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Foot alignments influence the effect of knee adduction moment with lateral wedge insoles during gait

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ABSTRACT

Lateral wedge insoles (LWIs) reduce the peak external knee adduction moment (KAM). However, the efficacy of LWIs is limited in certain individuals for whom they fail to decrease KAM. Possible explanations for a lack of desired LWI response are variations in foot alignments. The purpose of this study was to evaluate whether the immediate biomechanical effects of LWIs depend on individual foot alignments during gait. Fifteen healthy adults participated in this study. Their feet were categorized as normal, pronated, and supinated using the foot posture index. All subjects were subsequently requested to perform a normal gait under barefoot and LWI conditions. A three-dimensional motion analysis system was used to record the kinematic and kinetic data, included peak KAM, KAM impulse (KAAI), center of pressure displacement, and knee-ground reaction force lever arm (KLA). Furthermore, lower limb frontal plane kinematic parameters at the rear foot, ankle, knee, and hip were evaluated. Among all feet, there was no significant difference in the peak KAM and KAAI between the conditions. In contrast, the peak KAM was significantly reduced under the LWI condition relative to the barefoot condition in the normal foot group. Reductions in the peak KAM were correlated with a more lateral center of pressure and reduced KLA. In addition, a reduced KLA was correlated with decreased hip adduction. LWIs significantly reduced the peak KAM in normal feet, indicating that biomechanical effects of LWIs vary between individual foot alignments. Our findings suggest that it is helpful to assess individual foot alignment to ensure adequate insole treatment for patients with knee osteoarthritis.

1. Introduction

Knee osteoarthritis (OA) is one of the most common musculoskeletal disorders worldwide. The medial tibiofemoral compartment of the knee is the area that is most commonly affected by OA [1], additionally the local mechanical environment also plays an important role in its pathogenesis [2]. Excessive knee load is a significant risk factor for progressive structural degradation [3,4]. A high knee adduction moment (KAM) reflects the increased compressive forces that act on the medial aspect of the knee during gait [5], and this measure is widely regarded as a surrogate measure of medial knee compression [6].

The use of lateral wedge insoles (LWIs) is a treatment option that is frequently recommended in clinical guidelines [7] covering the clinical management of medial knee OA. LWIs have been shown to lower KAM [6] and to prevent or delay the progression of medial knee OA [8,9]. However, the efficacy of LWIs is limited in certain individuals for whom they fail to decrease and instead increase KAM [10–13]. In fact, this paradoxical increase is observed in approximately 20% of patients that use LWIs [11,13], although no study has fully documented the characteristics of patients that do not respond as intended to LWIs.

Possible explanations for a lack of desired LWI response are variations in foot alignments. Foot alignments have long been thought to contribute to the development of a range of lower limb

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musculoskeletal conditions [14,15] because changes in lower limb musculoskeletal conditions can alter the mechanical alignment and dynamic function of the lower limb [16]. In addition, a recent study has shown that different foot alignments are associated with differences in movement of the foot during gait [17]. Because the movement of the foot varies according to foot alignments, intervention to foot by LWI may have a different influence on not only foot but also the lower limb. However, most previous studies have been conducted using subjects having various types of foot alignments. Fisher et al. [12] reported that a decrease in KAM when wearing LWI varies between individuals for healthy adults. This result may be related to other factor such as variation in foot alignments rather than presence or absence of knee OA. A recent study reported that no association between walking ability and structural severity in people at risk of or with mild knee OA [18], thereby suggesting that their subjective symptom would be related to various factors such as age, BMI, knee injury, physical function, and psychosocial condition. Therefore, we must evaluate the biomechanical effects of LWIs on healthy subjects without any disease and/or walking disability toward furthering our understanding of foot alignment effects. It is effective to provide basic data enabling to guide the identification of individuals who respond positively to LWI treatment.

Thus, the primary purpose of this study was to evaluate whether the immediate biomechanical effects of LWIs depend on individual foot alignments as assessed during gait in healthy individuals. A secondary purpose was to gain an understanding of the relationships between changes in the lower limb, including rear foot and ankle frontal plane kinematics, and changes in KAM. It was hypothesized that in subjects with a normal foot alignment, KAM would significantly decrease with the use of LWI compared with barefoot conditions.

2. Methods

2.1. Subjects

This study evaluated 15 healthy young adults without any disease and/or current illnesses that would affect walking [mean $\pm$ standard deviation (SD) age, 22.5 ± 1.5 years; height, 1.65 ± 0.1 m; mass, 58.5 ± 10.1 kg; and body mass index, 21.3 ± 2.1 kg/m^2]. Foot alignment measurements were conducted on both feet for all subjects using the foot posture index (FPI), a six-item foot posture assessment performed with the subject standing and relaxed in the bipedal position [19]. According to a previous study [17], all feet were categorized into three groups as follows: normal foot (total score between +2 and +6), pronated foot (total score between +7 and +12), and supinated foot (total score between -12 and +1). This study was approved by the Ethics Committee of the Division of Physical Therapy and Occupational Therapy Sciences, Graduate School of Health Sciences, Hiroshima University (No. 1445). The intent and purpose of this study was explained to all participants, and informed consent was obtained prior to their participation.

2.2. Instrumentation

A three-dimensional motion analysis system that included six infrared cameras (VICON MX; Vicon Motion Systems, Oxford, UK) and eight force plates (Tec Gihan, Uji, Japan) was used to record the kinematic and kinetic data during walking at a sampling frequency of 100 Hz. Kinematic and kinetic data were low-pass filtered with a fourth-order Butterworth filter and cutoff frequencies of 6 and 15 Hz, respectively.

Prior to measurement, a total of 48 reflective markers were attached to the following landmarks on both sides of each subject: the temple, lateral end of the superior nuchal line, tragus, acromion, olecranon, ulnar styloid process, superior edge of the iliac crest, anterior superior iliac spine, posterior superior iliac spine, superior aspect of the greater trochanter, medial and lateral epicondyles of the femur, midpoint between the greater trochanter and the lateral epicondyle of the femur, medial and lateral tibial condyles, medial and lateral malleoli, midpoint between the lateral knee joint line and the lateral malleolus, posterior distal aspect of the calcaneus, posterior proximal aspect of the calcaneus, lateral calcaneus, sustentaculum tali, and the head of the first and fifth metatarsals. These anatomical markers were used to construct anatomical coordinate systems for the head, trunk, pelvis, thigh, shank, foot and heel segments. In addition, a marker was attached to the right scapula to distinguish between the right and left sides.

2.3. Procedures

This study involved a within-subject design where every subject was tested under two conditions: barefoot and wearing the LWI on a bare foot (LWI). The LWIs had base heights equal to that of the fifth metatarsal and were medially inclined, with the outside 7 mm thicker than the inside. The insoles were made of high-intensity silicon rubber (Nakamura Brace, Ohda, Japan), with a hardness of durometer type A (Shore A) 40 (Fig. 1). This silicon rubber has a 7-mm lateral elevation and a 75-mm width, which results in an approximately 5.3° inclination. The same products are used widely and generally in Japan and have also been reported previously [20,21]. Subjects were first asked to stand and then walk at their typical comfortable walking speed across a 10 m gait laboratory walkway. Measurements were performed during five successful trials for each condition. Prior to actual measurement, several practice trials were performed to ensure that participants walked naturally. The barefoot condition was performed first, following which the LWI condition was performed. To adapt LWIs, sufficient time was allotted before the LWI condition measurement. In the LWI condition, subjects walked across the walkway within a mean $\pm$ 5% of their walking speed under barefoot conditions. A pair of photoelectric timers (TM-02; Tamagawa Shop, Hiroshima, Japan) were used to monitor walking speed.

2.4. Data analysis

Data analyses were performed using BodyBuilder software (Vicon Motion Systems, Oxford, UK). The knee adduction moment and the coordinate of joint centers of the hip, knee, and ankle were calculated according to a previous study [22]. An eight-link segmental model was developed to calculate the hip, knee, and ankle kinematic and kinetic data using inverse dynamics according to the techniques described by Vaughan et al. [23]. Anthropometric parameters for mass, center of mass, and moment of inertia for each segment were obtained from a report by Okada et al. [24]. Additionally, the rear foot angle was also calculated as the heel segment relative to the shank segment in accordance with the Oxford Foot Model marker set [25]. A knee joint moment was calculated using the tibial coordinate system, with the origin in the knee joint center. Primary outcome variables of interest at the knee were the peak KAM and KAM impulse (calculated as the integral of the stance phase of the non-time normalized KAM curve, KAAI). The peak KAM was extracted during early stance (from the initial contact to 50% of stance). The peak KAM and KAAI were normalized to the subject's body mass (Nm/kg and Nm/kg·s, respectively). Furthermore, a knee-ground reaction force lever arm (KLA) and the position of the center of pressure in relation to the foot (COP offset) were both calculated at time of the peak KAM based on a report by Hinman et al. [13]. In this study, the COP offset was defined as distance of the COP from the line of the foot (calcaneus to the