QUANTITATIVE ASSESSMENT OF MECHANICAL ANKLE LAXITY AND RELATIONSHIP WITH TALOCRURAL AND SUBTALAR JOINT RANGE OF MOTION IN STANCE PHASE OF WALKING

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The purpose of this study was to examine the relationship between ankle joint laxity and talocrural and subtalar joint kinematics in healthy people. We obtained lateral fluoroscopic images from six healthy male volunteers during walking stance phase. Three-dimensional bone positions were determined using 3D-2D model image registration technique. Ankle laxity was measured using instrumented arthrometry. The arthrometry mesurements of anteroposterior displacement and eversion had strong correlation with the range of motion of subtalar eversion/inversion. The quantitative measurement by ankle arthrometry is important in understanding the nature of ankle laxity. Further research is needed to examine the linkage of joint laxity and abnormal kinematics for chronic ankle instability.

KEYWORDS: ankle joint, joint stability, kinematics, walk

INTRODUCTION: Ankle sprains are most prevalent injuries in sports and recreation (Fong, Hong, Chan, Yung, & Chan, 2007; Waterman, Belmont, Cameron, Deberardino, & Owens, 2010) with 0.47 – 35.9 sprains per 1000 exposures (Doherty et al., 2014; Hootman, Dick, & Agel, 2007) and characterized the high recurrent rates (Swenson, Collins, Fields, & Comstock, 2013; Yeung, Chan, So, & Yuan, 1994) among muscle skeletal injuries of lower extremity.
The increased ankle joint laxity from rupture or lengthening the ligamentous strictures by ankle sprain is possible to leads to abnormal joint kinematics. Several authors have reported that ankles with CAI showed increased displacement in anteroposterior displacement (Hubbard, 2008; Hubbard, Kaminski, Vander Griend, & Kovaleski, 2004) and inversion rotation (Hubbard, 2008; Kovaleski et al., 2014) compared to ankles without instability. Although the linkage of joint laxity and abnormal kinematics on ankle joint after repetitive ankle sprains have been suggested, the relationship between the laxity and kinematics is still unclear. Therefore, before clinical use, relationship between ankle joint laxity and kinematics must be documented.
The purpose of our study was to examine the relationship between ankle joint laxity and talocrural and subtalar joint kinematics in healthy people.

METHODS: This study was approved by the local institutional review board. Written informed consent regarding the purposes and procedures of this study was obtained from each participant prior to their involvement. Six healthy males (age 22.8 ± 1.1 years; 175.8 ± 5.3 cm; 69.0 ± 6.0 kg) participated in this study. All participants did not have experience of ankle sprain and were free from back and lower extremity pain, a history of serious injuries or any operative treatment and any subjective symptoms interfering sport activities.
The participants performed one gait cycle task (pace, 60 steps/min; stride, 40 cm) on their right foot on a customized walkway with a fluoroscopic C-arm. The static reference position, standing on the right foot was obtained before the trial for each subject. Trials were recorded using flat-panel lateral fluoroscopy (Infinix Celeve^{TM}-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 a slice thickness of 0.4 mm overlapping (200 mA/slice, 120 kV, 512 × 512 pixel images, CTDI 15.5 mGy) (IDT 16; Philips, Amsterdam,

Netherlands). Three-dimensional bone surface models of the tibia, talus, and calcaneus were created from the CT images using open-source segmentation software (ITK-SNAP).
In vivo three-dimensional position and orientation of each bone model was determined from the lateral fluoroscopic images and bone models using 3D-2D model-based registration technique (Banks & Hodge, 2004) (JointTrack, http://sourceforge.net/progects/jointtrack/) between the time of heel contact and toe off. The created bone models were projected onto the fluoroscopic images and precisely matched, frame-by-frame, until the silhouette of the projected bone models matched the osseous counter in the fluoroscopic images (Figure 1).
Instrumented measurement of ankle joint laxity was performed using a portable ankle arthrometer (Ankle Arthrometer, Blue Bay Research, Inc., FL, USA) that measure anteroposterior (AP) displacement and inversion-eversion (IE) rotation while load applying for ankles of all participants. For AP displacement, the ankles were loaded to 125 N of anterior and posterior force and the displacement was defined as anterior/posterior laxity in millimeters). For I-E rotation, the ankles were loaded to 4 N·m with inversion and eversion torque at 0° of dorsi/plantar flexion of ankle joint and the rotation was defined inversion/eversion rotation (degrees).
All statistical analyses were conducted using statistical software (IBM SPSS Statistics ver. 24, IL, USA). The correlations between the ankle laxity and the range of motion (ROM) of the talocrural and subtalar joints were statistically evaluated using Pearson correlation test. The significance was set at $p < 0.05$. The data were described as mean ± standard deviations.

Figure 1. Fluoroscopic image with 3D bone models.

RESULTS: Table 1 shows the ankle joint laxity of the subjects. Table 2 demonstrates the relationship between ankle laxity and the ROM of the talocrural and subtalar joint of the stance phase. The laxity of the anteroposterior and eversion had strong correlations with subtalar eversion/inversion.

Table 1. Ankle joint laxity of healthy people.

Variable	Mean	(SD)
anterior (mm)	8.6	2.4
posterior (mm)	6.5	1.0
ante-posterior (mm)	15.1	2.8
inversion (°)	21.5	5.3
eversion (°)	15.0	5.8
inversion-eversion (°)	36.5	8.9

Table 2. Relationship between ankle laxity and the ROM of the talocrural and subtalar joint of the walking stance phase.

Joint	Talocrural Joint		
Laxity	dorsi/plantar flexion	eversion/inversion	external/internal rotation
anterior	*p = 0.82*	*p = 0.66*	*p = 0.85*
posterior	*p = 0.11*	*p = 0.16*	*p = 0.68*
anteroposterior	*p = 0.74*	*p = 0.86*	*p = 0.77*
inversion	*p = 0.34*	*p = 0.77*	*p = 0.41*
eversion	*p = 0.62*	*p = 0.20*	*p = 0.40*
in-eversion	*p = 0.48*	*p = 0.32*	*p = 0.30*
Joint	**Subtalr joint**		
anterior	*p = 0.88*	*p = 0.13*	*p = 0.95*
posterior	*p = 0.39*	*p = 0.15*	*p = 0.56*
anteroposterior	*p = 0.57*	*p = 0.030* r = 0.755*	*p = 0.80*
inversion	*p = 0.24*	*p = 0.15*	*p = 0.66*
eversion	*p = 0.26*	*p = 0.019* r = 0.798*	*P = 0.35*
in-eversion	*p = 0.16*	*p = 0.86*	*p = 0.36*

DISCUSSION: We investigated the relationship between the ankle laxity and ROM of the talocrural and subtalar joints of stance phase in healthy volunteers. The anteroposterior and eversion laxity showed strong correlations with subtalar eversion/inversion.

The ankle arthrometer used in this study was developed as a measurement tool to provide objective and quantifiable assessment of ankle joint laxity; representing the sum of the motions occurring in the talocrural and subtalar joints. In this study, correlation between anteroposterior and eversion laxity and the ROM of subtalar eversion/inversion were observed. This result suggests that the movement at the subtalar joint was regulated structural stability. Ringleb et al. reported that the interosseous ligament was the greatest contributor to subtalar joint stability (Ringleb SI et al. 2011). On the other hand, the movement of the talocrural joint could be controlled by not only structural but neuromuscular system. Tricia et al. reported that anterior and AP displacement in functional unstable ankles by measurements same type of ankle arthrometer were significantly greater when compared with the uninjured ankle (Hubbard TJ et al. 2004). Further study is needed to examine the effect of ankle instability by comparing amount of ankle laxity and ROM of talocrural and subtalar kinematics while walking between healthy and unstable ankles.

This study has several limitations. First, we assumed a single gait cycle is representative of overground gait. Therefore, in this study, the measured walking speed was slower than actual daily walking. Second, the use of the 3D-2D model-based registration technique using single-plane fluoroscopy has much greater uncertainty for out-of-plane (i.e, mediolateral) translation, whereas the registration technique using biplane fluoroscopy has more uniform errors.

These data contribute to the quantitative understanding of the relationship between ankle joint laxity and the ROM of talocrural and subtalar joint while walking stance phase in healthy volunteers and can be used for comparison with data obtained from people with chronic ankle instability.

CONCLUSION: This study investigated the relationship between the ankle laxity and ROM of the talocrural and subtalar joint of stance phase in healthy volunteers and demonstrated anteroposterior and eversion laxity showed strong correlations with subtalar eversion/inversion. This result suggests that the movement at the subtalar joint was regulated structural stability on the other hand, the movement of the talocrural joint could be controlled by not only structural but neuromuscular system. The data contribute to the quantitative understanding of the relationship between ankle joint laxity and the ROM of talocrural and subtalar joint while walking stance phase in healthy volunteers and can be used for comparison with data obtained from people with chronic ankle instability.

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ACKNOWLEDGEMENTS: This work was supported by the JSPS KAKENHI, Grant Number 26870640 (Grant-in-Aid for Young Scientists (B)).