In Vivo 3D Analysis of Flatfoot Deformity Using A Custom-made Loading Device

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Introduction: Precise understanding of the kinematics of the tarsal bones under the weightbearing is important to reveal and treat foot and ankle disorders. Three-dimensional (3D) cadaveric studies have reported the deformity associated with flatfoot is complex and occurs in multiple joints [1, 2]. While Ledoux performed partial weightbearing CT scans and measured in vivo 3D orientation of the tarsal bones [3], there has not been reported the in vivo 3D evaluation of tarsal bones using the global coordinate system [4]. We reported previously in vivo 3D analysis of the cervical and tarsal bones kinematics in flexion, neutral and extension positions [5, 6]. At the AOFAS summer meeting 2010, we reported the full-body-weightbearing loading device of the foot and verified its accuracy and reproducibility. The aim of this study was to apply the loading device and to quantify the in vivo 3D kinematics of the mid-hindfoot bones of flatfoot deformity preliminary.

Materials and Methods: All signed informed consent in the IRB approved study. CT scans of 10 normal feet (3 males and 2 females aged 28-44, mean 35.8 years) and 10 feet with flatfoot deformity (3 males and 2 females aged 20-68, mean 37.6 years) were used to construct a model of mid-hindfoot bones (tibia, talus, navicular, and calcaneus). The scans were performed using a custom-made loading device of the foot (Rakuhoku Prosthetic and Orthotic Manufacturing Co., Ltd, Kyoto, Japan) that held the hip in 50 degree flexion, the knee in 90 degree flexion, and the foot in neutral positions. Setting up the vice between the foot and the knee, the load value was monitored with the scales on the kneepad. Pressure was applied by the vice with full body-weight (Figure 1). The images of the mid-hindfoot bones were reconstructed into 3D model using CAD software (Mimics, Materialise Inc, Ann Arbor, MI) (Figure 2). The volume merge method in three planes was used for calculating the rotation and translation of the talus relative to the tibia in the tibiotalar joint; the navicular bone relative to the talus in talonavicular joint; the calcaneus relative to the talus in talarcalcanean joint [6]. The global x-y-z coordinate system was used to describe screw axis orientation and position [4]. The data was analyzed using an unpaired t-test.

Results: There were no complications about lower limbs in using the device. The relative bone position of the talus in flatfoot tended to be more dorsiflexed to the talus (normal foot: -1.5 ± 0.4 degree; flatfoot: -1.8 ± 0.7 degree) and more abducted (normal foot: -0.2 ± 0.7 degree; flatfoot: -1.0 ± 0.5 degree) (mean ± SEM), comparing with the one in normal foot. The relative bone position of the navicular in flatfoot tended to be more dorsiflexed to the talus (normal foot: 1.3 ± 0.5 degree; flatfoot: 2.4 ± 0.6 degree), more everted (normal foot: 2.1 ± 1.0 degree; flatfoot: 4.5 ± 1.0 degree) and more abducted (normal foot: 2.4 ± 1.5 degree; flatfoot: 3.8 ± 0.8 degree). The relative bone position of the calcaneus in flatfoot tended to be more dorsiflexed to the talus (normal foot: 0.9 ± 0.4 degree; flatfoot: 1.9 ± 0.5 degree), more everted (normal foot: 1.2 ± 0.7 degree; flatfoot: 3.1 ± 0.6 degree) and more abducted (normal foot: 0.9 ± 0.9 degree; flatfoot: 2.4 ± 0.6 degree) (Figure 3).

Discussion: As previous studies have reported, we demonstrated that the deformity associated with tarsal instability was complex. Kitaoka suggested in cadaveric flatfoot model that the average talar-to-tibial position significant difference was -8.2 ± 3.2 degree in dorsiflexion, and the navicular-to-talar position significant difference was 10.5 ± 6.6 degree in dorsiflexion, 8.1 ± 3.9 degree in eversion, and 13.6 ± 5.0 degree in abduction, and the calcaneal-to-talar position significant difference was 2.7 ± 2.0 degree in eversion, and 2.2 ± 2.6 degree in abduction, compared to normal foot [1]. Blackman also reported similar results [2]. Because the number of cases was small, the unstable part was different depending on the cases and there were stable tarsal bones in some flatfoot cases, we just showed the similar tendency of the deformity associated with flatfoot. Understanding pathologic condition of flatfoot was important for effective treatment. This method may help to evaluate the progression of the flatfoot deformity and to select a proper treatment procedure, including surgical interventions, as well as the timing for such procedures.