THE EFFECT OF FOOT STRUCTURE ON 1ST METATARSOPHALANGEAL JOINT FLEXIBILITY AND HALLUCAL LOADING

Smita Rao PT, PhD[1, 3], Jinsup Song DPM, PhD[2], Andrew Kraszewski, MS[3], Sherry Backus MA, PT[3], Scott J. Ellis MD[3], Jonathan T. Deland MD[3] , Howard J. Hillstrom PhD[3]

[1]New York University, NY; [2] Temple University School of Podiatric Medicine, Philadelphia, PA; [3] Leon Root M.D. Motion Analysis Laboratory, Hospital for Special Surgery, NY.
email: smita.rao@nyu.edu

INTRODUCTION

- Foot structure, characterized by the height of the medial longitudinal arch, has been postulated to play an important role in lower extremity biomechanics and the possible development of osteoarthritis (OA) of the 1st metatarsophalangeal (MTP) joint [1, 2].
- Low arch foot structure may alter the orientation of the 1st metatarsal axis, [3] and consequently limit motion at the 1st metatarsophalangeal (1st MTP) joint. Over time, the limitation in joint motion may progress to degenerative OA. While biomechanical theory indicates that foot structure may influence 1st MTP motion, studies examining the effect of foot structure on 1st MTP motion and flexibility have reported conflicting results [1, 4].
- Independent of foot structure, 1st MTP joint motion and flexibility may have important functional consequences, and have been linked with increased hallucal loading during walking [5].
- In clinical populations such as patients with 1st MTP joint OA, restriction in 1st MTP joint motion and low arch foot structure may co-exist in addition to joint pathology [6, 7]. Consequently, the unique contributions of foot structure and joint flexibility to plantar load distribution cannot be identified from the literature.

The purpose of our study is to examine 1st MTP joint motion and flexibility and plantar load distribution in individuals with high, normal and low arch foot structure.

METHODS

Subjects: Asymptomatic individuals (n=61), with high, normal and low arches, based on resting calcaneal stance position (RCSP,°) and forefoot to rearfoot angle (FF-RF,°) [2].

Foot Structure: Quantitative measures with established reliability and validity, namely malleolar valgus index (MVI), and arch height index (AHI) were used to characterize foot structure. The reliability and validity of these measures has previously been established [8, 9].

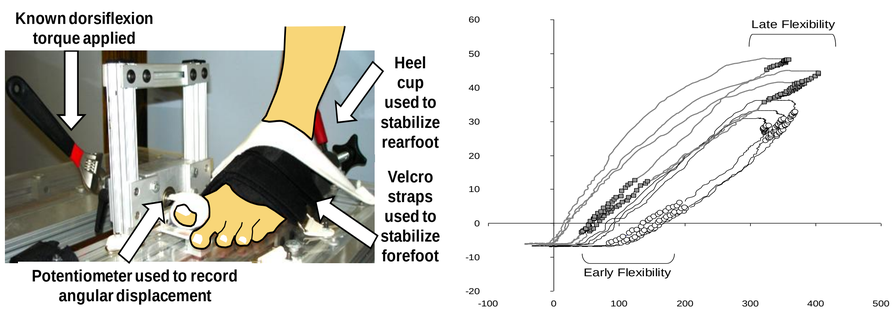

Figure 1. Picture of the jig used to quantify 1st MTP flexibility (left) and representative angle versus moment curve (right)

1st MTP flexibility and peak dorsiflexion (DF): 1st MTP joint flexibility was measured using a specially constructed jig (Figure 1, [10]). Peak dorsiflexion (DF) was measured using a goniometer.

Plantar Loading: Barefoot plantar loading was assessed using a pressure-sensitive plate embedded flush to the surface in the floor (Emed, Novel Inc, St Paul, MN). Data were collected using a mid-gait protocol as subjects walked at self-selected speed. Regional plantar loading was assessed using a standard "mask", in the following regions: hallux, 1st and 2nd metatarsals [11]. Plantar loading in each mask was defined using peak pressure (N/cm^2).

Statistical Analysis: A one-way ANOVA with Bonferroni adjusted post-hoc comparisons was used to assess between-group differences (Normal, high and low arch). Stepwise linear regression was used to identify predictors of hallucal loading.

RESULTS

	Low Arch	Normal Arch	High Arch
	n=22	*n=27*	*n=12*
Age (years)	35.6 (11.1)	33.1 (9.9)	42.8 (16.5)
BMI (kg/m^2)	22.2 (3.3)	24.4 (4.1)	24.0 (3.6)
RCSP (degrees)	- 6 (2)*+	-1 (1)*	0 (1)+
FF-RF (degrees)	7 (5)*,+	2 (1)*,#	-2 (1)+,#
MVI (%)	13.7(5.1)*,+	7.5 (4.0)*	6.3 (3.3)+
AHI (%)	0.34 (0.084)	0.36 (0.047)	0.38 (0.031)
Peak Pressure (N/cm^2)			
Hallux	41.5 (14.3)	35.1 (17.4)	31.9(13.3)
1st Metatarsal	29.0 (16.8)	36.2 (22.8)	33.7 (17.9)
2nd Metatarsal	51.3 (18.3)*,+	38.7 (13.3)*	36.5 (13.1)+

Table 1. Subject demographics, arch structure and peak pressure. Negative values indicate valgus. Significant post hoc differences are denoted by * (Normal vs. Low), # (Normal vs. High), and + (Low vs. High).

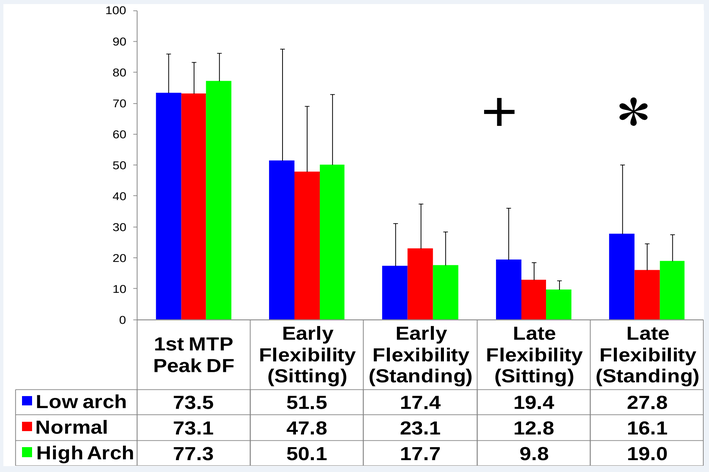

Figure 2. Summary of average 1st MTP joint dorsiflexion and flexibility. Error bars indicate standard deviation. Significant effect of foot type was noted for late flexibility in sitting and standing. Significant post hoc differences are denoted by * (Normal vs. Low), # (Normal vs. High), and + (Low vs. High).

Hallucal Peak Pressure = 31.85 + (1.33 x MVI) + (-0.162 x 1st MTP Early Flexibility in Sitting)

Figure 3. Stepwise regression indicated that foot structure (MVI) and 1st MTP joint early flexibility in sitting explain about 20% of the variance in peak pressure sustained under the great toe during walking (adjusted R^2=0.19, F(1,54)=5.49, P=0.023)

CONCLUSIONS AND DISCUSSION

- The unique findings of this study provide objective evidence confirming the effect of arch structure on 1st MTP joint motion and flexibility.
- Individuals with low arches demonstrated increased 1st MTP joint late flexibility during standing compared to individuals with normal arch structure, consistent with the biomechanical impression that a low arch foot may be less rigid.
- Regression findings indicate that foot structure (MVI) and 1st MTP early flexibility in sitting are explain approximately 20% of the variance in hallucal loading, supporting the contention that hindfoot alignment may influence hallucal loading [3]. Future studies addressing the role of arch structure and 1st MTP joint flexibility are indicated in clinical populations such as in patients with 1st MTP joint OA.

REFERNCES:
1. Mahiquez, M.Y., et al. Foot Ankle Int, 2006. 27(12): p. 1055-9.
2. Root, M.L., et al. 1977, Los Angeles: Clinical Biomechanics Corporation.
3. Glasoe, W.M., et al. Phys Ther. 90(1): p. 110-20.
4. Zammit, G.V., et al. J Orthop Sports Phys Ther, 2009. 39(10): p. 733-42.
5. Rao, S., et al. Gait Posture, 2010. 31(2): p. 251-5.
6. Van Gheluwe, B., et al. J Am Podiatr Med Assoc, 2006. 96(5): p. 428-36.
7. Zammit, G.V., et al. J Orthop Res, 2008. 26(12): p. 1665-9.
8. Butler, R.J., et al. J Am Podiatr Med Assoc, 2008. 98(2): p. 102-6.
9. Williams, D.S. and I.S. McClay. Phys Ther, 2000. 80(9): p. 864-71.
10. Song, J., et al. 2006. Spitzingsee, Germany: Clinical Biomechanics.
11. Putti, A.B., et al.. Gait Posture, 2008. 27(3): p. 501-5.

ACKNOWLEDGEMENTS:
This study was supported by the NICHD-NCMRR (1R03HD053135-01). The assistance and expertise of Jocelyn Frey, Mark Lenhoff, and Betty (Shingpui) Chow is gratefully acknowledged.

HOSPITAL FOR SPECIAL SURGERY