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Characterization of gait in female patients with moderate to severe hallux valgus deformity

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ABSTRACT

Background: Hallux valgus is one of the most common forefoot problems in females. Studies have looked at gait alterations due to hallux valgus deformity, assessing temporal, kinematic or plantar pressure parameters individually. The present study, however, aims to assess all listed parameters at once and to isolate the most clinically relevant gait parameters for moderate to severe hallux valgus deformity with the intent of improving post-operative patient prognosis and rehabilitation.
Methods: The study included 26 feet with moderate to severe hallux valgus deformity and 30 feet with no sign of hallux valgus in female participants. Initially, weight bearing radiographs and foot and ankle clinical scores were assessed. Gait assessment was then performed utilizing pressure insoles (PEDAR®) and inertial sensors (Physilog®) and the two groups were compared using a non-parametric statistical hypothesis test (Wilcoxon rank sum, $P < 0.05$). Furthermore, forward stepwise regression was used to reduce the number of gait parameters to the most clinically relevant and correlation of these parameters was assessed with the clinical score.
Findings: Overall, the results showed clear deterioration in several gait parameters in the hallux valgus group compared to controls and 9 gait parameters (effect size between 1.03 and 1.76) were successfully isolated to best describe the altered gait in hallux valgus deformity ($r^2 = 0.71$) as well as showed good correlation with clinical scores.
Interpretation: Our results, and nine listed parameters, could serve as benchmark for characterization of hallux valgus and objective evaluation of treatment efficacy.

1. Introduction

Hallux valgus (HV) deformity is an outward lateral angulation of the great toe and is most commonly found in female patients in clinical practice (Nix et al., 2010; Roddy et al., 2008). The deformity is progressive in nature, and can eventually become debilitating, compromising activities of daily living of the patients. At an advanced stage, the deformity is known to cause pathologic gait deviation due to continual pain and discomfort. Studies have even shown a link between severe HV and impaired balance/frequent incidence of falls in elderly patients (Menz and Lord, 2001, 2005).

There are a wide variety of surgical interventions available for the correction of HV, based on the type and severity of the deformity, yielding good to excellent outcomes depending on the profile of the patients and on the outcome measures applied (Lin and Bustillo, 2007). A number of studies have assessed the outcome of these surgical procedures, most of which are based on questionnaires and radiographic evaluation (Dennis and Das De, 2011; Garrido et al., 2008; Kopp et al., 2005) with relatively few on plantar loading (Bryant et al., 2005; Martinez-Nova et al., 2011). There are also few studies which have assessed gait deviation in HV patients (Canseco et al., 2010; Deschamps et al., 2010; Galica et al., 2013; Mickle et al., 2011; Waldecker, 2002; Wen et al., 2012). Based on the results of a systematic review by Nix et al. (2013) a number of fundamental limitations exist in these studies and there is no determinable agreement in the results. This would suggest that information regarding gait characterization in HV deformity is yet to be fully explored.

With the advancement of technology and further development in wearable motion sensors and pressure insoles (Lambrecht and Kirsch, 2014; Razak et al., 2012), it is likely that gait assessment will be included as part of diagnostic and outcome assessment in the foreseeable future. Studies have already isolated gait parameters which define gait deviations (Chopra et al., 2014; Mariani et al., 2012, 2013; Mickle et al., 2011; Rouhani et al., 2011a; Taranto et al., 2007; Yavuz et al., 2009), however not all of those parameters are clinically meaningful for specific deformities. It is therefore important that we not only characterize gait deviations in HV patients but also simplify the procedure by reducing the number of assessed parameters to the most clinically relevant. The gait parameter which displays significant alteration due to the extent of the HV deformity and positively correlates to the clinical scores,

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with a potential to accurately assess the prognosis post operatively will be counted among the clinically relevant gait parameters.

This study aims to investigate the gait characteristics in patients with moderate to severe HV deformity by assessing spatiotemporal, kinematic and plantar pressure parameters, as well as their variability. Furthermore, the study aims to simplify gait assessment by isolating the most clinically relevant parameters in defining gait alterations in HV patients.

2. Methods

2.1. Participants

Twenty six female feet with moderate to severe HV deformity and thirty healthy female feet were assessed. Inclusion criteria for the HV group include radiographic results of hallux valgus angle (HVA) and M1–M2 intermetatarsal angle (IMA) between 20–40° and 14–20° respectively, and presence of significant pain due to HV. In the case group, patients with HV present in both feet had each measured as an independent observation. The exclusion criteria included the presence of any other pathology of the foot and ankle and or previous surgeries or trauma of the lower limbs/other conditions which may affect their gait. All the participants gave their informed consent and approval of the ethics commission of the University hospital was obtained.

2.2. Clinical assessment

Commonly used foot and ankle questionnaires, including Foot and Ankle Ability Measure (FAAM) (Borloz et al., 2011) and American Orthopaedic Foot and Ankle Society (AOFAS) (Hunt and Hurwit, 2013) forefoot score, were administered to evaluate the preoperative functional status of patients with the HV deformity.

Radiographic assessment was performed by a single independent observer and illustrated the IMA, HVA and distal metatarsal articular angle (DMAA) (Fig. 1).

Fig. 1. Radiographic measurements in weight bearing position representing M1–M2 intermetatarsal angle (IMA), hallux valgus angle (HVA) and distal metatarsal articular angle (DMAA).

2.3. Gait assessment

Gait assessment was performed using ambulatory pressure insoles (Pedar-X®, Novel, Germany) and five 3-D inertial sensors, connected to two portable data-loggers (Physilog®, BioAGM, CH) (Rouhani et al., 2011b, 2012). The sensors were placed at the medial aspect of both tibias, and on the tested foot, to the posterior aspect of the great tuberosity of the calcaneus between the base of the first and second metatarsals, and on the dorsal aspect of the proximal phalanx of the first toe. The insoles were available in 4 different sizes along with the custom made sandals, can be found in Fig. 2.

To carry out the gait assessment, each participant was asked to walk twice, back and forth, along a 50 m long hospital corridor at their normal walking speed. The plantar pressure data were collected, from the 99 cells of the Pedar-X® insoles, at the sampling rate of 200 Hz. The stance time of the gait cycles for each trial was identified using sum of the pressure over loaded elements of the insole (Rouhani et al., 2011b). The kinematic data were collected, from the Physilog® system, during the 100% stance phase of the gait cycle at a rate of 200 Hz (Rouhani et al., 2012). For kinematic assessment, foot and ankle complex is divided into four joint segments (shank, hindfoot, forefoot and toes) and the joint angles were calculated based on the proximal and distal segments (Rouhani et al., 2012). To obtain repeatable joint angles consistently among subjects, the sensor signals and subsequent joint angles were expressed relative to the foot and shank's anatomical frames, instead of the inertial sensors' technical frames (Rouhani et al., 2012). A detailed description of the validated measurement protocol can be seen in previous publications (Rouhani et al., 2011b, 2012). The first and last three cycles of each trial were discarded to eliminate the wayward effects during initiation and termination of walking. The average of all remaining gait cycles was then taken for each trial. Spatiotemporal, kinematic (joint angles) and plantar pressure parameters were assessed for all gait cycles of each walking trial of 50 m. From an average of 35 to 40 gait cycles per trial for each participant spatiotemporal parameters were assessed, including: stance phase of the gait cycle time (GCT%); cadence, double support time (GCT%), inner-stance events (loading, foot-flat and push-off phase (stance phase %)); stride length (m), speed (m/s), peak swing speed (°/s), toe off pitch angle (°) and heel strike pitch angle (°). Three dimensional joint angles including dorsi-plantar flexion, inversion–eversion, internal–external rotation were assessed in their respective plane of movement i.e. sagittal, coronal and transverse plane during 100% of the stance phase for both the 1st metatarsophalangeal joint (MTP1) and the total foot, based on the forefoot–toe and shank–forefoot segments respectively. Plantar pressure

Fig. 2. Sensor placement for the tested foot.