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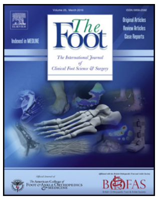

Original article

Kinematic analysis of ankle stiffness in subjects with and without flat foot

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HIGHLIGHTS

- The subjects with flat foot demonstrated increased ankle stiffness during dorsiflexion.
- This ankle stiffness difference was regardless of demographic factors.
- Future studies needed for kinematic analysis and joint stiffness.

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ABSTRACT

Background: Although the magnitude of ankle motion is influenced by joint congruence and ligament elasticity, there is a lack of understanding on ankle stiffness between subjects with and without flat foot.
Objective: This study investigated a quantified ankle stiffness difference between subjects with and without flat foot.
Methods: There were forty-five age- and gender-matched subjects who participated in the study. Each subject was seated upright with the tested foot held firmly onto a footplate that was attached to a torque sensor by the joint-driving device.
Results: The flat foot group (mean ± standard deviation) demonstrated increased stiffness during ankle dorsiflexion (0.37 ± 0.16 for flat foot group, 0.28 ± 0.10 for control group; $t = -2.11$, $p = 0.04$). However, there was no significant group difference during plantar flexion (0.35 ± 0.15 for flat foot group, 0.33 ± 0.07 for control group; $t = 0.64$, $p = 0.06$).
Conclusion: The results of this study indicated that the flat foot group demonstrated increased ankle stiffness during dorsiflexion regardless of demographic factors. This study highlights the need for kinematic analyses and joint stiffness measures during ankle dorsiflexion in subjects with flat foot.

1. Introduction

Ankle assessment devices for the use of robot-assisted measures have been developed over the last two decades to assess outcomes. Ankle joint stiffness contributes to injury of the lower extremities individuals with proprioceptive deficits which are related to joint stability [1,2]. A recent systematic review reported that the variations of foot posture were thought to be intrinsic risk factors for injury due to altered motion of the lower limb [3]. However, there was conflicting evidence regarding postural control and balance sway in subjects with different foot arch types [4–6].

Flat foot problems are reported as a common concern, and the incidence levels range from less than 1% to as much as 78% [7]. Flat foot is determined by the navicular drop (ND) test, which measures the amount of navicular tuberosity excursion between neutral and standing positions [8]. Those with a ND exceeding 9 mm excursion are classified as individuals with a flat foot deformity although the methods quantify limited dynamic navicular motion without considering task specificity [9].

Radiographic investigations have been a reference standard to determine magnitude of flat foot; however, they fail to quantify accurate stiffness of ankle motion to serve as an objective assessment of flat foot [10–12]. A variety of etiological factors might be related to flat foot since a loss of functional integrity may affect the ankle joint. Although there is no universally standardized measure of foot posture [10,12,13], ankle stiffness is often cited as a primary impairment leading to excessive injuries [14,15]. However, a valid and reliable measure of ankle stiffness and flat foot needs to be investigated further during passive motion in non-weight bearing position.

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It has been reported that ankle stiffness dominates the mechanical behavior of the ankle muscles, contributes to the risk of falls, and impairs standing balance in daily activities [16]. In individuals with flat foot, the medial arch height is decreased by plantar medial rotation of the talus and then a valgus deformation is usually accompanied with mechanical imbalance and pain [13,17]. The medial longitudinal arches of the feet act as shock absorbers for body weight and preserve stability during both walking and standing. Although the body of literature provides some evidence of a relationship between flat foot and intrinsic risk factors for leg injuries, most studies are not conclusive due to a lack of a valid and reliable measurement on heterogeneity between studies and small effect sizes on flat foot deformity [3]. Therefore, research using well-defined measurements is required to enable valid comparison of foot arch types and ankle stiffness.

Stiffness is generally defined as the ratio of moment to angular deflection of the specific joint [18,19] as quantified by the slope of the length–tension relationship [20]. The primary mechanism for lower limb stiffness is the adjustment of ankle stiffness, which is more important than that of knee and hip stiffness [21,22]. It is important to accurately quantify ankle stiffness in individuals with flat foot deformity in order to translate our clinical understanding of ankle stability while considering demographic factors.

Clinicians frequently assess movement performance to observe biomechanical deficits with degeneration of the sensory and motor systems in elderly patients [23,24]. A clinical assessment requires objective measurement of ankle stiffness and flat foot with individual characteristics. Altered movement with reduced force-generating capacity is especially true in an aging population [25,26]. Other demographic factors, such as body weight and height, have also been shown to be confounding factors for biomechanical effectiveness [27–29].

It is beneficial to accurately quantify mechanical changes as the primary focus of ankle stiffness for subjects with flat foot while considering demographic factors during passive motion in non-weight bearing positions. The purpose of this study was to compare ankle stiffness in subjects with and without flat foot based on demographic factors.

2. Methods

Subjects with flat foot were recruited from the University community by advertisement. Subjects were eligible to participate in the flat foot group if they: (1) had >9 mm on the ND test, (2) were 40 years of age or older, (3) were not diagnosed with any lower extremity injuries, and (4) had no acute pain or dysfunction surrounding the ankle or foot at the time of the study.

Individuals were excluded from participation if they: (1) had non-symmetric feet [6], (2) had continuous pain or underwent surgery on a lower extremity within the past 2 months, (3) had a diagnosed psychological illness that might interfere with the study protocol, (4) had experienced overt neurological signs (sensory deficits or motor paralysis), (5) had active medical, surgical, or neurologic illness, painful conditions, history of peripheral neuropathies, or any disorders affecting the central nervous system.

Subjects were withdrawn from the study if they requested to withdraw. The control group was recruited based on similar individual characteristics as the subjects with flat foot and who had less than 9 mm on the ND test. All subjects who met study inclusion criteria received information regarding the study and signed a copy of the Institutional Review Board approved consent form (IRB#8-15B).

2.1. Experimental setup

Each participant's subtalar joint was measured for the navicular height. The distance between the tubercle of the navicular bone was measured in sitting (non-weight bearing position) as well as in standing (full weight bearing position). The normal range of ND was defined between 5 and 9 mm [5]. Therefore, participants with a ND exceeding 9 mm were included in the flat foot group, and the participants with less than 9 mm comprised the control group. For reliability in our study, the intra class correlations were calculated to determine ND. The intra class correlation coefficients of type (3, 1) were used to determine the degree of test–retest reliability, ranged from 0.85 to 0.93, and were interpreted as excellent according to Shrout and Fleiss [30].

In this study, the outcome evaluation was performed using the Intel stretch device (Rehabtek, IL, USA). Fig. 1 represents the experimental setup for obtaining the ankle stiffness measurements. Each subject was seated upright with the tested foot held firmly onto a footplate that was attached to a torque sensor. The lower extremity being measured was strapped to the leg support at 60 degrees of knee flexion. The thigh and trunk were strapped to the seat and backrest, respectively, with the seat and leg support adjusted to a comfortable position for the knee and hip joints at 60 degrees and 85 degrees of flexion, respectively.

The aluminum footplate, lined with rubber pads, supported the whole length of the sole and the medial side of the foot. A molded clamping device with a firm cushioning pad pressed the dorsum

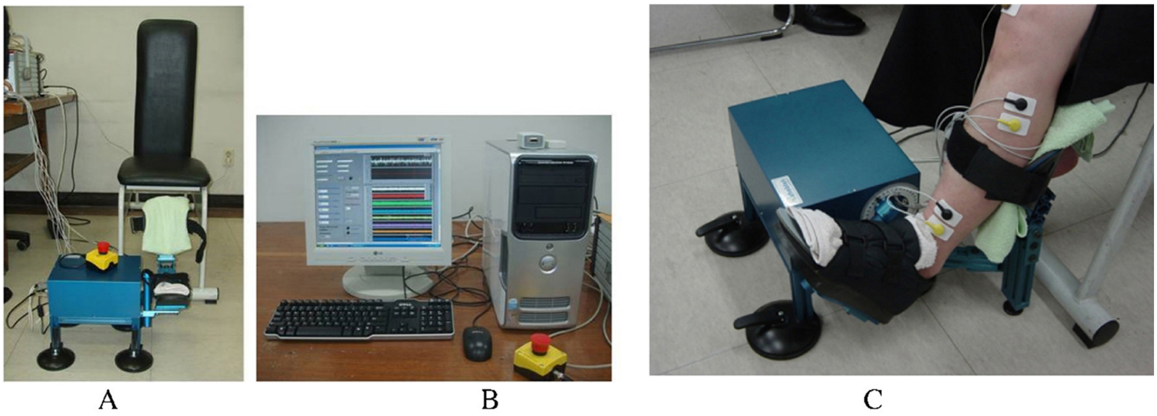

Fig. 1. The experimental setup for ankle stiffness measurements. The device was fixed to the chair to prevent movement relative to the subject. The seat was adjusted to align the ankle flexion axis at a selected knee flexion range of motion (ROM). The foot of the subject was fixed on the footplate, and the lower leg was fixed to a leg support (A). A LabVIEW program was designed to control the data-acquisition device and to obtain the data (B). A six-axis force sensor was mounted between the motor shaft and the foot attachment. The surface electromyography (EMG) electrodes were placed over the ankle muscles (C).