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KINEMATICS OF FOOT-SHANK COMPLEX IN "*KENDO*" AND ITS RELATIONSHIP WITH FOOT ARCH HEIGHT

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The purpose of this study was to demonstrate 1) the joint couple of foot-shank complex in the kendo motion and 2) the relationship between the kinematic values and the foot arch height. Seventeen experienced kendo athletes volunteered to participate in the study. We instructed the participants to perform three sets of kendo strike-thrust motion with the distance of 2.2m to the target. We obtained joint kinematic data of the foot eversion-inversion and shank rotation angles to the foot during the single support phase of the kendo motion. Our result demonstrated that the foot inversion and shank external rotation movements occur during the single stance phase in experienced kendo athletes in good health. In addition, the foot arch height –length ratio was significantly related to the total range of shank rotation to the foot.

KEY WORDS: lower extremity, sword fighting, motion analysis, joint couple

INTRODUCTION: Kendo, a Japanese martial art of sword fighting, is generally believed to be a low-risk sport; however, previous studies reported relatively high incidence of acute/chronic injuries on the left side of the lower extremity in kendo athletes. Regardless of their dominant side, most of the kendo athletes place their left foot behind their right foot in the straight line while holding a bamboo sword with both hands as the preparatory posture, and then they execute repetitive strike-thrust motions against a specific part of an opponent's body with forward-backward steps. During the motion, the main power source always lies on the left side of the lower extremity. Therefore, the bilateral difference of the injury occurrence appears to be associated with the characteristic of the kendo motion. However, few studies have addressed the risk of the injury occurrence in kendo in terms of joint biomechanics.
Previous studies indicate that the joint couple between foot eversion-inversion and shank (tibial) rotation may be greatly involved in the injury occurrence of the lower extremity in the running motion. It has also been reported that the foot structure such as foot arch height was related to the joint couple (Nawoczenski et al, 1998). These previous findings made us focus on the foot-shank kinematics of the left side of the lower extremity in the kendo motion and the effect of foot structure.
The objectives of this study were to demonstrate the joint kinematics of foot-shank complex in the kendo strike-thrust motion and determine its relationship with the foot structure. The result of our study will help us advance the injury prevention research in kendo athletes.

METHODS: Seventeen male collegiate kendo athletes (mean±SD age 20.3±0.7 y; height 1.71±0.02 m; weight 71.7±3.0 kg; years of kendo experience 11.2±2.1 y) participated in the study. The participants had to be without any history or current symptom of significant injury in the lower extremity. Prior to the participation, all the participants submitted informed consents in writing. The study protocol was approved by the university.
An experienced athletic trainer measured the foot length and the perpendicular distance between navicular bone of the foot and the floor as a foot arch height. We then calculated the ratio of the foot arch height to the foot length for normalization (foot arch height – length ratio).
We had a set of twenty-nine markers put on bony landmarks of the participant to define individual body segments and their three-dimensional motion in the working space. Seven segments of the lower limbs were determined as the anterior superior iliac spines, sacrum, thighs, shins, ankles, toes, and heel markers.

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The experimental protocol included three sets of the kendo strike-thrust motion at a distance of 2.2 m. The participant executed the kendo strike-thrust motion with a single forward step toward the target object at their maximum effort (Figure1).

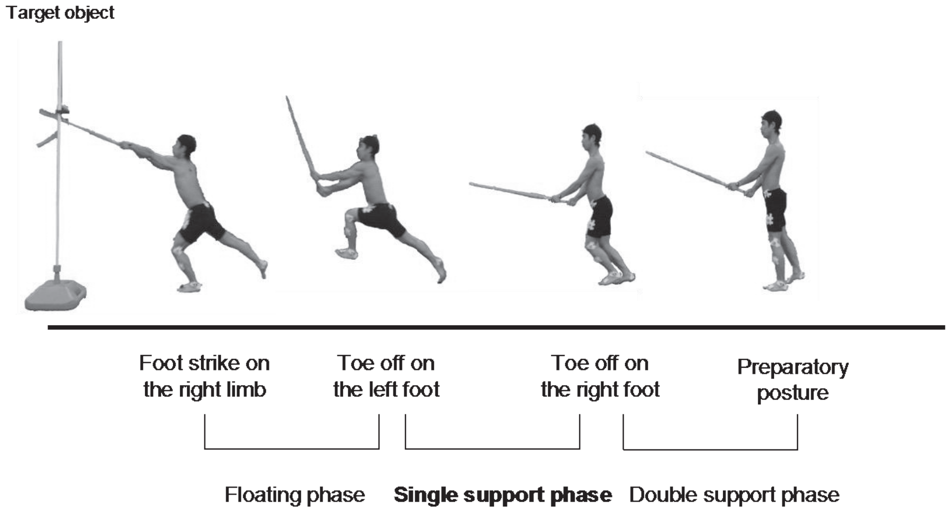

Figure 1: The phase of Kendo strike-thrust motion

We obtained the three-dimensional (3D) marker trajectory data of the kendo strike-thrust motion (150Hz) with an eight-camera of Mac3D motion analysis system (Motion analysis Corp., Santa Rosa, CA, USA). The marker trajectory data were then low pass filtered with the Butterworth filter at a 6 Hz cut off frequency. The joint angles of the left foot eversion-inversion and shank rotation to the foot during the single leg support phase were computed. The kinematic data were then normalized into 100 frames and were averaged to yield representative values. We also computed the total range of motion (ROM) of the foot eversion-inversion and shank rotation during the single support phase. The ROMs of the foot eversion-inversion and the shank rotation were defined as the difference between each of the peak values.
We used Pearson product coefficient to demonstrate the correlation between the foot eversion-inversion ROM and the shank rotation ROM as well as between the arch height index and the kinematic values of the foot-shank complex in the kendo motion ($p<0.05$)

RESULTS AND DISCUSSION: Mean (SD) values of the foot arch height–length ratio were 14.4(1.8), the shank rotation ROM 17.2°(5.9), and the foot eversion-inversion ROM 12.6 ° (6.2).
Figure 2 illustrated that the representative joint angle curves of the foot eversion-inversion and the shank rotation during the single support phase of the kendo strike-thrust motion. Based on the visual observation of the curve, the movements of foot inversion and shank external rotation to the foot was occurring during the single support phase. Unlike in the running motion, there may have been no or few, if any, foot eversion and shank internal rotation movements occurring during weight loading in the kendo motion.
Figure 3 illustrated that the individual participant data indicated the coupled relationship between the foot eversion-inversion ROM and the shank rotation ROM. There was medium but statistically significant relationship between the two variables (r=0.56, $p<0.05$).
Our result also demonstrated that the foot arch height-length ratio was significantly correlated to the ROM of the shank rotation (r=0.54, $p<0.05$) (Figure4), but not to the ROM of the foot eversion-inversion. The current result indicates that the participant who has high arch height

relative to their foot length will show the greater ROM of the shank rotation in the kendo motion.

Kishi et al (2000) reported that all the injured kendo athletes in the low foot-arch height group showed knee-in & toe-out alignment (the combined alignment with hip internal rotation, knee valugs, and toe abduction), and relatively large movements of rearfoot eversion and forefoot pronation occurred simultaneously. However, because our participants were injury-free at the time of the experiment, we were not able to conclude whether the foot-shank joint motion and the relationships with the foot structure would characterize the injury-prone kendo athletes. Further study is necessary to elucidate the direct correlation between the foot structure, the joint couple and the injury occurrence in kendo. Foot structure and function seem very important in executing high-performance kendo motion. Especially, the degree of foot rigidity may be crucial in transferring the ground reaction force and in driving them towards the target efficiently. Apart from the respect to the performance, we need to discuss its importance for the injury prevention because the too-rigid or too-soft foot may alter the joint couple of foot-shank complex. In future study, we also need to use the entire foot not as a single segment but as multiple segments distinguishing the forefoot and midfoot movements from the rearfoot movements in the kendo motion.

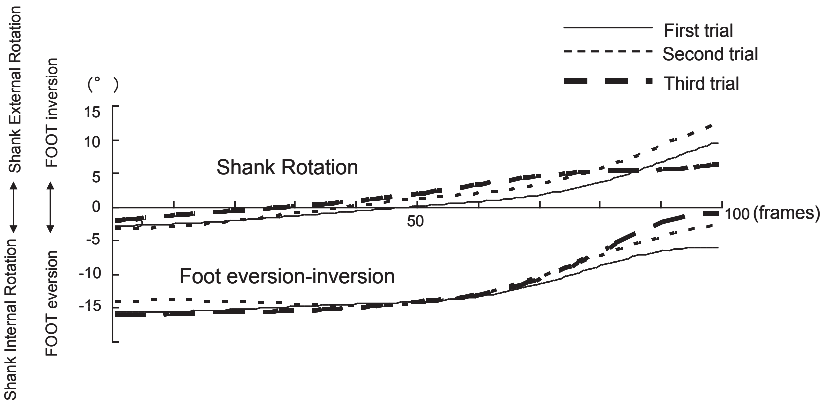

Figure 2: The representative data of foot eversion-inversion and shank rotation during the single support phase in the kendo strike-thrust motion

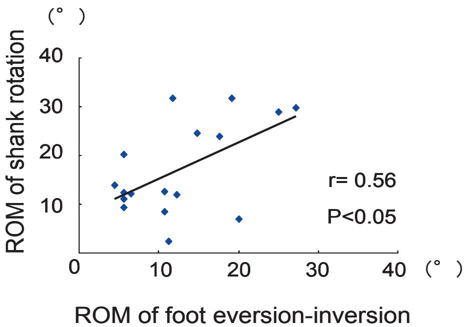

Figure 3: Individual participant data for joint coupling of foot eversion-inverstion and shank rotation (N=17)

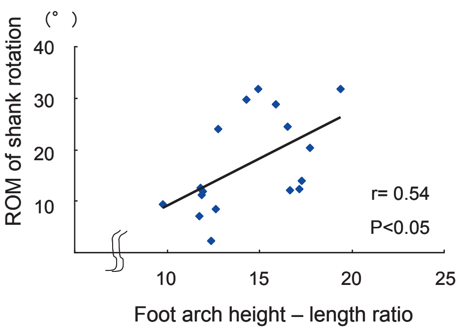

Figure 4: The scatter diagram of the ROM of shank rotation and the foot arch height-length ratio (N=17)

CONCLUSION: Our study showed that total range of the foot eversion-inversion and the shank rotation were correlated during the single support phase in the kendo strike-thrust motion. In addition, the foot arch height was also correlated to the total range of the shank rotation movement in the kendo motion.

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