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Can static foot posture measurements predict regional plantar surface area?

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ABSTRACT

Background: The intent of this study was to determine if the use of a single or combination of static foot posture measurements can be used to predict rearfoot, midfoot, and forefoot plantar surface area in individuals with pronated or normal foot types.
Methods: Twelve foot measurements were collected on 52 individuals (mean age 25.8 years) with the change in midfoot width used to place subjects in a pronated or normal foot mobility group. Dynamic plantar contact area was collected during walking with a pressure sensor platform. The 12 measures were entered into a stepwise regression analysis to determine the optimal set of measures associated with regional plantar surface area.
Results: A two variable model was found to describe the relationship between the foot measurements and forefoot plantar contact area ($r^2 = 0.79$, $p < 0.0001$). A four variable model was found to describe the relationship between the foot measurements and midfoot plantar contact area ($r^2 = 0.85$, $p < 0.0001$) in those individuals with a 1.26 cm or greater change in midfoot width.
Conclusions: The results indicate that clinicians can use a combination of simple, reliable and time efficient foot measures to explain 79% and 85% of the plantar surface area in the forefoot and midfoot, respectively.

1. Introduction

Numerous studies have been conducted to determine if a relationship exists between the amount of plantar surface area and various clinical measurements of static foot posture. The reason for this research interest stems from studies conducted in the 1920s and 1930s that used footprints as a method of classifying the vertical height of the medial longitudinal arch of the foot as flat, normal, and high arched. Although Cureton et al. [1] questioned the validity of using plantar surface area to determine the vertical height of the arch, numerous researchers have continued to utilize plantar surface contact area in an attempt to predict the vertical height of the medial longitudinal arch. Several studies have been conducted to determine if a relationship exists between increased plantar surface area, associated with pes planus or flat foot, and the development of lower extremity overuse injuries. Kaufman et al. [2] and Levy et al. [3] assessed military populations and reported that individuals with increased plantar surface area associated with a pes planus or flatfoot type had a significantly greater number of lower extremity overuse injuries. Michelson et al. [4] assessed plantar surface area in a group of collegiate athletes and reported that individuals with a pes planus or flatfoot were not at greater risk of lower extremity injury. More recently, Knapik et al. [5] prospectively assessed over 2600 military recruits to determine if assigning running shoes based on plantar surface area was a factor in the development of injury during basic training. They reported that the shape of the plantar surface area had little influence on injury risk. It should be noted that Knapik et al. [5] used a visual assessment method to classify the plantar surface area of the foot rather than a quantifiable method such as footprints or a pressure sensor platform. In determining the validity of the plantar surface visual assessment technique used by Knapik et al. Swedler et al. [6] reported that 35% of the plantar surface shapes were misclassified when compared with measured arch height. Thus, it would appear that any study attempting to classify plantar surface area should consider using a quantifiable method rather than visual assessment.

Since 1992, eight studies have attempted to predict the vertical height of the medial longitudinal arch based on measurements

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derived from footprints obtained from inked mats, photographs, or pressure sensor platforms. Six of these studies [6–11] have used either the height of the tuberosity of the navicular bone or the dorsum of the foot as the indicator of the vertical height of the medial longitudinal arch. Needless to say the results of these studies have been disappointing, reporting that plantar surface area can only explain between 15% and 55% of the vertical height of the medial longitudinal arch. That would mean that only 50% of the total height of the medial longitudinal arch could be explained based on the plantar surface contact area. Teyhen et al. [12] were able to explain 60% of the medial longitudinal arch height using a set of five different plantar pressure parameters obtained while subjects walked over a pressure sensor platform. The five pressure parameters that were predictive of medial longitudinal arch height were; forefoot width, area between the foot axis and gait line, the lateral hindfoot force-time integral, the 1st metatarsal region force-time integral, and the mean pressure of metatarsals three, four and five. Only one study to date has attempted to predict plantar surface area, based on static measurements of foot posture and mobility. McPoil et al. [13] were able to utilize a three variable model that explained over 75% ($r^2 = 0.76$) of the plantar surface contact area, excluding the toe region. The three variables in their predictive model included; heel width, midfoot width, and the arch height ratio (arch height divided by ball length) measured with equal weight on each lower extremity. While the results of this study would appear promising, the authors could only predict the total surface area of the plantar surface of the foot and failed to explain the amount of surface area in the rearfoot, midfoot, and forefoot regions. The ability for the clinician to be able to predict plantar surface area for specific regions of the foot, especially the midfoot, could be important when designing foot orthoses or footwear modifications. Recent research assessing the clinical effectiveness of foot orthoses for anterior knee pain reported that those individuals who had a 1.13 cm or greater change in midfoot width going from a non-weight bearing seated position to standing were more likely to benefit from the use of foot orthoses [14,15]. In addition, McPoil et al. [16] reported that those individuals with anterior knee pain who benefited from a contoured foot orthoses had a greater change in midfoot width in comparison to those who preferred a non-contoured orthoses. An important question based on the findings of these studies is whether the measured change in midfoot width is associated with an increase in midfoot plantar contact area. More recently, Queen et al. [17] reported that individuals with a pes planus or flat foot would appear to be at a greater risk for medial and lateral midfoot injuries during different athletic tasks. One could therefore hypothesize that one possible reason for this greater risk of injury is increased plantar surface area in the midfoot region.

Methods available to the clinician to assess plantar surface area range from the use of foot imprints obtained from inked mats to more sophisticated and costly sensor platforms designed to measure plantar pressures as well as surface area. While an inked mat is cost effective, obtaining and analyzing the foot impressions can be time consuming. While commercially available pressure sensor platform systems permit the clinician to quickly obtain and analyze footprints, the equipment and software are expensive. Ideally, it would be most beneficial for the clinician to be able to predict a patient's plantar surface area using a simple, reliable, and time efficient measurements of standing foot alignment.

Thus, the purpose of our study was to determine if the use of a single or combination of static foot posture measurements can be used to predict rearfoot, midfoot, and forefoot plantar surface area in individuals with pronated or normal foot types. The 12 static foot posture measurements that were assessed included forefoot width (FFWid), midfoot width (MFWid), heel width (HLWid), and dorsal arch height (DAH) that were assessed while the participant stood placing 10%, 50%, and 100% weight bearing on the tested lower extremity.

2. Methods

2.1. Participant characteristics

One hundred and seventy individuals volunteered to have the width of their midfoot measured in both weight bearing and non-weight bearing to determine the amount of change in midfoot width. The change in midfoot width was defined as the difference between the width of the midfoot assessed in bilateral standing with equal weight on both feet and in non-weight bearing. The assessment in non-weight bearing was performed while the volunteer sat on the end of table so that both lower legs were hanging in a perpendicular position to the floor with the feet non-weight bearing and ankles slightly plantarflexed. Both the weight bearing and non-weight bearing assessment of midfoot width were assessed at 50% of the total foot length with a caliper (described in the Section 2.2) positioned so that the edges of the two plastic plates where aligned laterally and medially to the 50% length point on the dorsum of the foot. From this cohort of volunteers, 26 individuals had a change in midfoot width of greater than 1.26 cm and were placed in the pronated group. From the remaining 144 volunteers screened, 26 individuals matched by age and gender to those individuals in the pronated group with a change in midfoot width of less than or equal to 1.22 cm were placed in the normal group. The criteria for group assignment using the change in midfoot width was based on normative data published by McPoil et al. [18]. In their study, the mean change in midfoot width for 345 individuals was 1.01 cm with a standard error of the measurement (SEM) equal to 1.3 mm. Based on 95% confidence limits of the SEM (1.3 mm multiplied by 1.96), change in midfoot width values for the normal group would therefore be between 0.75 cm and 1.26 cm.

The mean age of the 26 individuals (14 females, 12 males) in the pronated group was 26.3 ± 3.9 years with a range of 22–38 years. The mean age of the 26 individuals (14 females, 12 males) in the normal group was 25.6 ± 2.9 years with a range of 22–33 years. Participants were recruited from the Regis University population through community advertisements. In addition to the change in midfoot width, all participants met the following inclusion criteria: (1) no history of traumatic or overuse injury to either lower extremity in the 6 months preceding; (2) no congenital defect to either lower extremity; (3) no visible signs of foot pathology in both feet, including non-reducible claw or hammer toes, hallux valgus, hallux limitus and hallux rigidus. Each participant was instructed to conduct their normal activities of daily living prior to participation of the study. The Institutional Review Board of Regis University approved the protocol for data collection and all participants provided written informed consent prior to participation.

2.2. Instrumentation

To obtain the foot measurements, a measurement platform that has been previously described was used (Fig. 1) [18]. The platform had modified grooves to allow for a plastic block to slide alongside the participant's feet. The block contained a spring loaded reversible metal bar that was used to assess foot length. In addition to the platform, two addition instruments were constructed to allow for the measurements of arch height and the various foot widths. The weight bearing dorsal arch height gauge consisted of a digital caliper (Model #700-126, Mitutoyo America Corp., Aurora, IL 60502) with the fixed point attached to a 1.2 cm × 5.0 cm × 10.0 cm plastic block to hold the device in a vertical position. A sliding metal rod attached to the moving point of the caliper was used