An investigation into the aetiology of flexible flatfeet:

The role of subtalar joint morphology

A. Kothari[1], S. Bhuva[2], J. Stebbins[3], A.B. Zavatsky[4], T. Theologis[1]

[1] Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, Oxford, UK

[2] Churchill Hospital, Oxford University Hospitals NHS Trust, Oxford, UK

[3] Oxford Gait Laboratory, Nuffield Orthopaedic Centre, Oxford University Hospitals NHS Trust, Oxford, UK

[4] Department of Engineering Science, University of Oxford, Oxford, UK

Accepted for publication in *The Bone & Joint Journal*

5 November 2015

Abstract

There is an increasing body of evidence demonstrating that flexible flatfoot (FF) can lead to symptoms and impairment in health-related quality of life. As such we undertook a prospective, observational study of 84 children aged 8 to 15, investigating the aetiology of this condition, to help inform management protocols. It was hypothesised that as well as increased body mass index (BMI) and increased lower limb flexibility, an absent anterior subtalar articulation would be associated with a flatter foot posture. Each child had BMI calculated, flexibility assessed using the lower limb assessment scale (LLAS) and foot posture quantified using the arch height index (AHI). Each subject also underwent a sagittal T1-weighted MRI scan of their feet. An absent anterior subtalar articulation and increased LLAS were both significant predictors of a low AHI ($p < 0.001$ and $p = 0.001$ respectively). Increased BMI was not a significant predictor of a low AHI ($p = 0.566$). This is the first study to demonstrate the importance of subtalar joint morphology on underlying foot posture in-vivo. This finding alongside the importance of lower limb flexibility in development of FF has bearing on the management of this common presentation.

Level of evidence:- II

Introduction

Flexible flatfoot (FF) is a common presentation, prevalent in up to 20% of children and adolescents.(1) In the clinical setting, distinction needs to be made between FF in older children, developmental flatfoot in toddlers and young children, and rigid flatfoot due to an underlying structural abnormality. It is well accepted that developmental flatfeet require no intervention, and the treatment for rigid flatfeet commonly due to congenital vertical talus or tarsal coalition is well described. Significant controversy still exists about the clinical significance, and thus management of FF in older children. It has been suggested by a number of authors that FF is a benign normal variant requiring no intervention (2, 3). However there is now increasing evidence in the literature that a flat foot posture can lead to significant symptoms and impairment of health related quality of life. (4-7).

To understand how FF may cause symptoms, and how they might be remediated it is important to understand the underlying aetiology on this condition. Studies have demonstrated a correlation between FF and body weight, with the agreement that increased body mass index (BMI) leads to a flatter foot posture (8, 9). It has also been shown that flexibility relates to foot posture, with El et al. (10) demonstrating that hypermobile children had double the prevalence of FF than non-hypermobile children. Sex and heritable factors may also play a role in determining foot posture (11).

An aetiological factor, ignored by contemporary literature, was initially discussed in the seminal paper on flatfeet by Harris and Beath (12). From osteological specimens they suggested that two types of subtalar joint exist; one ‘firm’ supporting the talus well, and the other ‘weak’ allowing the foot to adopt a flatfoot posture. Subtalar joint morphology variation has subsequently been demonstrated by several authors, with the most striking variant being an absent anterior articulation (Figure 1) (13, 14). The anterior facet on the os calcis forms an integral part of the “acetabulum pedis” (15) supporting the talar head. It is theorized that absence of this articulation may lead to a flat foot posture (13). This is yet to be demonstrated in-vivo.

The treatment of symptomatic FF using orthotics and / or physical therapy is routinely undertaken, and when they fail, surgical intervention may be performed. Treatment aims are generally to make the foot appear more 'normal', with the general assumption that the flatter the foot, the worse the symptoms. However without fully understanding the aetiology of FF, it is unclear whether this approach is appropriate. If subtalar joint morphology is a significant determinant of FF then this may have further bearing on the efficacy of any intervention.

Thus the aim of this study was to assess the role of potential aetiological factors in determining foot posture, with emphasis on the importance of the subtalar joint. It was hypothesised that the morphology of the subtalar joint would be an important determinant of foot posture, alongside lower limb flexibility and BMI.

Materials and methods

Subjects

This study had approval by the local research ethics committee (ref:-12/SC/0334). Eighty four children were prospectively recruited from either the orthotic or orthopaedic outpatient clinic or the community. Inclusion criteria were: neutral or flexible flatfoot posture and age between eight and fifteen. Exclusion criteria were: any bone, joint or neurological disease, evidence of rigid flatfoot, previous spine or lower limb surgery or concurrent use of orthotics. The study population was part of the cohort from which health-related quality of life data was presented in a previous publication (4).

Foot posture assessment and clinical examination

The classification of foot posture on the basis of visual inspection is known to be subjective with poor reliability (16). As such foot posture was formally quantified using the arch height index (AHI), described by Williams and McClay (17). The AHI is the ratio of standing dorsal arch height as measured at 50% foot length divided by the truncated foot length (foot without toes). This measure has excellent inter- and intra-rater reliability (17, 18). Cut-off values of AHI can be applied to define low (< 0.31), neutral (0.31 to 0.37) and high arches (>0.37) (based on (19)), but in this study AHI was used as a continuous variable. Where a reduced medial longitudinal arch (MLA) was observed in the standing position, a double heel raise test was performed to ensure the MLA was reconstituted, to exclude rigid flat foot. All children demonstrated the same foot type for both left and right feet consistent with the findings of Mosca et al. (11).

Age and sex were recorded, and BMI was calculated. Flexibility was assessed using the lower limb assessment scale (LLAS)(20). The LLAS is scored out of 12 for each limb and is based on the range of motion of the hip, knee and foot and ankle joints. As the LLAS focuses on the lower limb and particularly the foot it was favoured over other commonly used measures.

Magnetic resonance imaging

Each child underwent a magnetic resonance imaging (MRI) scan of his or her feet (Philips Achieva 3.0 Tesla, Philips Medical Systems, Da Best, Netherlands). The imaging protocol included a sagittal T1-weighted spin-echo (T1-W) sequence of the foot and ankle. A SENSE Flex L coil was used to maximise spatial resolution. The T1-W sequence had a pixel size of 0.27 mm, slice thickness 1.5 mm - 2.5 mm, and slice increment 2.2 mm - 3.1 mm. Scans were only obtained from 127 feet of the 84 subjects, as a proportion of the children could not tolerate imaging of both feet. The sagittal MRI images were inspected in sequence from lateral to medial using Mimics software (Materialise, Belgium). A protocol based on that described by

Shahabpour et al.(21) was used to identify the articular facets of the subtalar joint. The subtalar joint was then formally classified using the classification described by Bruckner (13) (Figure 1).

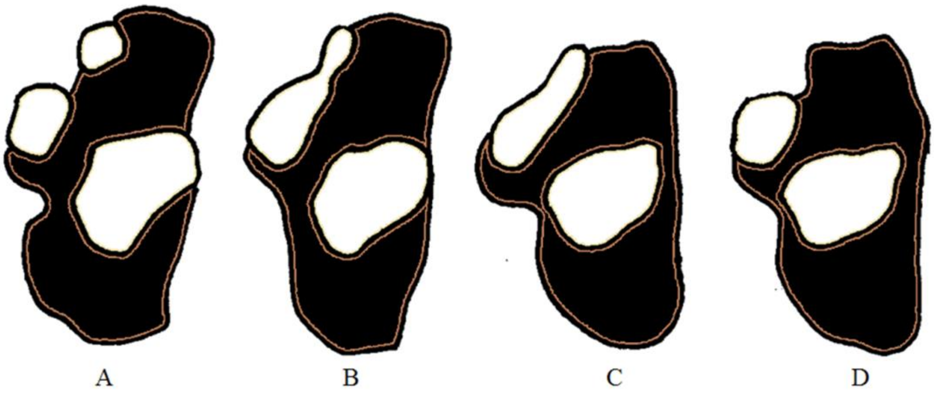

Figure 1. Variation in os calcis articulating surface morphology as described by Bruckner (13). A has three separate articular surfaces (anterior/middle/posterior). B and C have the anterior and middle articular surfaces joined. D is missing the anterior articular surface.

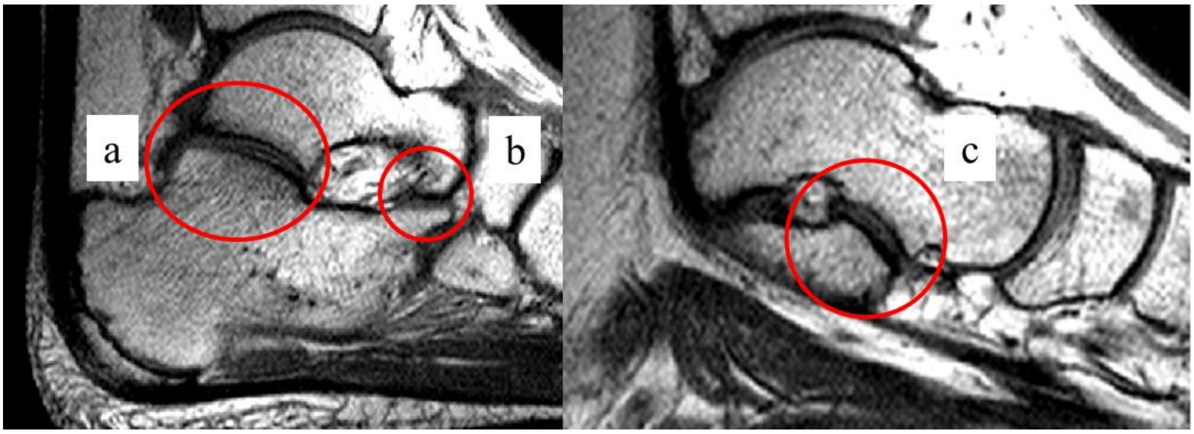

Figure 2. Subtalar joint morphology. Example of one subject. Discrete posterior (a), middle (c), and anterior (b) articular facets of the Os Calcis can be seen clearly.

An example of the visualisation of the three articular facets of the subtalar joint in one subject is shown in Figure 2. As these articular facets were not joined, this foot was classified as Bruckner type A (Figure 1 A).

Data analysis

Continuous data were assessed for skewness and kurtosis, with all variables demonstrating normality. Inter-rater and intra-rater reliability of subtalar joint classification in 20 feet was assessed by an orthopaedic surgeon and a radiologist. Cohen's kappa was used to quantify agreement, and reported as per recommendations by Landis and Koch (22). Multiple linear regression was used to assess how age, sex, BMI, LLAS, and subtalar morphology could predict AHI. Regression standard errors were adjusted to account for the existence of paired foot data, where required (23). Regression diagnostics were used to ensure that model residuals were normally distributed and that the residual versus fitted values did not demonstrate any heteroscedasticity. Alpha was set at (0.05). Effect size was reported using Cohen's f^2, calculated as $R^2/(1-R^2)$. The effect size gives an indication of the strength of the relationship between predictor variables and outcome (AHI), where $f^2=0.02$ is equivalent to a small effect size, $f^2=0.15$ medium effect size and $f^2=0.3$, a large effect size. For the multiple linear regression analysis of 84 subjects the analysis had 80% power to detect an overall model effect size (f^2) of 0.12. Sample size and power calculations were made using GPower (v3.1.9.2 Universitat Kiel, Germany). Data analysis was undertaken using SPSS v22 (IBM) and Stata v13.0 (Statacorp Texas).

Results

Descriptive statistics for age, sex, BMI and flexibility for the study subjects are summarised in Table 1. The mean and standard deviation of the AHI was 0.31 (±0.03) with a range of values from 0.22 to 0.37.

Parameter	All subjects (n=84)
Age (years) mean (SD), range	11.96 (±2.23), 8.08 - 15.99
Sex (M:F)	46:38
LLAS mean (SD), range	4 (±3), 0 - 11
BMI (kg/m^2) mean (SD), range	18.6 (±3.3), 12.1 - 28.3

Table 1. Summary statistics for age, sex, lower limb assessment score (LLAS) and body mass index (BMI).

Inter and intra-rater reliability of defining Os Calcis articular surface morphology.

The inter-rater reliability for the two raters was found to be Kappa = 0.718, 95% CI [0.600-0.836]. Intra-rater reliability was found to be Kappa = 0.863, 95% CI [0.773-0.953]. Whilst both were regarded as at least substantial agreement, difficulty was experienced in differentiating between Bruckner type B and C articular morphologies (22). On this basis, and because the main feature of interest was presence or absence of the anterior articulation, the articular morphology classification was simplified to a binary outcome; supportive (Bruckner A,B,C) and unsupportive (Bruckner D). Thus, a supportive morphology had the anterior articulation present, while the unsupportive did not. Using this classification inter-rater reliability and intra-rater reliability both improved to 0.886, 95% CI [0.776-0.996]. This would be regarded as almost perfect agreement (22), and thus this classification was used in the regression analysis.

The predictors of AHI

Of the 84 study participants approximately one third had unsupportive subtalar articulations. In cases where both feet underwent MRI, both feet had the same subtalar joint morphology. These results are summarised alongside corresponding mean AHI by group in Table 2.

	Subtalar joint morphology	
	Supportive	Unsupportive
Number of feet (proportion)	85 (67%)	42 (33%)
Number of subjects (proportion)	56 (67%)	28 (33%)
Mean AHI (SD)	0.31 (±0.03)	0.29 (±0.03)

Table 2. Summary table demonstrating subtalar joint morphology (supportive or unsuuportive) by numbers and proportion observed in study sample, alongside mean AHI with standard deviation (SD) by group. Pairs of feet had the same subtalar joint morphology.

The multiple linear regression model demonstrated that of the potential variables used to predict AHI, only two proved to be significant; LLAS and subtalar morphology. Regression output is summarised in Table 3. The overall R^2=0.32, which represents a large effect size (f^2=0.47). Of the overall variance in AHI that the model could explain, LLAS accounted for 22% (f^2=0.28) and subtalar morphology accounted for 9% (f^2=10). Thus the more flexible the leg, the flatter the foot, and the less supportive the os-calcis, the flatter the foot. Of note, BMI did not prove to be a significant predictor of AHI in this sample, nor did sex or age. There was no significant interaction between predictors.

Predictor	Coefficient	Robust std. error	Sig. (p)	95% Confidence interval	
LLAS	-0.0051	0.0014	0.001*	-0.0079	-0.0023
BMI	-0.0001	0.0010	0.566	-0.0003	0.0015
ST Morphology	0.0214	0.0060	<0.001*	0.0095	0.0333
Sex	0.0105	0.0062	0.094	-0.0018	0.2276
Age	-0.0010	0.0014	0.464	-0.0038	0.0018

Table 3. Summary of results of multiple linear regression, including regression coefficient, standard error (std. error), significance (Sig.) and 95% confidence intervals of coefficient.
* Denotes significant predictors.

Discussion

The main purpose of this study was to investigate the determinants of a flat foot posture, with emphasis placed on the relevance of an absent anterior subtalar articulation. Of the potential aetiological factors tested in this study, age, sex and BMI were not significant predictors of AHI. As age was not a significant predictor, we can safely assume that our test sample was out of the age range of developmental flatfoot. The fact that BMI was not relevant to foot posture went against our initial hypothesis and previous literature. Much of the literature describing the link between foot posture and BMI uses footprint measures (8, 9). It is accepted that increased BMI is associated with increased adiposity which will affect the footprint parameters accordingly (24). The foot may also appear flatter, when in reality underlying bony architecture is normal. An index like the AHI may be less sensitive to adiposity than footprint parameters, and as a result may be a better index for clinical practice. Alternatively these findings may be related to the BMI distribution of the study population, with a relatively low mean BMI of 18.6

kg/m^2. If more children with a greater BMI had been recruited into the study then perhaps the results would have been different.

This is the first clinical study to demonstrate the importance of subtalar morphology in underlying foot posture. The role of subtalar morphology in the determination of foot posture has previously been hypothesised on the basis of observations in osteological specimens, but never confirmed in-vivo (12, 13). The anterior articulation of the Os Calcis is an integral component of the talocalcaneonavicular joint also known as the Acetabulum Pedis (AP) (25). Dissection of foetal cadaveric specimens by Epeldegui and Delgado (15) demonstrated that the anterior facet of the Os Calcis normally forms part of the osseous floor of the AP, supporting the talar head. They suggested that variations in subtalar morphology would affect subsequent foot shape. Barbaix et al. (14) found that the articular surface area of the Os Calcis in the subtalar joint was significantly reduced when the anterior facet was missing suggesting that this morphology of Os Calcis provided reduced bony support to the talar head. Thus an absent anterior articulation of the subtalar joint places greater reliance on the plantar ligaments to support the talar head. Over time these may stretch, allowing plantar-medial deviation of the talar head with reduction of the MLA as seen in FF. Whilst no statistical interaction was noted between flexibility and subtalar morphology, one might have expected there to be an additive effect of both to further reduce arch height.

Increased flexibility may result in impaired static stabilisation of the foot and ankle joint by capsuloligamentous structures, thereby permitting increased joint motion, potentially to pathological levels. This would be especially important at the subtalar and midtarsal articulations. If treatment is considered, focus on muscle strengthening, to improve the dynamic stabilisation of the joints may reduce reliance on capsuloligamentous structures. Indeed muscle strengthening regimes have been utilised by some clinicians, with a suggestion that these may improve foot posture (26). Further work is required to evaluate this as a potential treatment strategy.

With respect to subtalar joint morphology, evidently there is no therapeutic intervention that can be undertaken to add an anterior articulation. However, there has been concern that lateral column lengthening may damage the subtalar articular surface (27). This may be less of a concern if there is no anterior articulation. If, however, the Os Calcis articular surface is a Bruckner type B or C, then no modification of the lateral column lengthening technique can save the surgeon from damaging the joint surface, and an alternative surgical approach may be preferred. Pre-operative imaging is recommended to assess articular morphology in FF if surgical intervention is planned.

The main limitation of this study was that MRI may not be the best modality to assess bony articular morphology. Three-dimensional reconstructed computed tomography would be the gold standard, but the dose of ionizing radiation precludes its use as a research tool in a paediatric population.

Conclusion

This study has demonstrated that two of the most important factors for determining the foot posture are flexibility and, the hitherto only speculated, subtalar joint morphology. Further work, however, is required to clarify the relationship between these factors and the development of symptoms in FF. This will have a bearing on the monitoring and treatment of FF, especially in asymptomatic individuals that demonstrate significant flat foot deformity.

Acknowledgements

AK was supported by a research training fellowship from the charity Action Medical Research (Ref: GN2019).

References.

1. Craxford AD, Minns RJ, Park C. Plantar pressures and gait parameters: a study of foot shape and limb rotations in children. Journal of Pediatric Orthopaedics. 1984;4:477-81.
2. Fixsen J. The Foot. In: Benson M, Fixsen J, Macnicol M, Parsch K, editors. Children's Orthopaedics and Fractures: Springer London; 2009. p. 523-39.
3. Staheli LT. Evaluation of planovalgus foot deformities with special reference to the natural history. J Am Podiatr Med Assoc. 1987 Jan;77(1):2-6.
4. Kothari A, Stebbins J, Zavatsky A, Theologis T. Health related quality of life in children with flexible flatfeet: a cross-sectional study. Journal of Children's Orthopaedics. 2014;8(6):489-96.
5. Moraleda L, Mubarak S. Flexible flatfoot: differences in the relative alignment of each segment of the foot between symptomatic and asymptomatic patients. Journal of Pediatric Orthopaedics. 2011;31(4):421-8.
6. Hösl M, Böhm H, Multerer C, Döderlein L. Does excessive flatfoot deformity affect function? A comparison between symptomatic and asymptomatic flatfeet using the Oxford Foot Model. Gait & Posture. 2013.
7. Benedetti MG, Ceccarelli F, Berti L, Luciani D, Catani F, Boschi M, et al. Diagnosis of flexible flatfoot in children: a systematic clinical approach. Orthopedics. 2011 Feb;34(2):94.
8. Pfeiffer M, Kotz R, Ledl T, Hauser G, Sluga M. Prevalence of Flat Foot in Preschool-Aged Children. Pediatrics. 2006;118(2):634-9.
9. Dowling AM, Steele JR, Baur LA. Does obesity influence foot structure and plantar pressure patterns in prepubescent children? Int J Obes Relat Metab Disord. 2001 Jun;25(6):845-52.

10. El O, Akcali O, Kosay C, Kaner B, Arslan Y, Sagol E, et al. Flexible flatfoot and related factors in primary school children: a report of a screening study. Rheumatology International. 2006;26(11):1050-3.

11. Mosca VS. Flexible flatfoot in children and adolescents. Journal of Children's Orthopaedics. 2010;4(2):107-21.

12. Harris RI, Beath T. Hypermobile flat-foot with short tendo achillis. Journal of Bone & Joint Surgery (American). 1948 Jan;30A(1):116-40.

13. Bruckner J. Variations in the human subtalar joint. J Orthop Sports Phys Ther. 1987;8(10):489-94.

14. Barbaix E, Van Roy P, Clarys JP. Variations of anatomical elements contributing to subtalar joint stability: intrinsic risk factors for post-traumatic lateral instability of the ankle? Ergonomics. 2000 Oct;43(10):1718-25.

15. Epeldegui T, Delgado E. Acetabulum pedis. Part I: Talocalcaneonavicular joint socket in normal foot. Journal of Pediatric Orthopaedics B. 1995;4(1):1-10.

16. Cowan DN, Robinson JR, Jones BH, Polly DW, Jr., Berrey BH. Consistency of visual assessments of arch height among clinicians. Foot Ankle Int. 1994 Apr;15(4):213-7.

17. Williams DS, McClay IS, Hamill J. Arch structure and injury patterns in runners. Clinical Biomechanics. 2001;16:341-7.

18. Saltzman CL, Nawoczenski D, Talbot K. Measurement of the medial longitudinal arch. Arch Phys Med Rehabil. 1995;76:45-9.

19. Butler RJ, Hillstrom H, Song J, Richards CJ, Davis IS. Arch height index measurement system: establishment of reliability and normative values. J Am Podiatr Med Assoc. 2008 Mar-Apr;98(2):102-6.

20. Ferrari J, Parslow C, Lim E, Hayward A. Joint hypermobility: The use of a new assessment tool to measure lower limb hypermobility. Clinical and experimental rheumatology. 2005;23:413-20.

21. Shahabpour M, Devillé A, Roy P, Vaes P, Mey J, Maeseneer M. Magnetic Resonance Imaging of anatomical variants of the subtalar joint. Surg Radiol Anat. 2011 2011/09/01;33(7):623-30.

22. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977:159-74.

23. Rogers W. Regression standard errors in clustered samples. Stata technical bulletin. 1994;3(13).

24. Riddiford-Harland DL, Steele JR, Baur LA. Are the feet of obese children fat or flat? Revisiting the debate. International Journal of Obesity. 2010;35(1):115-20.

25. Scarpa A. A memoir on the congenital club foot in children. Edinburgh: Constable. 1818.

26. Riccio I, Gimigliano F, Gimigliano R, Porpora G, Iolascon G. Rehabilitative treatment in flexible flatfoot: a perspective cohort study. Musculoskeletal Surgery. 2009;93(3):101-7.

27. Bussewitz BW, DeVries JG, Hyer CF. Evans Osteotomy and Risk to Subtalar Joint Articular Facets and Sustentaculum Tali: A Cadaver Study. Journal of Foot and Ankle Surgery. 2013;52(5):594-7.