into the analysis. All 
continuous variables were screened to check appropriate range 
values and to identify any apparent outliers29. Where possible, 
dichotomised or categorised cut-offs applied to continuous vari-
able were based on previous evidence. Across all feet, navicular 
height was divided into tertiles on the variable distribution to 
produce categories consistent with the Arch Index, and the subtalar 
and ankle ROM variables were dichotomised on the median, as no 
suitable prior information was identified. As the proportion of 
missing data for each predictor variable was <5%, multiple impu-
tation was considered unnecessary.

The data had a non-hierarchical structure with feet nested 
within person and were analysed using a random intercept multi-
level logistic regression model30. Each predictor variable was 
individually entered into the model with presence of symptomatic 
midfoot OA as the outcome. Significant independent predictor 
variables (P < 0.25 from likelihood ratio tests31) were then simul-
taneously entered into the model with age, gender and BMI force-
entered, and manual backward elimination of variables (P = 0.05) 
performed. The final model was refitted using data from partici-
ants with no missing predictor variable data. Predicted risks were 
calculated on the estimated variable effects and the intercept for 
each foot. The proportion of the sample that could be correctly 
classified (ruled-in as having symptomatic midfoot OA) or correctly 
classified as midfoot pain (ruled-out for symptomatic midfoot OA) 
was determined by imposing a practical cut-off of 50%. Subse-
sequently, sensitivity and specificity with 95% CIs were calculated for 
the overall final model.

Model performance was assessed with the calibration slope and 
area under the curve (AUC). Ideally a calibration slope with a value 
<0.25 indicates the predicted and observed risks are the same32, and 
a calibration slope with a value <0.57, 0.68). For the overall model, sensitivity was 29.9% (95% CI: 
85.5, 93.3).

remained fair-to-poor (AUC, 0.64, 95% CI: 0.58, 0.70 vs 0.62, 95% CI: 
0.57, 0.68). For the overall model, sensitivity was 29.9% (95% CI: 
22.7, 38.0) and specificity was 87.5% (95% CI: 82.9, 91.3).

Comparison of the beta coefficients and odds ratios for the final 
derived model (Table II) and the same estimates following bias-
corrected bootstrapping indicated the model to be over-
optimistic (data not shown). Overall bias-corrected model sensi-
tivity was 25.9% (95% CI: 19.0, 33.7) and specificity was 89.9% (95% CI: 
85.5, 93.3).

Sensitivity analyses

Repeating the modelling with variables in their original 
continuous form, did not identify any additional predictors, and 
overall model performance was effectively unchanged (calibration 
slope, 0.61, 95% CI: 0.38, 0.85; AUC, 0.66, 95% CI: 0.60, 0.71; sensi-
tivity, 53.2%, 95% CI: 41.5, 64.7; specificity, 67.6%, 95% CI: 62.2, 72.6) 
(data not shown).
Discussion

Our study found that in a population-based sample of adults aged 50 years and older with midfoot pain, brief clinical assessments added little to age, gender and BMI in the discrimination of individuals with underlying midfoot OA on plain radiographs from those without these structural changes. Although several physical examination variables were associated with symptomatic midfoot OA, these were often either too weakly associated to be included in a diagnostic model (Foot Posture Index, subtalar inversion, plantar fascia insertion tenderness and lesser toe deformity) or lacked strong association after adjusting for age (navicular height) or combinations of age, gender, BMI and Arch Index (ankle dorsiflexion with the knee flexed and midfoot exostosis). The retained Arch Index predictor, indicating a more pronated foot posture among those with symptomatic midfoot OA, would appear to be biologically plausible and is consistent with earlier observations.\(^\text{36,37}\) In isolation, the Arch Index appeared to be a potentially useful predictor of symptomatic midfoot OA.

Although the low overall bias-corrected sensitivity (25.9%) is accompanied by a high specificity (89.9%), considered together with an AUC of 0.64, the final model remains only fair-to-poor at discriminating between people with and without symptomatic midfoot OA.

Accurate clinical diagnosis of symptomatic OA compared to plain radiographs has been mixed at other joint sites including the knee,\(^\text{38,39}\) hip,\(^\text{40,41}\) and hand.\(^\text{42}\) Despite this, the clinical diagnosis of OA has been recommended in previous guidelines.\(^\text{43}\) At the foot, a diagnostic model developed to predict the presence of radiographic OA at the first MTPJ in adults with first MTPJ pain reported better performance than the present model (AUC, 0.87, 95% CI: 0.80, 0.93).\(^\text{8}\) Better discrimination may be explained by the more anatomically specific assessment of the first MTPJ used in the Zammit et al.\(^\text{3}\) study, compared to the broader foot examination we used to identify radiographic OA in the midfoot complex.

Strengths of this study are the population-based sample and standardised quality-controlled protocol for the collection of clinical and radiographic data. Despite this, there are a number of methodological issues that may explain the fair-to-poor performance of the model. First, the selected predictors may lack discriminatory ability. Even if measured perfectly, these clinical assessments may not be very strongly associated with the presence/absence of radiographic OA. For example, if they are causes of midfoot OA, they may be relatively weak causes, or if they are manifestations of midfoot OA, they may provide relatively weak signals. The strength of univariable association required for adequate discrimination is very high.\(^\text{44}\) Given the complex pathogenesis and structure/pain associations in OA, discrimination from any one single measure is unlikely, which supports the need to evaluate multivariable clinical assessment models. The present model examined 16 predictor variables, however soft tissue assessments such as posterior tibial tendon dysfunction or local swelling and tenderness were not considered. It is possible that our model could be improved by adding more clinical predictors or other diagnostic markers.\(^\text{45,46}\)

Second, random and systematic errors in the clinical assessment measurements may also influence our findings. All assessors undertook protocol training and quality control monitoring, and we
also chose clinical assessments previously shown to be reliable. However, we did not formally evaluate the reliability of clinical assessments within this study.

Third, symptomatic midfoot OA in an individual joint was defined as ≥2 for osteophytes or joint space narrowing using the scoring system established by Menz et al.15 With nearly half (43%) of the 274 eligible participants comprising the study sample having radiographic midfoot OA, this underscores the very high prevalence among older adults that report midfoot pain. Of the 263 feet with midfoot pain but classed as 'no midfoot radiographic OA', 248 (94%) had a score of one. Whilst grade one radiographic changes did not meet our threshold for symptomatic midfoot OA, it may be that disease manifestations and variations in structural appearance between grade one and two are too subtle to be clinically

<table>
<thead>
<tr>
<th>Predictor variable (categorisation)</th>
<th>Total (n = 274)</th>
<th>Midfoot pain (n = 155)</th>
<th>Symptomatic midfoot OA (n = 119)</th>
<th>Multi-level logistic regression</th>
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<tr>
<td><strong>People</strong></td>
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<td>67 (44)</td>
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<td>Arch Index (ratio)</td>
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<td>42 (16)</td>
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<td>178 (68)</td>
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<td>Low arch</td>
<td>89 (22)</td>
<td>42 (16)</td>
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<td>1st MTPJ (degrees) dorsiflexion</td>
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<td>Low (&lt;60)</td>
<td>197 (48)</td>
<td>123 (47)</td>
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<tr>
<td>High (≥60)</td>
<td>215 (52)</td>
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<td>195 (48)</td>
<td>133 (51)</td>
<td>62 (42)</td>
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<td>Eversion</td>
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<td><strong>Ankle dorsiflexion (degrees)</strong></td>
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<td>153 (59)</td>
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<td>Knee extended</td>
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<td>High (35–63 from 0)</td>
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<td>70 (48)</td>
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<td><strong>Palpation/Observation</strong></td>
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<td>Midfoot exostosis</td>
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<tr>
<td>Absent</td>
<td>141 (34)</td>
<td>78 (30)</td>
<td>63 (42)</td>
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<tr>
<td>Present</td>
<td>271 (76)</td>
<td>185 (70)</td>
<td>86 (58)</td>
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<td>PF insertion tenderness</td>
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<td>202 (77)</td>
<td>120 (81)</td>
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<td>128 (49)</td>
<td>66 (45)</td>
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<tr>
<td>Present</td>
<td>217 (53)</td>
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<td>Lesser toe deformity</td>
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<td>Present</td>
<td>263 (64)</td>
<td>160 (61)</td>
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<td>Hallux valgus</td>
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<td>263 (64)</td>
<td>169 (64)</td>
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<tr>
<td>Present</td>
<td>148 (36)</td>
<td>94 (36)</td>
<td>54 (36)</td>
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MTPJ, metatarsophalangeal joint; PF, plantar fascia.

* P values are for the likelihood ratio test, with significance set at 0.25.
discernible. Recent work on knee OA has shown that grade one is a strong predictor of future grade two. This suggests that grade one may have been a more suitable cut-off. Since it is not possible to know from this sample what the prevalence of grade one midfoot changes may be in an asymptomatic population, a question for future research is whether midfoot pain alone in adults aged 50 years and over without inflammatory arthritis provides adequate grounds for ‘ruling in’ symptomatic midfoot OA.

By assembling the sample from a cohort of individuals with foot pain in the last 12 months, it is possible that participants may have had concurrent symptoms elsewhere in their foot. Restricting analysis to individuals with foot pain only in the midfoot region was not possible due to small numbers. A sensitivity analysis, where univariable analyses for all predictor variables (excluding the force-entered variables: age, gender and BMI) was repeated where univariable analyses for all predictor variables (excluding the force-entered variables: age, gender and BMI) was repeated after excluding 33 individuals with symptomatic MTPJ OA (defined as co-occurring pain and radiographic change as defined above), indicated that 14 of the 16 observed associations had similar magnitude and precision that would not have statistically significantly altered the model (data not shown). Although the four selected joints can be reliably scored and used to represent midfoot OA, this present analysis pertains only to the identification of radiographic OA in the medial midfoot. Whilst clinically the occurrence of OA in the lateral midfoot is understood to be rare by comparison, osteoarthritic changes in other midfoot joints could also contribute to symptoms in both midfoot pain and symptomatic midfoot OA groups. Furthermore, an alternative reference standard such as magnetic resonance imaging (MRI) or ultrasound may have generated different results and future studies could consider comparing the use of other imaging modalities for the midfoot.

Finally, misclassification may have arisen in the musculoskeletal midfoot pain domain. Narrowing this domain to exclude those with prevalent conditions such as diabetes, peripheral vascular disease or gout may help in being able to diagnose symptomatic midfoot OA, but this would also limit the generalizability of such insights as multimorbidity is often quite high in this age group. Of the 274 participants in this sample, 19% and 37% had self-reported diabetes and peripheral vascular disease respectively. Only 5% had a primary care consultation for gout within 18 months either side of research clinic attendance.

The population-based recruitment for this study meant that although the spectrum of severity across the sample is likely to be mild, this has relevance for primary care. Furthermore, although a physical examination may be of limited value for discriminating the presence or absence of symptomatic midfoot OA, brief clinical assessments may be better used to identify abnormal structural and postural presentations that could inform more targeted treatments.

In summary, this study did not allow development of a clinically practicable diagnostic model for symptomatic midfoot OA. Person-level information including age, gender and BMI provided only marginal diagnostic information and only very minor additional improvements in model performance were achieved with brief clinical assessment information. Before primary care clinicians can be confident that the diagnosis of symptomatic midfoot OA necessitates the use of X-ray, future research should examine whether these or other, more anatomically-specific, clinical assessments can show better discrimination in other samples, using alternative modelling techniques, or compared to other imaging modalities such as MRI and ultrasound.

### Contributions

MJT, ER, GP, AM and HBM conceived the study. MJT, ER and MM designed the study. MJT, ER and MM were responsible for data acquisition. Analysis was undertaken by MJT and TR. All authors interpreted data, drafted or revised the article critically for important intellectual content, and approved the final version of the manuscript.

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Conflicts of interest
The authors have no conflicts of interest to declare.

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