EFFECTS OF SHOD AND BAREFOOT RUNNING ON THE IN VIVO KINEMATICS OF THE FIRST METATARSOPHALANGEAL JOINT

Faning Zhang[1], Dongqiang Ye[1], Wanyan Su[1], Xiaole Sun[1], Weijie Fu[1]

School of Kinesiology, Shanghai University of Sport, Shanghai 200438, China

The purpose of this study is to investigate the differences of the first metatarsophalangeal joint's 6 degree-of-freedom (6DOF) kinematics during shod and barefoot conditions by using a high-speed dual fluoroscopic imaging system (DFIS). Fifteen healthy male runners were recruited. Computed tomography (CT) scans were taken of each participant's right foot for the construction of 3D models and local coordinate system. The fluoroscopic images of the right foot during the stance period were acquired under shod and barefoot condition with rearfoot strike pattern Radiographic images were acquired at 100 Hz while the participants ran at a speed of 3±5% m/s in a track and 6DOF kinematics were calculated by 2D-3D registration. Paired sample t-test was used to compare the kinematic characteristics of the first MTPJ 6DOF kinematics between shod and barefoot. Compared with barefoot, wearing shoes 1) decreased the peak medial, posterior, and superior translation of the first MTPJ during stance ($P < 0.05$); 2) decreased maximum extension angle, minimum extension angle, and flexion/extension range of motion of the first MTPJ during stance ($P < 0.05$); 3) increased minimum adduction angle of the first MTPJ during stance ($P < 0.05$). It suggests that shoes may affect the function of the first MTPJ and increase the risk of hallux valgus. Our study makes up for the deficiency of traditional motion measurement methods that only focus on the sagittal flexion and extension movement of the first MTPJ and provides a more comprehensive understanding of the potential relationship between joint motion and injuries

KEYWORDS: dual fluoroscopic imaging system, shoe-wearing, barefoot, first metatarsophalangeal joint, in-vivo kinematics.

INTRODUCTION: Shoes are primarily used to protect the foot from injuries and improve running performance (Wolf et al., 2008). In the shod condition, the foot and shoe act together to modulate the mechanical function of the first metatarsophalangeal joint (MTPJ). In other words, the function of the first MTPJ is influenced by the shoe properties. (Fu et al., 2013). Previous studies have shown that while footwear can ameliorate the function of the first MTPJ (Menz et al., 2016), it may also disturb its normal structure (Yu et al., 2020). The technical deficiencies of traditional motion capture systems based on the reflective markers limit the studies on in vivo foot biomechanics. The dual fluoroscopic imaging system (DFIS) has enabled accurate and noninvasive measurements of the dynamic motion in the joints of the body and is not affected by the relative movement of soft tissue. It can effectively make up for the defects of traditional measurement methods and has been applied in the field of clinical medicine and biomechanics (Ye et al., 2021).
Therefore, the purpose of this study is to investigate the six degrees of freedom (6 DOF) kinematic difference of the first MTPJ between shod and barefoot conditions by using the high-speed dual fluoroscopic imaging system to clarify the potential relationships between foot movement and injuries.

METHODS: 15 healthy male runners (age 30.9 ± 7.3yrs, height 172.7 ± 4.4cm, weight 70.3 ± 8.4) were recruited. All participants were habitual rear-foot strike runners, running more than 20km per week, and with no lower limb injuries in the past 6 months. Computed tomography (CT) scans were taken of each participant's right foot for the construction of 3D models and local coordinate system (Welte et al.,2021). The fluoroscopic images of the right foot during the stance period were acquired under wearing shoes (traditional footwear, heel-to-toe drop: 6 mm; midsole material: TPU, EVA; upper structure: textile fabric; toe box: width, 11cm, depth, 8cm, height, 3cm, size, 9; without any arch support) and barefoot condition with rearfoot strike pattern Radiographic images were acquired at 100 Hz while the participants ran at a speed of 3 m/s ± 5% in a track. The kinematics results of the first MTPJ in those two conditions were calculated by 3D–2D registration. The first proximal phalanx translates with respect to the first metatarsal represented the translation of the first MTPJ. Experimental parameters included the first MTPJ 6DOF kinematics, peak angle, and range of motion (ROM). Paired sample T-test was used to compare the kinematic characteristics of the first MTPJ 6DOF kinematics between shod and barefoot. The significance level was set to 0.05.

RESULTS:

1. Joint translation: compare with barefoot, in shod condition the, first MTPJ 1) translated less inferiorly at 50% of the stance ($P = 0.032$); 2) translated less superiorly at 90% and 100% of the stance ($P = 0.014$, $P = 0.007$); 3) translated less anteriorly at 20%, 60%, and less posteriorly at 90%, and 100% of the stance ($P < 0.05$) (figure 1). And the peak medial ($P = 0.039$), posterior ($P < 0.001$), superior translation ($P = 0.043$), anterior to posterior ROM ($P = 0.002$), and superior to inferior ROM ($P<0.001$) in shoe-wearing were significantly smaller than barefoot (figure 2).
2. Joint rotation: Compared with barefoot, in shod condition the first MTPJ's 1) extension angle was larger at 30%, 40%, 50%, and 60% of the stance ($P < 0.05$), but smaller at 90% and 100% of the stance ($P < 0.05$); 2) adduction angle was larger at 10%, 20%, 50%, and 60% of the stance ($P < 0.05$); 3) maximum extension of the first MTPJ was smaller ($P<0.001$); 4) minimum extension ($P = 0.009$), and minimum adduction angle were significantly larger ($P = 0.009$); 5) flexion/extension ROM was significantly smaller ($P < 0.001$)(figure 2).

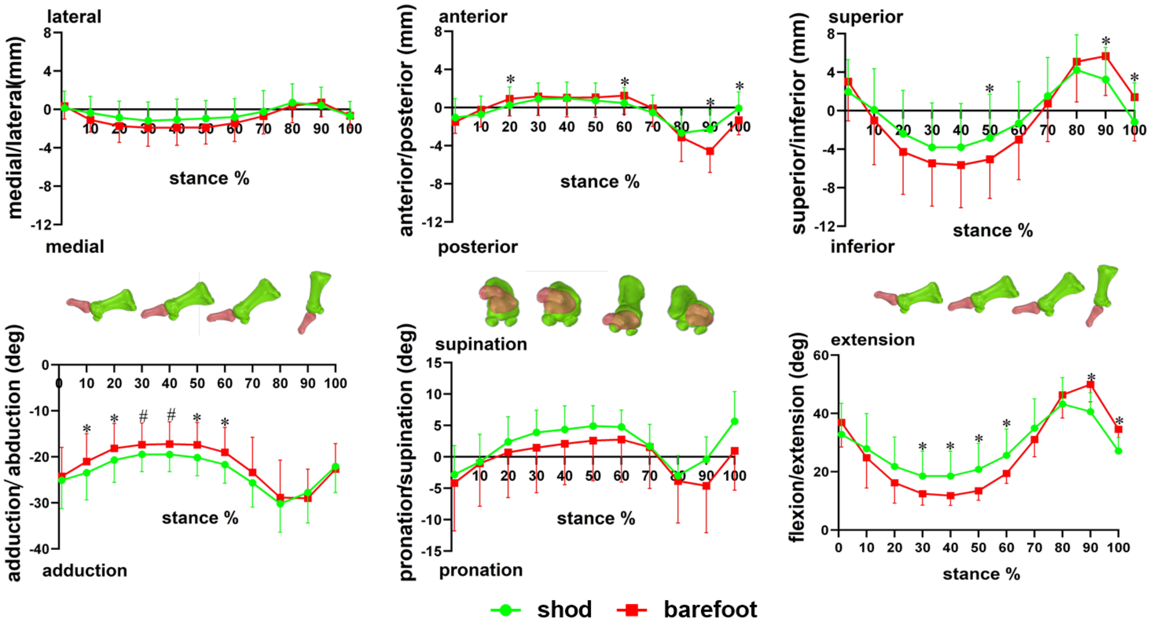

Figure 1 6DOF of the first MTPJ during stance

*: compared to barefoot, there are significant differences in shoe-wearing, $P < 0.05$, the same below

#: compared to barefoot, there is a different trend in shoe-wearing, $P < 0.1$

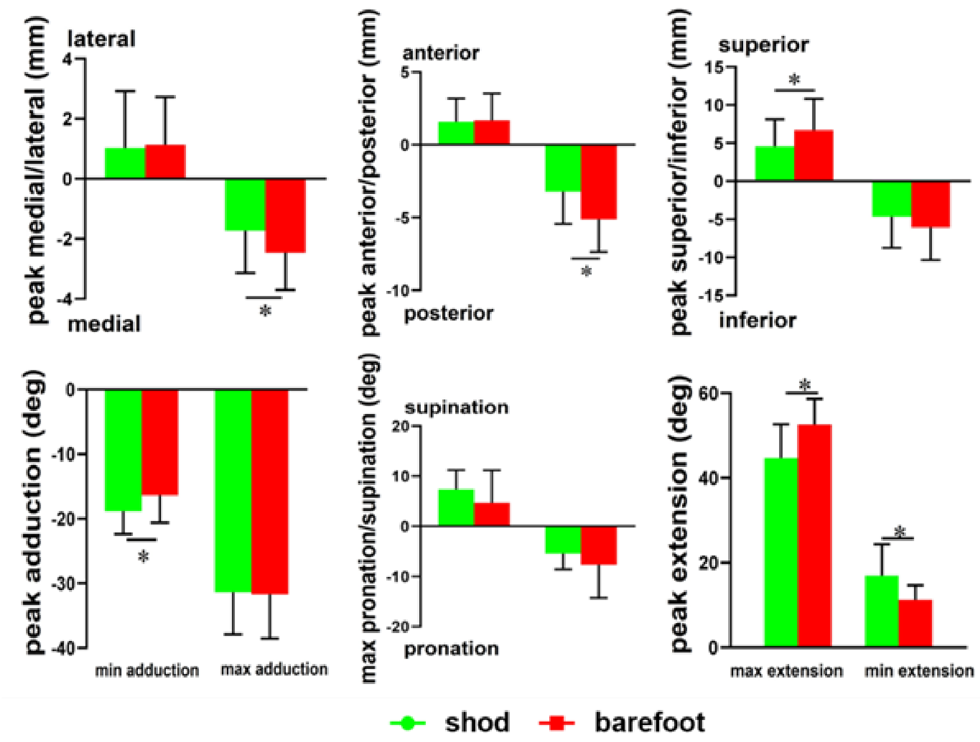

Figure 2 peak angle of first MTPJ in shoe-wearing and barefoot

DISCUSSION: Our study found that in joint translation, the peak medial, posterior, and superior excursion is significantly reduced in shoe-wearing; in joint rotation, shoe-wearing limited the extension of the first MTPJ, including the maximum extension angle, the minimum extension angle, and the flexion/extension ROM, while increasing the adduction angle during stance.
Specifically, flexion and extension of the first MTPJ in the sagittal plane were significantly reduced in shod conditions, which was consistent with previous studies (Lin et al., 2013; Wegener et al., 2015). But the minimum and maximum extension angles during the support period were larger than those in previous studies using traditional motion capture. Midfoot plantarflexion, primarily the first metatarsal, during propulsion is believed to occur due to the windlass mechanism ((Carlson et al., 2000; Wegener et al., 2015). The larger EX angle in the current study might be the result of the plantarflexion of the first metatarsal. However, traditional motion capture methods cannot easily detect the in-vivo motion of the first metatarsal, thus failing to obtain the most accurate motion of the first MTPJ. In addition, the EX of the first MTPJ plays an important role in calculating joint dynamics, and the underestimation of FL/EX activity by traditional motion capture methods may have affected the joint dynamic results of previous studies. However, the current research based on high-speed DFIS is still at an early stage. Moreover, we did not calculate the dynamics in this study. Therefore, future studies should compare the differences in the dynamic results of the first MTPJ obtained by DFIS and other motion capture methods.
The adduction angle of the first MTPJ in shoe-wearing was significantly larger than barefoot. Yu et al. (2020) used finite element simulation to find that with the increase of adduction angle of the first MTPJ, the stress on the medial joint capsule increased, and the stress on the medial joint capsule in shoe-wearing was significantly higher than barefoot. The footwear protects the foot from external injuries, but the narrow toe box not only limits first MTPJ's movement but also potentially accelerates the development and progression of hallux valgus.

CONCLUSION: By using a high-speed DFIS, the 6DOF kinematic difference of the first MTPJ in the whole stance was investigated, which provided a more accurate measurement method for studying the movement of the small joint of the foot. The results showed that shoe-wearing limited the extension and joint translation of the first MTPJ, suggesting that shoes could limit the push-off effect and ROM of the first MTPJ. Shoe-wearing increased the horizontal adduction angle which may increase the risk of hallux valgus. Our study provides a more comprehensive understanding of the first MTPJ motion characteristics during running and the potential relationship between joint motion and injuries. It suggests that the shoemaking should both take into account to raise the capacity of the forefoot movement and to lower the risk of injury.

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