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A multi-segment foot model based on anatomically registered technical coordinate systems: Method repeatability and sensitivity in pediatric planovalgus feet

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ABSTRACT

Several multisegment foot models have been proposed and some have been used to study foot pathologies. These models have been tested and validated on typically developed populations; however application of such models to feet with significant deformities presents an additional set of challenges. For the first time, in this study, a multisegment foot model is tested for repeatability in a population of children with symptomatic abnormal feet. The results from this population are compared to the same metrics collected from an age matched (8–14 years) typically developing population. The modified Shriners Hospitals for Children, Greenville (mSHCG) foot model was applied to ten typically developing children and eleven children with planovalgus feet by two clinicians. Five subjects in each group were retested by both clinicians after 4–6 weeks. Both intra-clinician and inter-clinician repeatability were evaluated using static and dynamic measures. A plaster mold method was used to quantify variability arising from marker placement error. Dynamic variability was measured by examining trial differences from the same subjects when multiple clinicians carried out the data collection multiple times. For hindfoot and forefoot angles, static and dynamic variability in both groups was found to be less than 4° and 6° respectively. The mSHCG model strategy of minimal reliance on anatomical markers for dynamic measures and inherent flexibility enabled by separate anatomical and technical coordinate systems resulted in a model equally repeatable in typically developing and planovalgus populations.

1. Introduction

Numerous multisegment foot models have been proposed [1–8] and recently some applications to foot pathologies have been reported [9–11]. To date, these models have been tested for reliability only in typically developed populations. These models rely on accurate identification of anatomic landmarks using standard retroreflective markers to establish anatomical coordinate systems. This process may be difficult or even impossible in feet with significant deformities. The general aims of these models are to establish either differences between individuals with pathologies and a typically developed population, or to measure outcomes within subjects studied longitudinally. In order to make such measures, the model may be applied by various clinicians within a group of subjects or by the same clinician to the same subject(s) at different times. To utilize these models for clinical and research applications, it is necessary to quantify the intra-clinician and inter-clinician variability of this model applied to a population with foot pathologies.

This study reports the variability of the modified Shriners Hospitals for Children, Greenville (mSHCG) foot model when applied to a group of children with planovalgus feet. The mSHCG model was developed to minimize model outcome variability by minimizing the required number of anatomical markers and critical alignments, and to provide marker placement flexibility to accommodate a wide range of foot deformities [12]. The model relies on technical markers to track the foot segments dynamically. The relationships between the anatomical and technical coordinate systems are established during a static subject calibration. Small (4 mm diameter) hemispherical markers are used to identify the anatomical landmarks. 9 mm diameter spherical markers are used as technical markers to track segment motion to achieve better visibility during dynamic trials. The variability of this model has been reported in a typically developing (TD) population [12].

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data. Inter-segmental joint angles between the two groups were compared at each 2% of the gait cycle (Fig. 3). Statistical differences ($p < 0.05$) were observed in all the angles which characterize the planovalgus deformity. The ankle was significantly more plantarflexed with a reduced range of motion in the sagittal plane, and the subtalar joint was more everted. There were no significant differences in transverse ankle rotation. The midfoot (forefoot with respect to calcaneus) was significantly different in all three planes throughout gait. The planovalgus midfoot was more inverted reflecting the valgus position of the hindfoot relative to the forefoot (pronation), the arch was decreased reflecting the planus alignment, and the forefoot was abducted relative to the hindfoot. Hallux flexion exhibited a shift toward plantarflexion, also reflecting the planus of the forefoot. In general, higher standard deviations were observed in the PV group; this is expected as there are a range of deformities represented.

These results may be compared to results from adults with flat feet reported using the Oxford model [11]. While midfoot results are nearly identical after taking into account model differences in sagittal plane offsets, ankle motions exhibit some differences. Levinger et al. [11] report nearly identical ranges of motion in the sagittal plane whereas the mSHCG model results indicate a decrease. In the symptomatic planovalgus population a decreased range of motion associated with tight gastrocnemius muscles was anticipated. Conversely, the Oxford model reports internal transverse plane rotations in planus feet, whereas the mSHCG model demonstrated no differences between groups. Ankle inversion results were consistent between models, with planus populations exhibiting greater eversion, but did not reach significance in the Levinger et al. study, whereas in the current work highly significant differences were established. Across all motions, the mSHCG model determined more angles that were statistically different and higher levels significance. Standard deviations reported in the current study are consistently smaller than those reported from the Oxford model which may indicate better repeatability and statistical sensitivity of the mSHCG foot model. Since populations between the two studies differed however, many of these differences may be due to the subjects studied and not the models used.

Although the model was observed to be equally repeatable in the pathologic group compared to typically developing individuals, the conclusions from this study are limited by the fact that only one specific foot deformity (planovalgus) was tested. The mSHCG model also needs to be tested for other foot deformities to examine its potential to detect additional foot pathologies. All feet that were clinically described by referring physicians as planovalgus were studied. By measure of calcaneal pitch, most feet did not have severe deformities. This may have helped to minimize the repeatability values in this group; on the other hand, the mild deformities challenged the ability of the model to show significance between the TD and PV groups. A further limitation of this study is that the groups were studied consecutively rather than simultaneously which may have allowed for a training factor to influence results.

The current work represents the first study of repeatability of a foot model in a pathologic population. Results indicate that the mSHCG model can be reliably applied by different clinicians or by the same clinician at different measurement sessions with equal confidence to the same procedure applied to typically developing feet. Additionally, the model has proved capable of determining significant differences in the kinematic motions between feet clinically categorized as planovalgus and typically developing. These differences support the clinical expectations of the pathology.

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