Research Square

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A flat foot and a heavy load: the radiographic phenotype of isolated central tarsometatarsal osteoarthritis

Chethan B Shetty

chethan.shetty@manipal.edu

Kasturba Medical College, Mangalore

Craig Maguire

Golden Jubilee National Hospital

Kalpesh Shah

Golden Jubilee National Hospital

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Abstract

Introduction

Isolated osteoarthritis (OA) of the second and third (central) tarsometatarsal (TMT) joints is an under-characterised cause of midfoot pain that may require arthrodesis. We compared the demographic and radiographic phenotype of patients undergoing isolated central TMT fusion with that of patients undergoing first metatarsophalangeal (MTP) fusion and assessed measurement reliability.

Materials and Methods

In this retrospective cohort study, 54 feet undergoing isolated second and third TMT arthrodesis for primary OA (2019–2024) were compared with 96 first MTP fusions for degenerative OA (2021–2024). Demographic data, body mass index (BMI) and six weight-bearing radiographic measurements were recorded. Interobserver reliability was assessed with the intraclass correlation coefficient (ICC). Cohorts were compared with Welch t-tests and chi-square/Fisher tests; logistic regression assessed independence from BMI.

Results

The TMT cohort had a higher BMI (29.6 ± 4.4 versus 26.2 ± 4.2 kg/m²; $p < 0.001$), more obesity (44.4% versus 17.7%; $p < 0.001$) and more women (92.6% versus 63.5%; $p < 0.001$), with similar age ($p = 0.133$). It had lower calcaneal pitch (20.2 ± 4.7° versus 24.4 ± 5.1°; $p < 0.001$) and higher Meary's angle (12.5 ± 11.4° versus 6.0 ± 7.3°; $p < 0.001$); hallux valgus and metatarsus adductus angles did not differ. Lower calcaneal pitch remained associated with central TMT OA after adjustment for BMI (adjusted odds ratio 0.85 per degree, 95% confidence interval [CI] 0.78–0.93; $p < 0.001$); a model combining calcaneal pitch and BMI had an area under the curve of 0.77. Across 68 double-read feet, ICC was 0.92 (95% CI 0.88–0.95) for calcaneal pitch, 0.78–0.86 for four other measurements and 0.62 for Meary's angle.

Conclusions

Patients requiring isolated central TMT fusion show a reproducible planovalgus phenotype—a flatter hindfoot and raised BMI—distinct from patients with first-ray degeneration despite similar hallux valgus. Calcaneal pitch is a reproducible, accessible marker of this phenotype.

Introduction

Osteoarthritis (OA) of the midfoot is a common but under-recognised source of foot pain and disability, affecting a substantial proportion of older adults with foot symptoms [1, 2]. Within the midfoot, degenerative change frequently involves the tarsometatarsal (TMT) joints. While first-ray disease — first

metatarsophalangeal (MTP) joint OA and hallux valgus — is well characterised and commonly treated, isolated degeneration of the second and third (central) TMT joints is less well understood, even though it can progress to severe pain and functional limitation requiring arthrodesis.

Community-based radiographic studies have advanced understanding of midfoot OA considerably. Midfoot OA has been shown to cluster into recognisable patterns, and to be associated at the person level with female sex, older age, obesity, previous injury and manual occupations [3, 4]. Structural analyses have further reported that individuals with midfoot OA tend to have a flatter foot, with a lower arch and altered hindfoot alignment, and a higher body mass index (BMI) [3, 5]. Selected operative and radiographic series of atraumatic TMT OA have likewise noted associated deformities, including pes planovalgus and hallux valgus [6–9], and biomechanical factors such as functional second-metatarsal length have been implicated [10].

What remains undescribed is the radiographic phenotype of the specific patient who reaches isolated central TMT fusion, and how that phenotype compares with a contemporary operative population undergoing first-ray fusion. Much of the existing evidence derives from community cohorts of symptomatic older adults rather than from surgical populations at the severe end of the disease spectrum, and prior operative series predate routine reporting of measurement reliability [6, 8]. Establishing whether a distinct, reproducibly measurable radiographic phenotype characterises surgical central TMT OA has practical value: it could help clinicians recognise the at-risk foot and inform counselling and operative planning.

We therefore performed a retrospective comparative cohort study with three aims: (1) to compare the demographic profile of patients undergoing isolated second and third TMT fusion with those undergoing first MTP fusion; (2) to compare their weight-bearing radiographic morphology across a defined set of forefoot, midfoot and hindfoot measurements; and (3) to quantify the interobserver reliability of those measurements, so that any phenotype we describe rests on reproducible data.

Methods

Study design and ethical approval

We performed a single-centre retrospective comparative cohort study at a tertiary referral centre for elective orthopaedic surgery. Because the study used routinely collected, de-identified clinical and radiographic data, individual patient consent was not required.

Cohorts

The index cohort comprised consecutive feet undergoing isolated arthrodesis of the second and/or third TMT joints for primary (atraumatic) OA over five years (February 2019 to February 2024). Feet were

excluded if the degeneration was post-traumatic, inflammatory, or part of a wider deformity correction rather than isolated central TMT disease, or if adequate weight-bearing radiographs were unavailable.

The comparison cohort comprised feet undergoing primary first MTP joint arthrodesis for degenerative OA. Because the institution operates a regional “treat-only” model with a case mix that changed during the COVID-19 pandemic, the comparison cohort was drawn from a partially overlapping, post-pandemic operative period (2021 to 2024) to reflect contemporary practice. The two cohorts were not intended to be strictly contemporaneous; the first MTP fusion group serves as an internal surgical reference population of end-stage primary forefoot OA against which the midfoot phenotype could be compared.

Data collection and radiographic measurements

Demographic variables (age, sex, BMI, laterality, smoking status and diabetes) were extracted from the electronic record. Foot morphology was recorded from standardised weight-bearing anteroposterior and lateral foot radiographs. Six radiographic measurements were made: the hallux valgus (HV) angle and first–second intermetatarsal angle (IMA) on the anteroposterior view; the metatarsus adductus angle (MTA) and functional second-metatarsal length [10] on the anteroposterior view; and Meary's (talo–first-metatarsal) angle and calcaneal pitch on the lateral weight-bearing view. Reduced calcaneal pitch and an increased (apex-plantar) Meary's angle were taken to indicate a flatter, more collapsed medial longitudinal arch.

Interobserver reliability

To assess measurement reproducibility, two observers independently measured the six radiographic parameters in a sample of feet drawn from both cohorts, blinded to each other's readings. Agreement was quantified using the intraclass correlation coefficient (ICC), estimated with a two-way random-effects, absolute-agreement, single-rater model [ICC(2,1)] with 95% confidence intervals (CIs). ICC values were interpreted as poor (< 0.50), moderate (0.50–0.74), good (0.75–0.90) or excellent (> 0.90) [11]. Systematic bias and 95% limits of agreement between observers were additionally examined using the Bland–Altman method [12].

Statistical analysis

Continuous variables are summarised as mean ± standard deviation and compared with the Welch (unequal-variance) t-test; mean differences are reported with 95% CIs. Categorical variables are compared with the chi-square test or Fisher's exact test, with odds ratios (ORs) and 95% CIs. To assess whether radiographic associations were independent of BMI, a multivariable logistic regression model was fitted with cohort (central TMT versus first MTP) as the outcome; discrimination was summarised with the area under the receiver-operating-characteristic curve (AUC). A two-sided p-value < 0.05 was considered statistically significant. Analyses were performed per foot; because measurements were not

available for every foot, denominators are reported for each variable. Analyses were performed in SPSS version 21

Results

Study population

Fifty-four feet undergoing isolated second and third TMT arthrodesis met the inclusion criteria (Fig. 1). Two feet whose patients also appeared in the index cohort were excluded from the comparison group to preserve the independence of the two groups, leaving 96 first MTP joint fusions. The demographic characteristics of the two cohorts are summarised in Table 1.

Demographic comparison

Patients undergoing isolated TMT fusion were of similar age to those undergoing first MTP fusion (62.5 ± 8.0 versus 60.2 ± 10.3 years; mean difference 2.29, 95% CI − 0.68 to 5.25; p = 0.133). The TMT cohort had a significantly higher BMI (29.6 ± 4.4 versus 26.2 ± 4.2 kg/m²; mean difference 3.32, 95% CI 1.89 to 4.76; p < 0.001) and were more than three times as likely to be obese (44.4% versus 17.7% with BMI ≥ 30 kg/m²; OR 3.72, 95% CI 1.76 to 7.87; p < 0.001). The TMT cohort was also markedly more likely to be female (92.6% versus 63.5%; OR 7.17, 95% CI 2.39 to 21.55; p < 0.001). Current smoking was less common in the TMT cohort (13.0% versus 27.1%; OR 0.40, 95% CI 0.16 to 1.00; p = 0.045). Laterality and diabetes did not differ between groups (Fig. 2).

Table 1
Demographic characteristics of the two cohorts

Characteristic	Isolated 2nd/3rd TMT fusion (n = 54)	1st MTP fusion (n = 96)	Effect estimate (95% CI)	*p*
Age (years), mean ± SD	62.5 ± 8.0	60.2 ± 10.3	MD 2.29 (− 0.68 to 5.25)	0.133
Female, n (%)	50 (92.6)	61 (63.5)	OR 7.17 (2.39 to 21.55)	< 0.001
BMI (kg/m²), mean ± SD	29.6 ± 4.4	26.2 ± 4.2	MD 3.32 (1.89 to 4.76)	< 0.001
Obesity (BMI ≥ 30), n (%)	24 (44.4)	17 (17.7)	OR 3.72 (1.76 to 7.87)	< 0.001
Right foot, n (%)	26 (48.1)	50 (52.1)	OR 0.85 (0.44 to 1.66)	0.644
Current smoker, n (%)	7 (13.0)	26 (27.1)	OR 0.40 (0.16 to 1.00)	0.045
Diabetes, n (%)	8 (14.8)	18 (18.8)	OR 0.75 (0.30 to 1.87)	0.541

BMI, body mass index; CI, confidence interval; MD, mean difference; MTP, metatarsophalangeal; OR, odds ratio; SD, standard deviation; TMT, tarsometatarsal. Continuous variables compared with the Welch t-test; categorical variables with chi-square/Fisher tests.

Radiographic comparison

Weight-bearing radiographic measurements are summarised in Table 2 and Fig. 2a. The two cohorts differed principally in hindfoot and midfoot morphology rather than in forefoot deformity. The TMT cohort had a significantly flatter hindfoot, with a lower calcaneal pitch (20.2 ± 4.7 versus 24.4 ± 5.1°; mean difference − 4.23, 95% CI − 5.91 to − 2.55; p < 0.001) and a higher (more apex-plantar) Meary's angle (12.5 ± 11.4 versus 6.0 ± 7.3°; mean difference 6.50, 95% CI 3.07 to 9.92; p < 0.001) — two independent measures that both indicate a lower medial longitudinal arch (Fig. 3). The IMA (11.7 ± 5.2 versus 10.0 ± 4.3°; p = 0.054) and functional second-metatarsal length (p = 0.035) showed smaller differences of marginal significance that should be interpreted cautiously. By contrast, the HV angle did not differ between groups (23.4 ± 17.3 versus 21.3 ± 13.7°; p = 0.458), nor did the MTA (p = 0.119).

Table 2
Weight-bearing radiographic measurements

Measurement	TMT cohort, mean ± SD	MTP cohort, mean ± SD	Mean difference (95% CI)	*p*
Calcaneal pitch (°)	20.2 ± 4.7 (n = 54)	24.4 ± 5.1 (n = 81)	−4.23 (− 5.91 to − 2.55)	< 0.001
Meary's angle (°)	12.5 ± 11.4 (n = 54)	6.0 ± 7.3 (n = 81)	6.50 (3.07 to 9.92)	< 0.001
Intermetatarsal angle (°)	11.7 ± 5.2 (n = 54)	10.0 ± 4.3 (n = 82)	1.67 (− 0.01 to 3.34)	0.054
Metatarsus adductus angle (°)	15.5 ± 7.1 (n = 54)	13.7 ± 5.6 (n = 82)	1.80 (− 0.44 to 4.05)	0.119
Functional 2nd MT length (mm)	4.2 ± 1.5 (n = 54)	3.5 ± 2.0 (n = 82)	0.65 (0.05 to 1.25)	0.035
Hallux valgus angle (°)	23.4 ± 17.3 (n = 54)	21.3 ± 13.7 (n = 82)	2.08 (− 3.39 to 7.56)	0.458

CI, confidence interval; MT, metatarsal; MTP, metatarsophalangeal; SD, standard deviation; TMT, tarsometatarsal. A lower calcaneal pitch and a higher Meary's angle both indicate a flatter medial longitudinal arch. Denominators vary because measurements were not available for every foot.

Independence and discrimination

Because BMI and arch morphology may be related, we examined whether the calcaneal-pitch association was independent of BMI. In a multivariable logistic regression model, a lower calcaneal pitch remained independently associated with isolated central TMT OA after adjustment for BMI (adjusted OR 0.85 per degree increase in pitch, 95% CI 0.78 to 0.93; $p < 0.001$), as did higher BMI (adjusted OR 1.16 per unit, 95% CI 1.06 to 1.28; $p = 0.002$). A model combining calcaneal pitch and BMI discriminated the two operative cohorts with an AUC of 0.77, indicating a moderate ability of foot shape and body habitus together to distinguish the two populations.

Interobserver reliability

Interobserver reliability, assessed in a pooled sample of 68 double-read feet, is summarised in Table 3 and Fig. 4. Agreement was excellent for calcaneal pitch (ICC 0.92, 95% CI 0.88 to 0.95) and good for the HV angle, IMA, MTA and functional second-metatarsal length (ICC 0.78 to 0.86). Meary's angle showed only moderate reliability (ICC 0.62, 95% CI 0.36 to 0.77), with a small but consistent systematic bias between observers (mean difference approximately 3°) that persisted after repeat measurement, indicating a genuine difference in how the angle was constructed rather than random error. Bland–Altman analysis showed no meaningful systematic bias for the remaining measurements. The key marker of the midfoot phenotype — calcaneal pitch — was therefore the most reproducible of the six measurements.

Table 3
Interobserver reliability of radiographic measurements (pooled, 68 double-read feet)

Measurement	ICC (95% CI)	Agreement	Mean bias	95% limits of agreement
Calcaneal pitch	0.92 (0.88 to 0.95)	Excellent	−0.2	−4.1 to + 3.7
Hallux valgus angle	0.86 (0.78 to 0.91)	Good	+ 0.1	−14.8 to + 14.9
Intermetatarsal angle	0.80 (0.66 to 0.88)	Good	+ 1.1	−4.1 to + 6.3
Functional 2nd MT length	0.80 (0.70 to 0.87)	Good	−0.1	−2.1 to + 1.8
Metatarsus adductus angle	0.78 (0.67 to 0.86)	Good	+ 0.6	−7.2 to + 8.4
Meary's angle	0.62 (0.36 to 0.77)	Moderate	+ 3.0	−7.5 to + 13.5

ICC, intraclass correlation coefficient [two-way random-effects, absolute-agreement, single-rater, ICC(2,1)]; MT, metatarsal. Agreement categories per Koo and Li [11]: <0.50 poor, 0.50–0.74 moderate, 0.75–0.90 good, > 0.90 excellent.

Discussion

The principal finding of this study is that patients requiring isolated arthrodesis of the second and third TMT joints for primary OA have a distinct and reproducibly measurable radiographic phenotype: a flatter hindfoot (lower calcaneal pitch and higher Meary's angle) and a higher BMI, when compared with patients undergoing first MTP fusion. Importantly, this difference was not explained by forefoot hallux valgus, which was equally prevalent in both operative groups. The two arch measurements changed in the same direction, and the calcaneal-pitch association persisted after adjustment for BMI, supporting a genuine structural difference rather than a simple consequence of body habitus.

These findings are best interpreted as confirmatory rather than novel, and they sit within an established body of work that we do not seek to overstate. Community-based radiographic studies have previously reported that midfoot OA is associated with a flatter foot and a higher BMI [3, 5], and that midfoot degeneration clusters into identifiable patterns often accompanied by first-ray disease [4]. Operative series of atraumatic TMT OA have likewise recognised associated pes planovalgus deformity [6, 8, 9]. The contribution of the present study is to demonstrate these associations at the severe, surgical end of the disease spectrum — in a population defined by having undergone isolated central TMT fusion — using a direct first-ray surgical comparator and with formal quantification of measurement reliability, which earlier operative series did not report.

A mechanistic interpretation is plausible and consistent with the data. Collapse of the medial longitudinal arch, reflected here in a reduced calcaneal pitch and increased Meary's angle, alters load distribution across the midfoot [13] and may transfer force to the lesser (central) TMT joints, which are relatively rigid and poorly adapted to increased shear and compressive loading. A raised BMI would be expected to amplify these loads. Over time this may predispose to central-column degeneration, offering a coherent explanation for the phenotype we observed. This remains a hypothesis generated by cross-sectional data and cannot be confirmed by the present study.

From a clinical standpoint, the reproducibility of calcaneal pitch is notable. It was the most reliable of the six measurements (ICC 0.92), is readily obtained from a standard lateral weight-bearing radiograph and independently distinguished the two operative populations. It may therefore be a practical marker with which to identify the flatter, heavier foot that appears over-represented among patients progressing to central TMT fusion, and to prompt consideration of arch-supporting measures earlier in the pathway. By contrast, Meary's angle, although concordant in direction, showed only moderate interobserver reliability with a systematic bias, and we would caution against relying on it as a sole quantitative marker without a standardised measurement protocol.

Strengths and limitations

The strengths of this study include a clearly defined surgical index population, a direct operative comparison group, and the formal reporting of interobserver reliability with CIs and limits of agreement — data absent from most prior series. Several limitations must be acknowledged. First, this is a retrospective, single-centre study, and the cohorts were not strictly contemporaneous: the first MTP comparison group was drawn from a partially overlapping post-pandemic period, which may introduce case-mix differences. Second, analyses were performed per foot; a small number of patients contributed both feet, which may introduce a degree of clustering. Two patients whose feet appeared in both cohorts were excluded from the comparison group to preserve the independence of the groups. Third, radiographic measurements were not available for every foot, so denominators vary, and the reliability sample, although larger than in previous series, remained modest and its expansion was concentrated in the first MTP cohort. Fourth, the moderate reliability of Meary's angle limits confidence in that specific measurement. Fifth, this study reports morphology and associations only; we did not assess functional outcomes, union or revision after fusion, and the cross-sectional design cannot establish causation. Finally, as a comparison of two operative populations, the findings describe what distinguishes patients selected for central TMT fusion and should not be extrapolated to the general population or used as a diagnostic test.

Conclusions

Patients undergoing isolated second and third TMT fusion for primary OA demonstrate a reproducible planovalgus midfoot phenotype — a flatter hindfoot and a raised BMI — that distinguishes them from patients undergoing first MTP fusion, despite similar forefoot hallux valgus. These findings confirm, in a

surgical population and with reliable measurement, associations previously described in community cohorts, and are consistent with a mechanism in which medial-column collapse transfers load to the central TMT joints. Calcaneal pitch, the most reproducible measurement in this study, offers a simple and reliable radiographic marker of this phenotype. Prospective work linking this phenotype to functional and surgical outcomes is warranted.

Declarations

Author Contribution

1. CBSLiterature search, data analysis, statistical analysis, Manuscript editing2. CMDesign Study, Data acquisition, Data analysis, Manuscript writing3. KSConcept of study, design of study, manuscript review, and manuscript editing.DeclarationsEthics approval. This retrospective study was performed in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments.Consent to participate. We did not obtain individual patient consent, as this was a retrospective study using routinely collected, de-identified clinical and radiographic data.Institutional Committee allowed waiver of consentStudy no 2106Study completion date: 12/9/24Email: clinical.audit@gjnh.scot.nhs.ukAddressClinical Effectiveness DepartmentNHS Golden JubileeAgamemnon StreetClydebankG81 4DYNo participants included any minors or other vulnerable groups and their ages or age ranges.Consent to publish. Not applicable. The manuscript contains no identifiable patient information or images.Data availability. The datasets generated and analysed during the current study are not publicly available owing to patient confidentiality but are available from the corresponding author on reasonable request.Funding statement: The author(s) received no financial support for the research, authorship, and/or publication of this article. Declaration of conflicting interest: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. AI Declaration: The authors used Claude (Anthropic, San Francisco, USA) to assist with restructuring and refining the manuscript as per Journal requirements. All scientific content, data interpretation, and conclusions are the authors' own. The authors verified all information and accept full responsibility for the integrity and accuracy of the work

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Figures

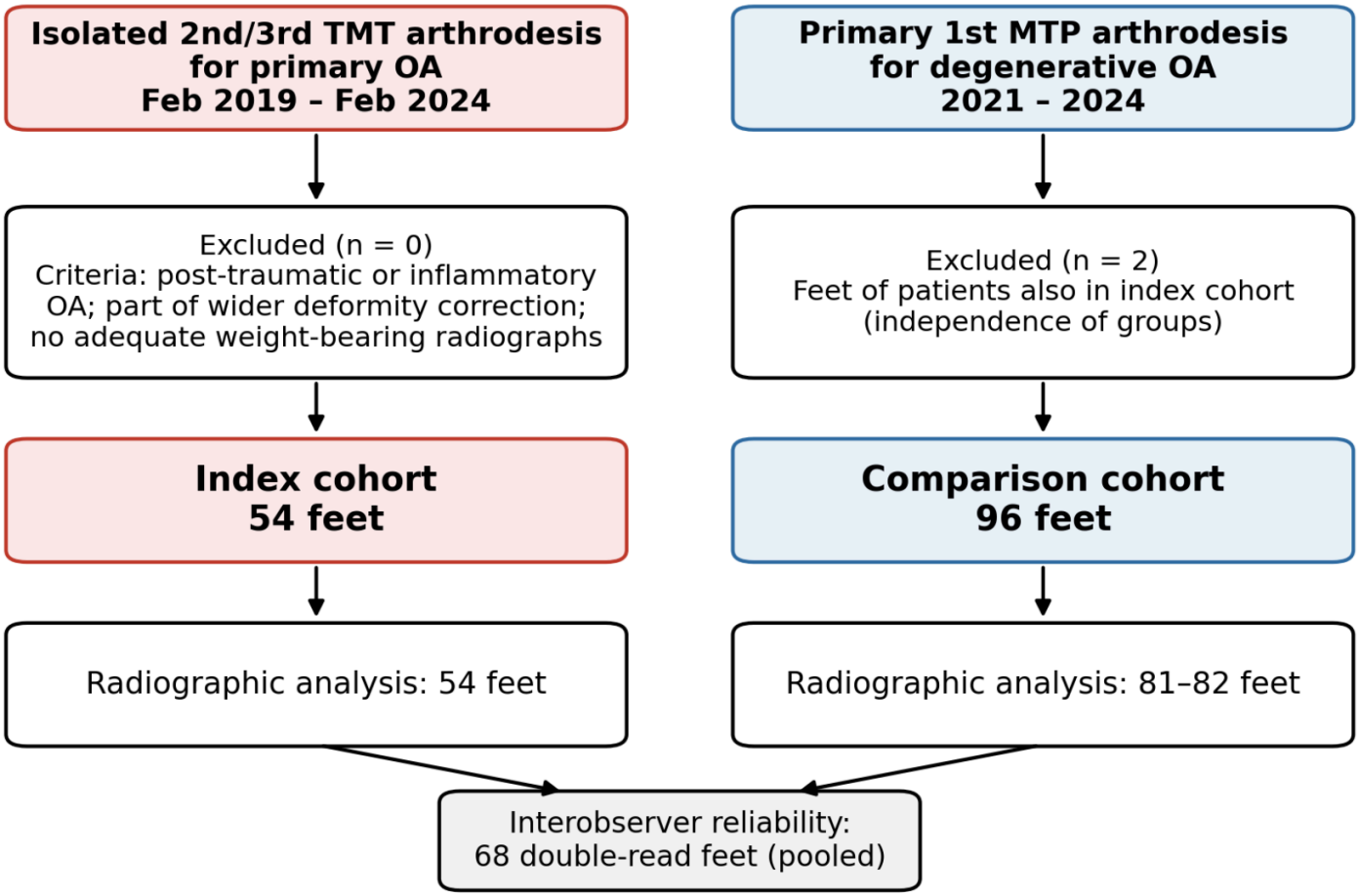


Figure 1

Flow diagram of feet included in the index cohort (isolated second/third tarsometatarsal [TMT] arthrodesis) and the comparison cohort (first metatarsophalangeal [MTP] arthrodesis), and of the pooled interobserver reliability sample. OA, osteoarthritis

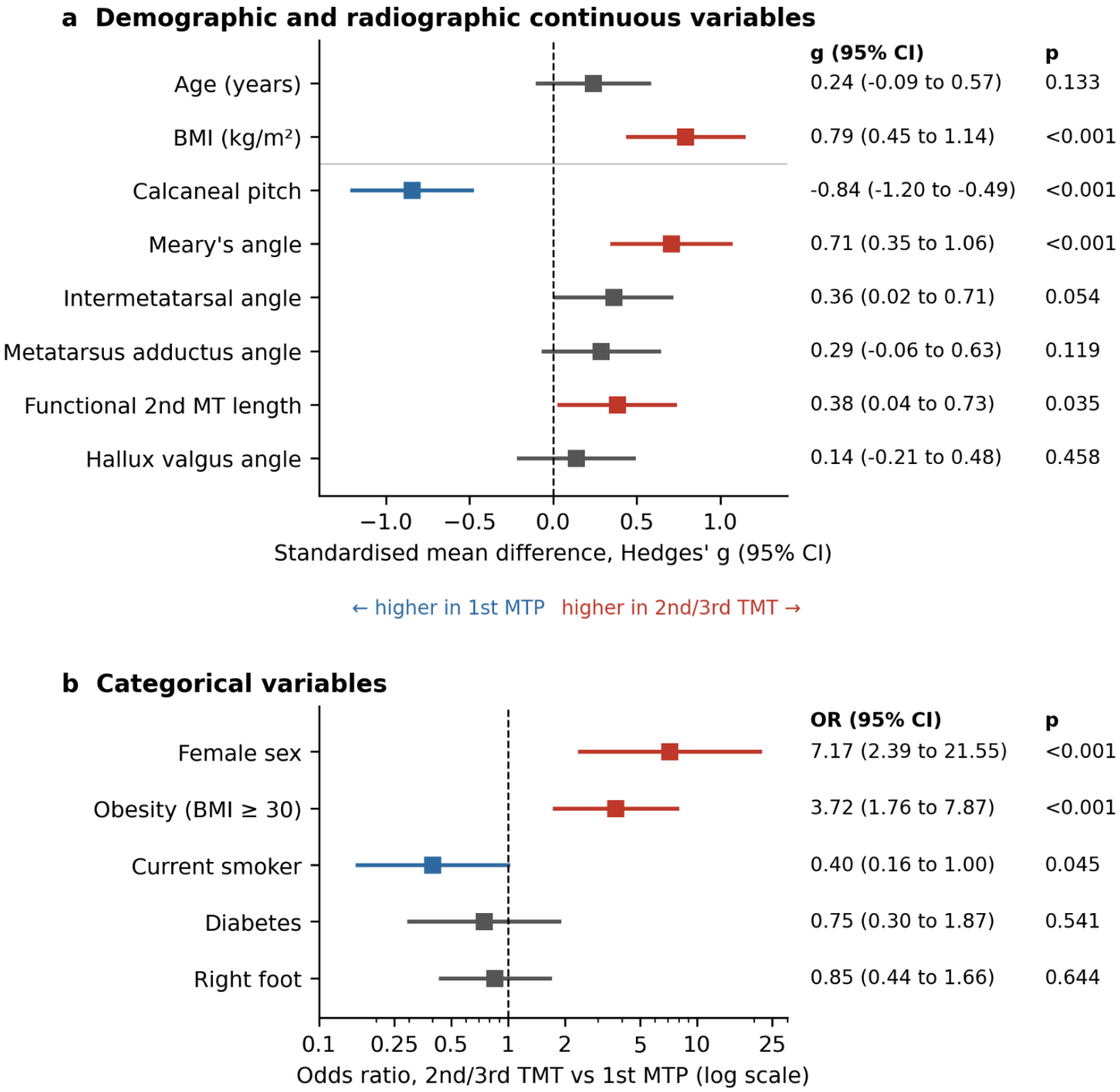
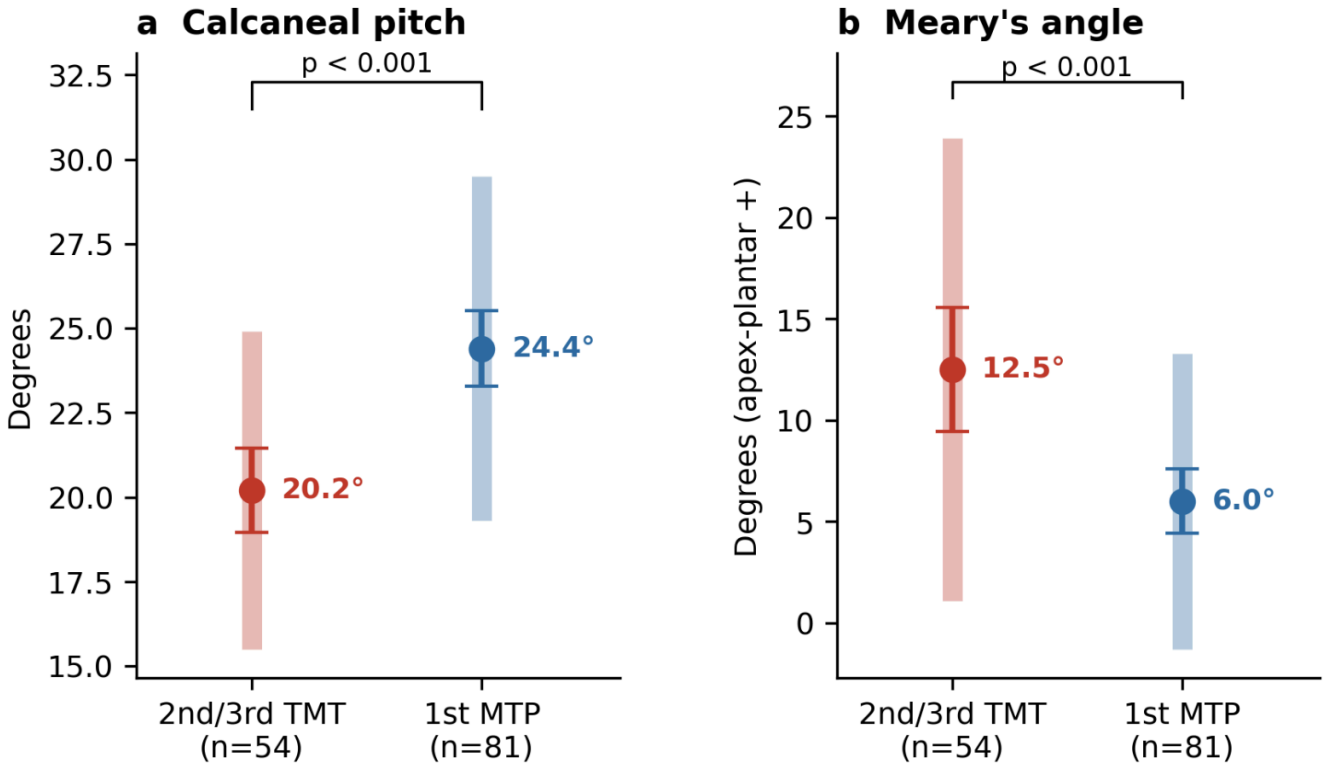


Figure 2

Differences between the isolated second/third TMT fusion cohort and the first MTP fusion cohort. a Standardised mean differences (Hedges' g, calculated from summary data using the pooled standard deviation) with 95% confidence intervals (CIs) for continuous variables; positive values indicate higher values in the TMT cohort. b Odds ratios with 95% CIs for categorical variables (log scale). Coloured

markers indicate p < 0.05 on the primary analyses (Welch t-test; chi-square or Fisher's exact test). BMI, body mass index; MT, metatarsal



Dot = mean; thin bar = 95% CI; shaded bar = ± 1 SD. Lower pitch and higher Meary's angle indicate a flatter arch.

Figure 3

Weight-bearing arch measurements by cohort. a Calcaneal pitch. b Meary's angle. Circles show means, error bars 95% CIs and shaded bars ±1 standard deviation. A lower calcaneal pitch and a higher Meary's angle indicate a flatter medial longitudinal arch

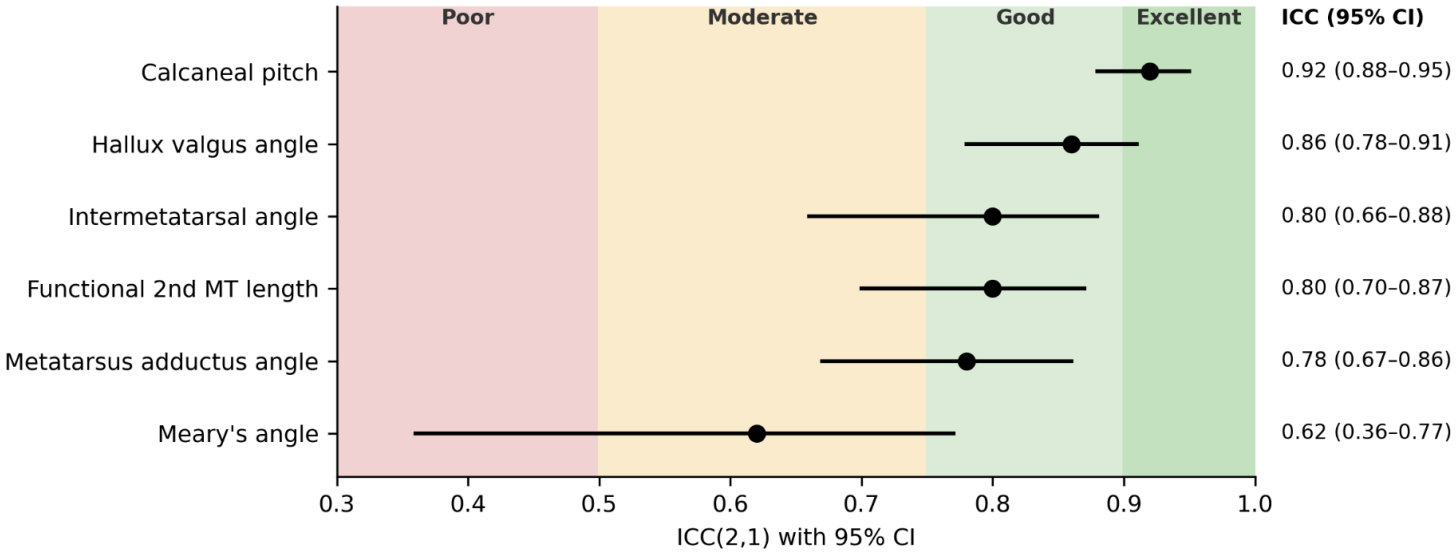


Figure 4

Interobserver reliability of the six radiographic measurements in 68 double-read feet. Intraclass correlation coefficients [ICC(2,1)] with 95% CIs; shaded bands show agreement categories according to Koo and Li [11]. MT, metatarsal