Gait & Posture 39 (2014) 1–6

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Winner of the GCMAS 2012 Best Paper Award

Classification of midfoot break using multi-segment foot kinematics and pedobarography

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ARTICLE INFO

Article history:
Received 3 April 2013
Received in revised form 2 August 2013
Accepted 8 August 2013

Keywords:
Midfoot break
Multi-segment foot model
Kinematics
Gait
Pedobarography

ABSTRACT

Midfoot break (MFB) is a foot deformity that can occur when ankle dorsiflexion is restricted due to muscle spasticity or contractures, causing abnormal increased motion through the midfoot. MFB has been previously described in terms of forefoot (FF) and hindfoot (HF) motion in the sagittal plane. The purpose of this study was to further classify MFB by describing FF and HF motion in the coronal and transverse planes along with plantar pressures, with the goal of optimizing treatment of this deformity. Three-dimensional foot kinematics were assessed using a multi-segment foot model in children with MFB (n = 30) and children with no foot or gait abnormalities (n = 30). The MFB group was subdivided into three categories: (1) Pronated MFB, (2) Supinated MFB and (3) Flat Foot MFB. Unique patterns of plantar pressures and foot kinematics were identified for each MFB group. The Pronated MFB group had increased medial midfoot pressures, increased forefoot pronation, and increased external forefoot rotation (forefoot abductus). The Supinated MFB group had increased lateral midfoot pressures, increased forefoot supination, and increased internal forefoot rotation (forefoot adductus). In the Flat Foot MFB group, midfoot pressures were increased and distributed uniformly between the medial and lateral sides, forefoot pronation was increased, and internal forefoot rotation was present. By combining this new information with previously reported methods of measuring sagittal plane kinematics of MFB, it is now possible to characterize midfoot break in terms of severity and foot-floor contact pattern.

1. Introduction

Midfoot break (MFB) is a severe foot deformity that occurs most often in children with cerebral palsy (CP) [1]. CP is defined as a group of permanent disorders of the development of movement and posture causing activity limitation that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain [2]. The prevalence of MFB in children with CP has been reported as high as 30%, with the greatest incidence among children with quadriplegia (50–68%) [3,4]. In a foot with MFB, increased tightness in the gastrocnemius-soleus complex pulls the hindfoot into equinus. The increased muscle forces cause the longitudinal arch of the foot to collapse due to lack of support for the talus. Early identification of MFB may guide clinicians in preventative treatments and appropriate interventions. Although MFB can be a fixed deformity, the focus of this study was on dynamic or flexible MFB.

When mild, MFB can be treated using an orthosis to support the foot during walking. However, in many cases, MFB worsens over time, and surgical correction is often required. This typically involves a lateral column lengthening in the immature foot or triple arthrodesis in the mature foot [5,6]. Subtalar arthrodesis also remains an option for both groups with "severe" deformities that are non-correctable on physical exam. Currently, X-rays and clinical exam are the only means for determining the most appropriate intervention. Conventional X-rays measure a static foot position in stance only whereas gait analysis and plantar pressures measure the foot during the dynamic phase of stance. Additional information about the 3-dimensional foot motion and plantar pressures may help surgeons to customize their treatment of MFB to address the medial or lateral column pathology.

The current study is a continuation of previous work, in which MFB was described by sagittal plane kinematics [7]. When compared to controls, children with MFB had a significant decrease in peak ankle dorsiflexion and a significant increase in peak midfoot dorsiflexion. Forefoot (FF) and hindfoot (HF) position was described in two ways: (1) relative to the proximal segment and (2) relative to the floor. While it is important to understand "joint"

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http://dx.doi.org/10.1016/j.gaitpost.2013.08.015

motion at the midfoot, the position of the foot relative to the ground may provide additional information related to increased pressures on the foot and guide the prescription of custom orthotics. In the first phase of this study, different patterns of MFB were observed in the coronal plane. All children in the study had increased midfoot motion in the sagittal plane with diminished heel contact, but some had diminished forefoot contact on the lateral border, some had diminished forefoot contact on the medial border, while others had a flat forefoot. It was determined that MFB could be further characterized and better understood by incorporating all three planes of motion and plantar pressure measurements.

The purpose of the current study was to describe and quantify three different patterns of MFB that are commonly observed in children with CP, using three-dimensional multi-segment foot kinematics and plantar pressures. By further classifying MFB into sub-types, clinicians will gain additional information to better guide the treatment of this foot deformity.

2. Materials and methods

This study is a further analysis of the data collected for our initial characterization of MFB in the sagittal plane [7].

2.1. Participants

Two groups of participants were recruited for this study:

(1) children with unilateral or bilateral midfoot break (MFB group)
(2) children with no evidence of MFB or any gait abnormalities (Control group)

The MFB group was comprised of 30 feet from a total 20 children between the ages of 5 and 16 (mean 9.6 ± 3.3 years). Participants in the MFB group were recruited through routine gait analysis referrals to Sunny Hill Health Centre for Children. These patients were identified as having MFB based on clinical assessment by the referring orthopaedic surgeon. This diagnosis was confirmed by a comprehensive physiotherapy exam at the gait lab appointment. During this exam, the sub-talar joint was stabilized, and midfoot motion was observed. If midfoot motion was present the patient was included in the study. This group of participants was sub-divided based on an observational gait assessment by the physiotherapist. The child was asked to walk while the physiotherapist observed the foot-floor contact pattern. If the child's forefoot maintained contact with the floor on both medial and lateral sides throughout stance, he or she was placed in the Flat Foot MFB group ($n = 9$). If the foot maintained contact with the floor on the lateral side only, the child was in the Supinated MFB group ($n = 13$), and if forefoot contact occurred on the medial side only, the child was in the Pronated MFB group ($n = 8$). The Control group for comparison of kinematic data was recruited through children of staff at Sunny Hill and siblings of children in the MFB group. Participants in this group were also assessed by a physiotherapist to rule out any gait abnormalities. The Control group included 30 feet from a total of 15 children between the ages of 7 and 15 (mean 10.1 ± 2.5 years). The study size represents a convenience sample, from which future study samples may be estimated. For the pressure data, Control values were taken from a database of 146 children (age range 1.6–14.9 years) [8].

The study was approved by the University of British Columbia Clinical Research Ethics Board and the Children's and Women's Hospital of British Columbia's Research Review Committee.

2.2. Data acquisition and testing procedures

A comprehensive gait analysis was conducted at the Shriners Gait Lab. One of two trained physiotherapists placed the retro-reflective markers on the subject's skin, according to the modified Shriners Hospital for Children Greenville (mSHCG) foot model [9]. In this model, the hindfoot valgus angle is defined using a goniometric measurement. A slight modification was made to the model, using markers placed on the proximal and distal aspects of the calcaneus to define the valgus angle [7]. In addition, markers were placed on the rest of the body according to the conventional Helen Hayes marker set [10,11]. A twelve-camera Motion Analysis system (Motion Analysis Corporation, Santa Rosa, CA) was used to record the 3-dimensional positions of the markers. Participants were asked to walk at a comfortable pace along the gait walkway until three representative stride cycles were recorded on the affected side(s). Upon completion of the kinematic walking trials, participants were asked to walk several times over a plantar pressure mat (HR MAT, Tekscan, Inc., Boston, MA) until three representative trials were recorded for each foot.

2.3. Data analysis

The first phase of this study focused on midfoot motion in the sagittal plane [7]. In the current study, FF and HF motion was evaluated in the coronal (pronation/supination) and transverse (internal/external rotation) planes as well. "Joint" motion was calculated relative to the proximal segment coordinate system (SCS), but FF and HF positions were also calculated relative to the lab coordinate system ((LCS), i.e. relative to the floor). This allowed examination of the foot-floor contact patterns in relation to plantar pressures. In addition to presenting the mean values of the kinematic and pressure data (Table 1), a representative example from each group is shown in Figs. 1–4. Due to the unique characteristics of each child's foot deformity, it was important to examine the relationship between pressure data and kinematics within each subject. Results from this phase of the study are descriptive due to the small sample size within each MFB sub-group.

Table 1
Medial/lateral midfoot pressures and FF/HF kinematics in the coronal and transverse planes. Pressures represent a percentage of the maximum pressure recorded. Pronation/supintation in degrees with positive values indicating supination and negative values for pronation (see points A and B, Fig. 1). Internal/external rotation in degrees with positive values indicating internal and negative values for external (see points C and D, Fig. 1). "Wrt floor" means angles are measured with respect to the floor and "wrt HF" means angles are measured with respect to the hindfoot segment.

Type of MFB	Pronated MFB ($n = 8$)	Supinated MFB ($n = 13$)	Flat foot MFB ($n = 9$)	Control
Peak Medial MF Pressure (% Max)	42.9 ± 11.0	3.6 ± 3.0	30.8 ± 9.2	1.3 ± 1.3 ($n = 146$)
Peak Lateral MF Pressure (% Max)	16.3 ± 5.7	47.2 ± 17.5	30.4 ± 9.4	19.2 ± 8.8 ($n = 146$)
Max FF Pron/Sup wrt Floor (Neg = Pronation)	−13.2 ± 18.1°	−4.2 ± 6.5°	−10.9 ± 9.0°	−2.0 ± 3.6° ($n = 30$)
Min FF Pron/Sup wrt Floor (Pos = Supination)	6.1 ± 10.6°	22.1 ± 11.7°	9.3 ± 7.8°	8.7 ± 7.5° ($n = 30$)
Max FF Int/Ext Rotation wrt HF (Pos = Internal)	−4.9 ± 5.9°	20.1 ± 10°	−2.1 ± 14.5°	8.2 ± 10.0° ($n = 30$)
Min FF Int/Ext Rotation wrt HF (Neg = External)	−11.4 ± 7.3°	9.2 ± 8.1°	−11.3 ± 12.4°	0.7 ± 7.8° ($n = 30$)