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Effects of foot orthoses on gait patterns of flat feet patients

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ABSTRACT

Background: Although foot orthotics are widely prescribed for the treatment of flatfoot, the biomechanical effects of such devices are not yet fully clear. Accordingly, this study conducted an experimental investigation to evaluate the effects of orthoses on the gait patterns of patients with flatfoot during level walking.

Methods: Eleven adults with flatfoot deformities were recruited. For each participant, kinematic and kinetic data were measured under three test conditions, i.e. walking barefoot, walking with shoes, and walking with shoes and insoles. During each test, the participants' gaits patterns were recorded and analyzed using a motion analysis system, two Kistler force plates and EVaRT software.

Findings: The results showed that walking with shoes and insoles and walking with shoes conditions increased the peak ankle dorsiflexion angle and moment, and also reduced the peak ankle plantarflexion angle and moment. Furthermore, walking with shoes and insoles and walking with shoes conditions increased the peak knee varus moment. The effects of the orthoese on knee and hip were minimal and no significant differences were observed between walking with shoes and insoles and walking with shoes.

Interpretation: The results suggested that the foot insoles and shoes developed in this study might benefit the ankle joint in patients with flat feet. In view of the minimal changes between walking with shoes and insoles and walking with shoes, further studies may be required to clarify the interaction between the foot and the insole/shoe.

1. Introduction

Pes planus, commonly known as “flatfoot” or “fallen arches”, is a medical condition in which the medial longitudinal arch (MLA) which runs the length of the foot is flattened out or lowered. Flatfoot may affect one or both feet, and not only increases the load acting on the foot structure, but also interferes with the normal foot function. As a consequence, individuals with flat feet experience discomfort while standing for long periods of time and exhibit a distinctive flat-footed gait (Messier and Pittala, 1988). Typical flatfoot symptoms include a tenderness of the plantar fascia, a laxity of the ligaments (Bertani et al., 1999), a rapid tiring of the foot, pain under stress (Rose, 1991), and instability of the medial side foot structure. Over time, the mechanical overloading resulting from the flattened MLA is transferred to proximal areas such as the knees, hips and lower back (Franco, 1987), and thus flatfoot is recognized as a contributory factor in a wide variety of medical conditions, including lower limb musculoskeletal pathologies such as plantar fasciitis (Messier and Pittala, 1988), Achilles tendonitis (Clement et al., 1984; Kaufman et al., 1999), and patello-femoral joint pain (Ilahi and Kohl Iii, 1998).

Flatfoot deformities are commonly treated using some form of orthotic device. Such devices are designed to provide stability and to realign the foot arch, and have a demonstrable success in alleviating patients' symptoms (Franco, 1987; Noll, 2001; Rodgers, 1995; Stell and Buckley, 1998). Recent biomechanical studies have shown that orthotic insoles improve the arch alignment, increase the duration of the stance phase of level walking, and reduce both the maximum pronation angle of the foot and the tibial internal rotation (Eng and Pierrynowski, 1994; Kitaoka et al., 2002; McCulloch et al., 1993; Nawoczenski et al., 1995). McCulloch et al. (1993) investigated the lower limb kinematics of ten subjects wearing orthotics to control excessive forefoot varus, and found that the orthotic devices resulted in a significant reduction in the degree of pronation. Mundermann et al. (2003) found that different orthotic designs (i.e. flat, posting, custom-molding, posting and custom-molding) yielded different effects on the comfort, kinematics, kinetics and muscle activity of the wearer. However, this finding contradicts the results presented in some previous studies regarding the effects of orthotic insoles. For example, Brown et al. (1995) noted that different orthoses resulted in no apparent difference in the maximum pronation, calcaneal eversion, or total pronation of

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the foot. Nigg et al. (1988) compared the changes in the peak vertical force, the time of occurrence of the peak vertical force, and the maximum vertical loading rate in a group of runners wearing running shoes with four different types of viscoelastic insole. The results showed that the different insoles had no appreciable effect on the measured values of the kinematic and kinetic variables. In addition, the improvement in the gait patterns of the runners was far less than expected; particularly in the sagittal plane. Eng and Pierrynowski (1994) reported that the use of soft orthotics had no apparent effect on the sagittal plane movements of patients with patello-femoral pain syndrome, but reduced the angle of the talocrural/subtalar joint by around 1–3° in the frontal and transverse planes.

From the discussions above, it is evident that the biomechanical effects of the orthotics used in the clinical treatment of flatfoot are not yet fully understood. Furthermore, the published literature focuses principally on the effects of orthotic devices on the foot structure rather than on the lower limbs, and thus the wider biomedical implications of orthoses are unclear. Last but not least, the biomechanical investigations reported in the literature are invariably performed using healthy subjects rather than flat feet patients (Branthwaite et al., 2004; Gross et al., 1991; Nester et al., 2003; Stacoff et al., 2000). In an attempt to address these limitations, this study conducts an experimental investigation into the effect of orthoses on the gait patterns of 11 patients with flatfoot deformities during level walking with focus on the stance phase. The experimental results provide useful insights into the short-term efficacy (or otherwise) of orthotic insoles in alleviating the discomfort experienced by flatfoot patients in the ankle, knee and hip joints.

2. Methods

2.1. Subjects

The gait analysis experiments were conducted using 11 adults with flatfoot (six males and five females; mean ± SD age: 45.9 ± 15.66 years; height: 160.9 ± 6.9 cm; weight: 64.8 ± 7.2 kg). For each subject, the static feet postures were in either a "planus" or a "pronated" position. Furthermore, each subject had no record of any physical or neurological abnormality of the lower extremities. The MLA of each participant was measured using the arch index (mean ± SD: 0.11 ± 0.019) (Williams and McClay, 2000), i.e. the ratio of the navicular height to the foot length. The foot measurements were acquired with the subjects stood upright on a flat surface with their feet positioned shoulder width apart and even with one another. The navicular height was measured from the floor to the most anterior–inferior portion of the navicular, while the foot length was measured from the most posterior portion of the calcaneus to the end of the longest toe.

2.2. Shoes and insoles

Shoes and insoles were custom made for each participant by Jun-Da Biotechonology Co., Ltd, Taiwan (see Fig. 1). The shoes were made of rubber and PU, while the insoles were made of vinyl-acetate and 12 ± 3% far-infrared nanopowders. The insoles were molded by clinical podiatrists with the aim of reducing the pronation of the foot. To reduce sliding between the insoles and the shoes, the insoles were fixed firmly in place using Velcro.

2.3. Data collection

After obtaining the participants' consent, anthropometric parameters were measured using 15 spherical retro-reflective markers (diameter 1.2 cm, 7 lower body segment models, Helen Hayes marker set) attached to selected anatomic landmarks. The marker set was configured as follows: bilateral anterior superior iliac spine (ASIS), top of the sacrum, bilateral mid-thigh-cuff (marker on wand), bilateral lateral femoral epicondyles, bilateral mid-shank-cuff (marker on wand), bilateral lateral malleoli, bilateral heels, and bilateral toes between second and third metatarsal heads. Note that in the shod test conditions, the four markers on the bilateral heels and toes could not be attached directly to the participants' skin, and thus anatomic landmarks were attached instead to appropriate positions on the vamp of the shoe.

During the experiments, the trajectories of the reflective markers were sampled at a frequency of 100 Hz by an eight-camera Eagle digital motion analysis system (Motion Analysis Corporation, Santa Rasa, CA, USA). In addition, the ground reaction force during walking was measured using two Kistler force plates (Kistler Instruments, Inc., Amherst, NY) with a sampling rate of 1000 Hz synchronized with the motion analysis system.

Before commencing the gait analysis experiments, the subjects were asked to walk a number of trials along the test walkway at a self-selected velocity wearing their own shoes and insoles so as to familiarize themselves with the experimental surroundings. In addition, prior to each experiment condition, a static trial was measured with the participants in a static position in order to establish the relationship amongst the markers for each subject's initial anatomical position. Data were then collected under three specific test conditions, i.e. walking barefoot (WB), walking with shoes (WS), and walking with shoes and insoles (WSI). For each condition, three trials of gait data were acquired for each subject while walking at a self- selected speed.

2.4. Data processing and analysis

Utilizing the data acquired in the experimental trials, three-dimensional trajectories were constructed using EVaRT 4.2 software (Motion Analysis Corporation). In constructing the trajectories, the joint angles were determined from the anatomical and segmental coordinate systems, and the positions of the markers were smoothed using a low-pass digital filter with an estimated optimum cutoff frequency of 6.0 Hz. In addition, the body segment motion and foot/floor reaction data were processed using OrthoTrak 5.0 software (Motion Analysis Corporation, Santa Rosa, California) in order to evaluate the angle, force and moment data associated with the ankle, knee and hip joints of each participant. Note that prior to performing the analysis, the data acquired

Fig. 1. Custom-made shoes and insoles.