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The midfoot load shows impaired function after ankle arthrodesis

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ABSTRACT

Background: A large number of parameters are registered by pedobarography, usually requiring a research setting for interpretation. The purpose of this study was to evaluate which pedobarographic parameters (adjusted for walking speed and body weight) discriminate between healthy volunteers and patients after ankle or tibiotalocalcaneal arthrodesis. Furthermore, we evaluated which parameters are associated with the American Orthopaedic Foot and Ankle Society (AOFAS) score.

Methods: Thirty-five healthy volunteers, 57 patients with ankle and 42 with tibiotalocalcaneal arthrodesis were assessed by AOFAS scores and dynamic pedobarography. The arthrodesis patients were further investigated with radiographs. Median follow up was 4 years. Eighteen basic parameters were measured each in the hind-, mid-, and forefoot. For dimension reduction, we represented a pre-selected set of 9 parameters by two indices (load, rollover). We used ordinal logistic and multiple linear regression to address the questions.

Findings: The midfoot index of load was the most important pedobarographic predictor (interquartile range odds ratio 100; 95% confidence interval 13, 771) for belonging to the healthy volunteers rather than the ankle or tibiotalocalcaneal arthrodesis groups. Similarly, it was an independent predictor for the AOFAS score (interquartile range effect 5 points; 95% confidence interval 1, 9). Healthy volunteers had a deeper midfoot depression in the force/pressure time graphs compared to patients after arthrodesis.

Interpretation: When evaluating foot function after ankle or tibiotalocalcaneal arthrodesis, the interpretation of a large number of pedobarographic parameters can be reduced to the interpretation of the midfoot index of load and the evaluation of the force/pressure time graphs.

1. Introduction

Dynamic pedobarography is widely used for evaluation of foot function in several pathologic conditions as well as subsequent to foot surgery to get insight into the function of the foot during gait (Burns et al., 2005; Chang et al., 2002; Child et al., 2009; MacWilliams and Armstrong, 2000; Rammelt et al., 2004). Compared to static radiographs, pedobarography offers dynamic information of the foot during the rollover process. Pedobarography is easy to use in the clinical setting, is cost efficient (equipment costs between US $ 12,000 and $30,000) and can be completed in approximately 10 min. To date pedobarography has been used to observe the correlation of foot pain with abnormally high pressure areas in clubfeet (Burns et al., 2005; Cooper and Dietz, 1995), to identify high pressure areas at risk for ulceration in diabetic feet (Duckworth et al., 1985), and to investigate the mechanical change in patients with rheumatoid arthritis (Rosenbaum et al., 2006), metatarsalgia (Holmes and Timmermann, 1990), hallux valgus (Hutton and Dhanendran, 1981), and cavovarus deformity (Metaxiotis et al., 2000).

Several parameters such as average pressure (Schmiegel et al., 2008), maximal force, peak pressure (Bosch et al., 2009), coronal index (Chang et al., 2002; Frigg et al., 2010), pressure time integral, and contact time (Burns et al., 2005; Rammelt et al., 2004) have been measured in research settings. However, it remains unclear which parameters are clinically relevant. Furthermore, the interpretation and comparison of pedobarographic data is difficult due to the following issues: (1) Many studies did not adjust for the patients' body weight despite the obvious relationship between body weight and force or pressure (force = weight * acceleration, pressure = force/area) (Burns et al., 2005; Horisberger et al., 2009; Rammelt et al., 2004; Schmiegel et al., 2008; Schuh et al., 2011). This makes comparisons between different studies impossible. (2) The influence of walking speed has not been taken into account in many studies (Bosch et al., 2009; Burns et al., 2005; Rammelt et al., 2004; Schmiegel et al., 2008; Schuh et al., 2011). However, two studies (Rosenbaum et al., 1994; Williams, 2008) showed that walking speed altered the pressure distribution by 2–3 times the body weight as well as towards a higher pressure under the heel and medial

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forefoot. (3) Loading patterns of the injured foot are usually compared either with the contralateral foot (assuming that the healthy foot shows normal function) or with a group of healthy subjects. However, due to pain or discomfort, patients show substantial variations in gait dynamics compared to control, including the unaffected contralateral side not exhibiting a healthy walking pattern (Rosenbaum et al., 2006; Valderrabano et al., 2006). (4) Additionally, peak pressure values should be interpreted with caution, as local callosities or deformities may cause high peak pressures and alter the results.

The output of pedobarography of the Novel emed m/E system consists of 18 basic and a number of optional parameters per area of interest. Usually the foot is divided into 3 (hind-, mid-, and forefoot) to 10 areas (Peter Richard Cavanagh PRC mask) (Simoneau et al., 1994). Furthermore, all parameters are recorded for the total foot as a separate, additional area. Therefore, the final pedobarographic output consists of 4 to 11 areas, each with at least 18 parameters. This results in 72–198 parameters per patient. For the clinical interpretation of such vast amounts of data, usually a research setting is needed – it makes a fast interpretation in the daily clinical setting impossible.

In simplifying the assessment of our own patients with ankle (AA) or tibiotalocalcaneal arthrodesis (TTC), we wanted to know which parameters – adjusted for walking speed and body weight – show a difference compared to healthy volunteers, and which parameters are associated with a better clinical outcome. Therefore, the primary purpose of this study was to evaluate which pedobarographic parameters (adjusted for walking speed and body weight) are associated with one of the three groups: healthy volunteers and patients after ankle or TTC arthrodesis. The secondary purpose was to determine which pedobarographic parameters (adjusted for walking speed and body weight) are associated with the clinical outcome as measured by the American Orthopaedic Foot and Ankle Society (AOFAS) score (Kitaoka et al., 1994).

2. Methods

2.1. Study participants

We prospectively analyzed all 236 patients who underwent ankle or TTC arthrodesis from 2003 to 2006. For the present study, we included patients meeting the following criteria: (1) unilateral successful ankle or TTC fusion performed at the Department of Foot and Ankle Surgery, University of Calgary, Canada, with a minimum follow up of 2 years, (2) complete radiographs available on a DICOM/PACS system, and (3) residing a maximum 1-hour's drive away from the authors' institution. We excluded patients with persistent painful nonunion (n = 5), who were bedridden (n = 22), deceased (n = 6), had amputations during follow-up (n = 8), with comorbidities that precluded walking over the pedobarograph (e.g., blindness, neuromuscular diseases, paralysis of the lower extremity) (n = 7), with incomplete preoperative radiographs (n = 13), with incomplete data during follow-up (n = 7), living more than a 1-hour drive away (n = 23), refusing to participate in the study (n = 32), or had moved away without forwarding addresses (n = 14). Having excluded these 138 patients, a total of 99 patients with arthrodesis of the ankle (n = 57) or TTC (n = 42) remained.

To determine the physiologic load distribution, the pedobarographic data of 35 healthy volunteers (both feet) were used. Healthy volunteers were recruited from the patients' companions. Inclusion criteria were (1) no history of foot complaints or disorders, (2) physiologic foot form on clinical exam, (3) unlimited walking capability (AOFAS score 100 points). Volunteers with any complaints about the foot or a non-physiologic foot form on clinical exam (e.g. flat-, cavus-foot) were not eligible. No radiographs of the healthy volunteers were taken. The same group of healthy volunteers and patients had been investigated in a previous study not related to this work (Frigg et al., 2010).

All subjects gave informed consent to participate in the study, which was approved by the ethical board of the University of Calagary, Canada. The study was performed in accordance with the World Medical Association Declaration of Helsinki.

2.2. Surgical intervention

Indications for surgery were osteoarthritis of the ankle and/or subtalar joint. Ankle fusions were performed using a transfibular approach using three 6.5-mm screws for tibiotalar fixation and two 3.5-mm screws for fixation of the fibula. TTC fusions were performed using a transfibular approach and a straight retrograde intramedullary nail (Biomet, Warsaw, IN; Stryker, Kalamazoo, MI). Alignment was adjusted by the surgeons using visual judgment and intraoperative antero-posterior and lateral radiographs of the ankle.

2.3. Follow up

The follow up for this study conducted in 2008 consisted of three parts: (1) AOFAS score (Kitaoka et al., 1994); (2) radiographic follow up with antero-posterior, lateral, and hindfoot alignment views (HAV) (Saltzman and el-Khoury, 1995); (3) dynamic pedobarography (Novel emed m/E). The follow up was performed by two study nurses and one research fellow in 2008 blinded for the type of intervention. The median follow up was 4 years (range 2, 6).

2.4. AOFAS score

The American Orthopaedic Foot and Ankle Society ankle and hindfoot score (Kitaoka et al., 1994) encompasses the dynamics of pain, function, alignment and ranges from 0 to 100.

2.5. Radiographic follow up

Radiographs undertaken on patients were evaluated by one board-certified research fellow trained in skeletal radiology on a high-resolution wide screen using a DICOM/PACS system. The following measurements were undertaken on the HAV-view: (1) The HAV-distance, defined as the distance from the most inferior point of the calcaneus to the tibial axis and (2) the lateral tibial ground angle, defined as the angle between the tibia and the ground while standing on lateral radiographs.

2.6. Pedobarography

All patients and healthy volunteers were examined using dynamic pedobarography on a 10-m runway made of hard plastic (Novel emed m/E, St Paul, MN). This platform consists of 2736 sensors with a spatial resolution of 4 sensors/cm^2 and measures dynamic foot loading with a frequency of 50 Hz. Patients were asked to walk with normal steps and at a self-selected speed. To avoid effects of acceleration and deceleration, patients took five steps before and after hitting the platform (five-step method) (MacWilliams and Armstrong, 2000). To obtain eight footprints accepted by the software, patients performed eight or more runs per foot. These footprints were then averaged by the software. Additionally, the walking speed was measured with a light gate.

The feet were analyzed barefoot in a four-area mask from the Novel scientific software (hindfoot, midfoot, forefoot, toes). Boundaries between heel to midfoot and midfoot to forefoot were defined as 45% and 73% of length (Simoneau et al., 1994). As the toes are not as critical for the rollover process and single toes may exhibit high pressures, the toe mask was excluded from analysis.

The Novel software delivered 18 primary parameters per area (4 describing contact time, 4 describing peak pressure, 4 describing maximal force, 6 describing the centre of pressure velocity) in three