A NEW METHOD FOR QUANTIFYING FOOT BONE-TO-BONE POSITIONS

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INTRODUCTION

There are many means of quantifying foot shape, including arch indices, X-rays, static hindfoot alignment devices and computed tomography (CT) scans. However, each of these has some inherent difficulties. For a more detailed review, please see Ledoux (2006). Briefly, arch indices typically have a subjective component and do not provide information on specific bones. X-rays are two-dimensional (2D) and have a subjective component (someone must draw the lines). Hindfoot alignment devices only describe part of the foot and require an operator to position them. CT scans are three-dimensional (3-D), but also typically require a user to draw lines. Our own group has developed an objective, 3-D method of quantifying foot bone-to-bone position from CT scans (Ledoux, 2006). However, this method, which consisted of embedding coordinate systems in each bone by assuming uniform density and calculating the inertial matrix, was not without problems. Namely, the orientation of the embedded coordinate system was due to the nothing but the shape of the particular bone. This worked well (i.e., well aligned neutral coordinate systems) for some bones (e.g., the talus), but other bones (e.g., the calcaneus) had coordinate systems that were askew. Consequently, although meaningful data were collected for some bone-to-bone relationships (first metatarsal to talus), it was not sensitive enough to measure differences in hindfoot eversion/inversion (i.e., calcaneus relative to talus) between different foot types. Therefore, the purpose of this study was to develop a means of objectively quantifying foot bone-to-bone position in 3D with a method sensitive enough to measure hindfoot trends across pes cavus (high arched), neutrally aligned (normal arch) and pes planus (flat arched).

METHODS

We performed partial weightbearing (20% body weight) CT scans on subjects between the ages of 18 and 75 with pes cavus (n = 10 subjects, 14 feet), neutrally aligned (n = 10, 20), asymptomatic pes planus (n = 10, 18) and symptomatic pes planus (n = 10, 13) (Ledoux, 2006). Pes planus were split into two groups based on the presence of pain; both feet were included on subjects that had the same foot type bilaterally. The CT data were segmented using *Multi-Rigid*, a custom software package for modeling the morphology and tracking the movement of multiple articulated bones/joints simultaneously via medical imaging (Hu, 2006). *Multi-Rigid* was also used to automatically and objectively determining the embedded coordinate systems for the foot bones. By consensus, three 'experts' constructed a coordinate system for each bone in a template set (i.e., the gold standard) by identifying several prominent feature points on the bone surface, which were used to embed a coordinate system. These points (and the corresponding coordinate systems) were then mapped onto subject datasets through non-rigid image registration (i.e., 'warped' via affine transformation and B-spline deformation). Each bone in each foot had an objective, 3-D, well aligned coordinate system. The only subjective component was the gold standard. Preliminary work found that the mean distances between the computed points and those picked by the experts were close to the mean distances between the points picked by different experts, suggesting that our method was comparable to the experts (<4 mm). The Cardan angles (alpha, beta and gamma, in the sagittal, frontal and transverse planes respectively) between the bones of interest were calculated. Here we report one relationship that was significant with our previous methods (first metatarsal to talus) and one that was not (calcaneus to talus).

RESULTS

All data have been collected, but only 7 pes cavus, 12 neutrally aligned, 8 asymptomatic pes planus and 5 symptomatic pes planus have been analyzed. There were significant differences ($p<0.05$) across foot types for all six angles that are reported (Table 1). (Numerous other relationships were also different, but are not reported here.) The relationship of the hindfoot, from inverted pes cavus to everted symptomatic pes planus can been seen qualitatively (Figure 1).

DISCUSSION

We have successfully developed a new method of objectively embedding foot bone coordinate systems that was sensitive to position of the hindfoot (i.e., subtalar joint).

REFERENCES

Ledoux, W. R., et al., (2006). *J Orthopaedic Research*, **24**, 2176 - 2186.

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Table 1: The M1Ta and CaTa angles in degrees (mean ± SD) for the four foot types.

Foot type	M1Ta Alpha (sagittal)	M1Ta Beta (frontal)	M1Ta Gamma (transverse)	CaTa Alpha (sagittal)	CaTa Beta (frontal)	CaTa Gamma (transverse)
Pes cavus	59.0 ± 9.2	-4.4 ± 9.3	-36.5 ± 10.3	16.2 ± 5.6	12.0 ± 5.7	2.3 ± 3.6 [a,b]
Neutrally aligned	24.3 ± 6.3	-20.5 ± 11.4 [a]	-25.4 ± 3.8	7.6 ± 4.0 [a,b]	-4.8 ± 3.5 [a]	4.2 ± 2.6 [a,c]
Asymptomatic pes planus	11.1 ± 6.1 [a]	-28.2 ± 6.3 [a,b]	-9.6 ± 4.8	6.6 ± 3.6 [a,c]	-8.4 ± 7.3 [a]	4.7 ± 3.1 [b,c]
Symptomatic pes planus	-0.1 ± 11.2 [a]	-34.6 ± 5.6 [b]	0.6 ± 7.3	1.7 ± 6.4 [b,c]	-16.2 ± 6.7	10.1 ± 4.8

M1Ta = first metatarsal relative to talus, CaTa = calcaneus relative to talus, Alpha + = plantar flexion, - = dorsi-flexion; Beta + = inversion, - = eversion; Gamma + = external rotation, - = internal rotation, [a,b,c] = no significance

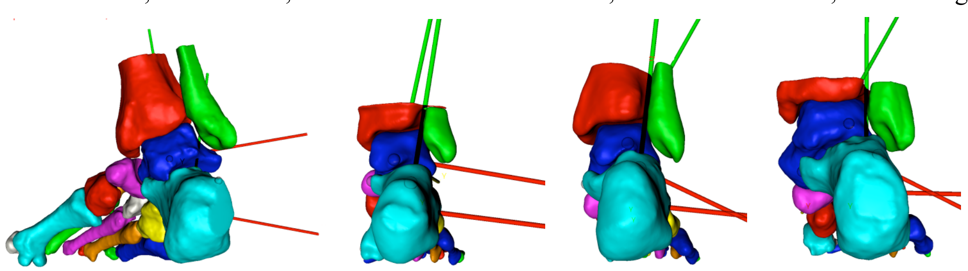
a) b) c) d)

Figure 1: Representative frontal plane hindfoot positions for the following foot types: a) pes cavus, b) neutrally aligned, c) asymptomatic pes planus and d) symptomatic pes planus.