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Full Length Article

Sex differences in three-dimensional talocrural and subtalar joint kinematics during stance phase in healthy young adults

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A R T I C L E I N F O

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A B S T R A C T

The ankle joint, including the talocrural and subtalar joints, plays an important role in human locomotion. Sex differences in walking patterns among young and old adults have been studied; however, little information exists on sex-based variations in talocrural and subtalar joint kinematics during walking. Thus, the purpose of this study was to investigate sex-based differences in the talocrural and subtalar joint kinematics during walking.

We obtained lateral fluoroscopic images from 10 male and 7 female healthy volunteers during stance phase, and determined the three-dimensional bone orientations using 3D-2D model-image registration techniques to compare sex-specific differences.

The orientation of the tibia, talus, and calcaneus were comparable in the static reference position. Sex-based differences in the range of motion were observed in talocrural dorsi/plantar flexion, subtalar eversion/inversion and subtalar external/internal rotation while walking. The ranges of motion in talocrural dorsi/plantar flexion (male, 13 ± 4°; female, 17 ± 3°), subtalar eversion/inversion (male, 8 ± 3°; female, 11 ± 3°) and subtalar external/internal rotation (male, 5 ± 2°; female, 7 ± 2°) were significantly larger in females than in males.

Differences in rearfoot kinematics between males and females may reflect anatomic, physiologic and locomotor differences. Greater bone rotations in the female hindfoot may predispose women to different pathologies, or merit different treatments, than men based upon subtalar and talocrural kinematics during gait.

1. Introduction

The synergistic movement of the ankle joint, including the talocrural and subtalar joints, is crucial for human locomotion. Walking is an essential daily activity that habitually loads the joints of the lower extremities and likely contributes to the development and progression of joint degeneration such as osteoarthritis. Therefore, accurate knowledge of the kinematics during walking can contribute to understanding of the etiology of lower extremity joint degeneration.

Sex differences in walking patterns and ankle motion among young and old adults have been reported. Young healthy females tended to have shorter stride length, slower gait speed (Cho, Park, & Kwon, 2004), and greater ankle flexion/extension range of motion (ROM) (Bruening, Frimenko, Goodyear, Bowden, & Fullenkamp, 2015) compared to healthy young men while walking at self-

Abbreviations: ROM, Range of motion; BMI, Body mass index; ANOVA, Analysis of variance; CT, Computed tomography; ICC, Interclass correlation coefficient

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selected speeds; additionally, elderly women walked with less hip ROM and greater ankle ROM than elderly men (Boyer, Beaupre, & Andriacchi, 2008; Ko, Tolea, Hausdorff, & Ferrucci, 2011), and adult females ranging from 23 to 62 years old had more plantar flexion at toe-off and early swing than males (Roislien et al., 2009). Despite this knowledge of sex-based kinematic differences in gross motion while walking, it is unknown whether sex-based differences exist specifically in talocrural and subtalar joint kinematics during walking. Sex-based differences in walking mechanics could lead to differences in the occurrence of certain diseases and/or degeneration related to aging (Boyer et al., 2008). For example, ankle osteoarthritis is more frequent in males than in females (Cushnaghan & Dieppe, 1991; Koepp et al., 1999). Deeper understanding of such sex differences might offer insight into the design of interventions to maintain normal gait or prevent mobility limitations (Ko et al., 2011). Thus, we hypothesized that sex-based variations in talocrural and subtalar joint kinematics exist during walking.

3D-2D model image registration techniques have been used to evaluate *in vivo* ankle kinematics in recent years (Campbell, Wilson, LaPrade, & Clanton, 2014; de Asla, Wan, Rubash, & Li, 2006; Fukano, Kuroyanagi, Fukubayashi, & Banks, 2014; Yamaguchi, Sasho, Kato, Kuroyanagi, & Banks, 2009), and an advantage of this method is its ability to describe talocrural and subtalar joint kinematics separately without artifacts produced by skin movement. Current motion analysis techniques using reflective skin markers on selected anatomical landmarks are unable to provide precise talocrural and subtalar joint kinematics due to artifacts produced by skin movement and the absence of palpable landmarks of the talus (Nester et al., 2007; Westblad, Hashimoto, Winson, Lundberg, & Arndt, 2002). Although the 3D-2D model image registration technique can provide good spatial accuracy, to the best of our knowledge, a detailed comparison between sexes of talocrural and subtalar joint movement during stance phase has not been reported.

Thus, the purpose of the present study was to investigate sex-based differences in the talocrural and subtalar joint kinematics during walking.

2. Methods

This study was approved by the Ethics Committees on Human Research of Waseda University, Tokyo, Japan. Written informed consent regarding the purposes and procedures of this study was obtained from each participant prior to their involvement.

Seventeen healthy volunteers, 10 males (age 21.2 ± 1.2 years; height 171.0 ± 5.6 cm; weight, 65.6 ± 5.8 kg) and 7 females (age 24.1 ± 3.0 years; height 160.3 ± 4.5 cm; weight, 55.7 ± 7.8 kg) participated in this study. Regarding the subjects' physical characteristics, the height and weight of the males were significantly greater than that of the females ($F = 3.09$ and 0.42 respectively, $p < .05$). Body mass index (BMI) (male, 22.4 ± 1.2; females, 21.7 ± 2.5) was comparable between sexes. All subjects were free of lower extremity and lower back pain and had no history of serious injuries or any operative treatment, and no subjective symptoms interfering with sport activities. When we conducted this experiment, each individual was participating in various recreational sports activities two or three times per week. We planned this study using repeated measures ANOVA to test between-within interactions. A sample size calculation based on prior normally distributed data indicated that a total of 16 participants were required to reject the null hypothesis (effect size = 0.25, $p < 0.05$, power = 0.9, number of groups = 2).

The participants were required to perform one gait cycle task (pace, 60 steps/min; stride, self-defined) on their right foot on a raised walkway with a fluoroscopic C-arm (Fig. 1). Participants prepared themselves by standing upright on the walkway and striding forward on their right foot. Each participant was instructed in the proper walking technique and required to practice beforehand. The static reference position, standing on the right leg, was obtained before the trial for each subject. The participants wore radiation shielding coats (Magical light, Maeda & Co., Ltd., Tokyo, Japan; lead equivalent: 0.25 mmPb) during trial and computed tomography scanning.

Each trial was recorded using flat-panel lateral fluoroscopy (Infinix Celeve™-i INFX-8000C; Toshiba Medical Systems Corporation, Tochigi, Japan). Ankle images during one gait cycle were obtained at a rate of 60 Hz, with 1 ms X-ray pulses (200 mA, 50 kV, 512 × 512 pixel images, 0.004 mGy/frame).

Participants underwent computed tomography (CT) scanning from 15 cm proximal to the lateral malleolus to the plantar surface, with overlapping slices with a thickness of 0.4 mm (200 mA/slice, 120 kV, 512 × 512 pixel images, CTDI 15.5 mGy) (IDT 16; Philips,

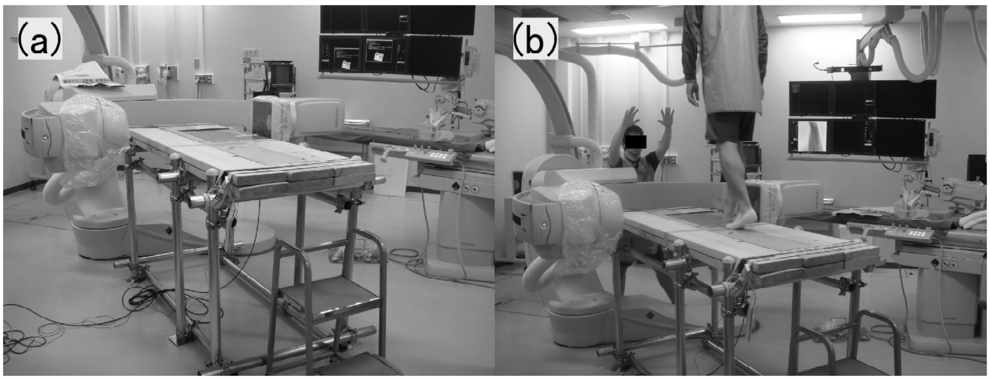

Fig. 1. Experimental set-up of the fluoroscopy system and walkway (a) and the participants walking (b).