ANALYSIS OF THE TRIPOD THEORY USING PLANTAR SHEAR FORCES

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INTRODUCTION

In 1970, Kapandji proposed the notion that "Viewed as a whole, the plantar vault [of the foot] can be compared with an architectural vault supported by three arches". The three ground supports to which Kapandji was referring occur at the first and fifth metatarsal heads (MTHs), as well as the calcaneus[1]. The present study focused on (i) the existence of a tripod under the foot, and (ii) the ability of neuropathic, diabetic patients to support the arches.

METHODS

Pressure and shear stress data were collected on 29 human subjects: 16 control patients (9M, 7F; Age: 47.6±5.8 years; Weight: 824 N) and 13 neuropathic, diabetic patients (8M, 5F, Age: 61.6±14 years, Weight: 944 N). Each subject walked barefoot across a custom built shear and pressure collection system that is aligned in the center of a 3 m. x 0.6 m. platform[2]. Four steps were analyzed for each subject and all plantar surfaces were divided into ten regions (Figure 1) using custom-written Matlab code. The present study focuses on four of the ten regions: regions 4, 6, 9 and 10 (Figure 1).

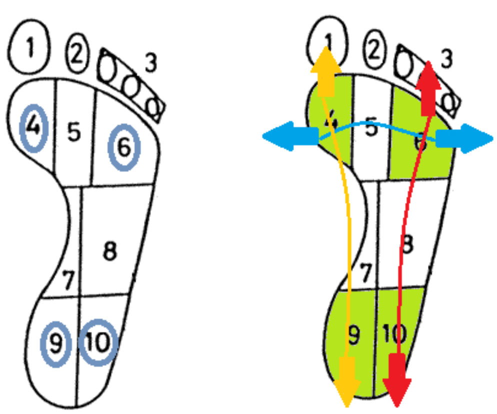

Figure 1: Display of shear force directions for regions of primary interest in present study. The green areas correspond to the base of a tripod.

It was hypothesized that evidence of a collapse of a plantar tripod could be demonstrated using the mean shear values in the regions previously listed. In support of the medial longitudinal arch, the differences were determined between mean anterior shear under the first MTH and mean posterior shear under the medial heel. For the lateral longitudinal arch, the differences were calculated between mean anterior shear under the fourth and fifth MTHs and mean posterior shear under the lateral heel. Lastly, for the transverse arch, shear differences were examined between the mean medial shear under the first MTH and the mean lateral shear under the fourth and fifth MTHs. These values were determined for all 116 steps then steps compared between control and diabetic, neuropathic groups.

RESULTS AND DISCUSSION

The presence of peripheral neuropathy correlates with loss of nerve, as well as intrinsic muscle control. Therefore, it was hypothesized that the existence of three arches could be demonstrated using differences in shear values, and moreover that diabetic patients would exhibit greater shear differences due to splaying of their foot (i.e., the tripod) during gait.

The differences in shear forces for each element of the tripod were significant for all three elements of the tripod. The medial longitudinal arch had mean values of 11.5 ± 3.7 kPa and 15.1 ± 5.4 kPa for control and diabetic, neuropathic participants, respectively ($p < 0.01$). The mean values of force differences for the lateral longitudinal arch were 9.3 ± 2.8 kPa and 13.1 ± 4.0 kPa for control and experimental subjects, respectively ($p < 0.01$). Lastly, the mean differences across the metatarsal heads were 17.7 ± 4.6 kPa for the control group and 22.5 ± 9.0 kPa for the diabetic, neuropathic subjects ($p < 0.01$) (Figure 2 and Table 1.)

CONCLUSIONS

This is the first study to examine the relationship between shearing forces on the plantar surface of the foot and each element of "Kapandji's tripod". In our opinion, any diminished ability to maintain these arches would be manifested through slippage of the skin relative to the support surface, and concomitant changes in shearing stresses on the plantar surface of the foot.

Due to the presence of peripheral neuropathy in the diabetic subjects, it was hypothesized that intrinsic muscles would have diminished capabilities to oppose the collapsing of the three arches during gait. The differences were determined between mean anterior shearing forces under the first MTH and fourth and fifth MTHs and the mean posterior shears under the medial and lateral calcaneus, respectively. The same methods were utilized for medial shear under the first MTH and lateral shear under the fourth and fifth MTHs to demonstrate the collapse of the transverse arch. Significantly higher differences were found for the diabetic, neuropathic subjects along all three arches in comparison to the control subjects. These data not only support the existence of three arches and in turn the tripod theory; but also support the claim that the feet of diabetic subjects with peripheral neuropathy are less capable of opposing the outward shear forces that lead to the collapse of these three arches.

REFERENCES

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2. Stucke, S. et al. (2012). "Spatial relationships between shearing stresses and pressure on the plantar skin surface during gait." Journal of biomechanics 45(3), 619-622.

ACKNOWLEDGEMENTS

This research was possible due to support from National Institutes of Health (Grant # 4R44DK084844-02) & the collaborations of Akron General Medical Center.

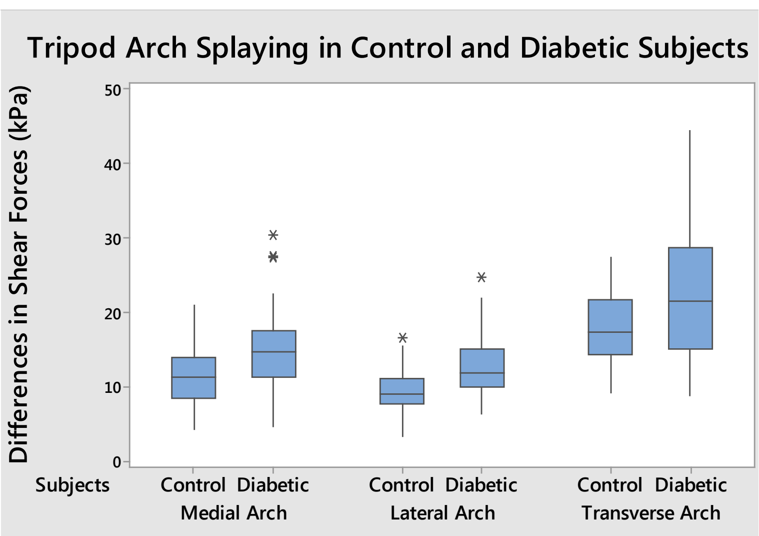

Figure 2: Boxplot displaying mean shear differences across three plantar arches

Table 1: Numerical differences in shearing forces for each element of the tripod.

	Shear Force Splaying (kPa)		
	Medial Arch	**Lateral Arch**	**Transverse Arch**
Control Subjects	11.5 ± 3.7	9.3 ± 2.8	17.7 ± 4.6
Diabetic Subjects	15.1 ± 5.4	13.1 ± 4.0	22.5 ± 9.0
P - Value	< 0.01	< 0.01	< 0.01