Analysis Of Mechanical Strength In Talus Using CT-osteoabsorptiometry; In Vivo Study

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Introduction: In clinical practice, the chondral degeneration and progression of osteoarthritis (OA) was diagnosed based on the loss of joint space in radiographs. The radiographic evaluation of OA was much used than magnetic resonance imaging (MRI). In the OA patients, the joint space width was decreased. The measurement of subchondral bone mineralization is of decisive importance in assessing the functional adaptation of bony tissue to various individual stresses. Previous study showed that local density of the spongy bone closely follows the distribution of the applied mechanical load in the photoelastic model. Muller-Gerbl developed CT-Osteoabsorptiometry (CT-OAM) as a reliable method for assessing the distribution of subchondral mineralization (1). Relationships between strength and subchondral bone density (SBD) of the human joint are known (2).
Contact area and intra-articular pressure in the ankle joint have mostly been studied using in vitro cadaveric ankle specimens and finite element models (3).

We have reported the in vivo 3D kinematics of tarsal bones in flatfoot using weight-bearing CT scanning. It is important to understand the kinematics of peritalar bones under the weight-bearing accurately in order to reveal and treat foot and ankle disorders. We think that CT-OAM is useful to evaluate the relation between the alteration of the intra-articular width and stress distribution, when we compared the SBD with and without loading. We hypothesized that the intra-articular width especially decreased at high concentrate area of stress distribution.
The purpose of this study was to measure the SBD of ankle joint surface using a novel 3D measurement method in vivo, and to compare the depth between with and without weightbearing.

Methods: Eighteen ankles of nine normal subjects between the ages of 21-44 years (4 males and 5 females) underwent ankle CT scans (IRB approved). The images were taken with 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 position. Setting up the vise between the foot and the knee, the load value was monitored with the scales on the kneepad. Pressure was applied with using the vise with full body-weight. The images of hindfoot bones were reconstructed into 3D model by using CAD software (Mimics, Materialise Inc, Ann Arbor, MI). CT-image data from tibia to talus were converted to point-cloud 3D models. SBD at each point of talus was calculated in Hounsfield Units (HU). Curved 3D ankle joint surface data were set on the talus joint surface and virtual layers parallel to the talus joint surface were analyzed in 0.5mm increments down to 3.0 mm depth.
The mean HU within the ankle joint surface at each depth was calculated and the depth of highest mean value was used. (Figure1)

Results: There were no complications about lower limbs with using the device.
SBD values for ankle surface without weightbearing were 231±79, 311±103, 449±183, 554±240, 589±251, 586±244, 573±233 HU at 0mm, 0.5mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm, 3.0mm deep from talus joint surface, respectively. SBD values for ankle surface with weightbearing were 480±209, 619±274, 673±288, 669±276, 646±259, 314±112, 226±80 HU at 0mm, 0.5mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm, 3.0mm deep from talus joint surface, respectively. The highest SBD with weightbearing were obtained at 1.0mm depth, and without weight bearing were obtained at 2.0mm depth.

**Discussion:** Distribution of mineralization in the subchondral bone plate of an articular surfaces reflects distribution of strain on that surface over an extended periods. Therefore, the mineralization of the subchondral plate is a morphological correlate of long-term strain on articular surface. CT-OAM can assess long-term stress distribution at individual joints in living subjects by measuring SBD. The theoretical background for this method is that subchondral bone mineralization functionally adapts to repeated and long-term changes in joint loading. Elucidation of mineralization patterns thus allows investigators to predict mechanical conditions in joints. The results obtained indicate alterations in stress distributions through the ankle joint in living subjects.

OA of the ankle with pain and limited range of motion is mostly occurred by post-traumatic origin such as ankle fractures and lateral ligament dysfunction. In primary OA of the ankle mostly shows varus deformity, thus the intra-articular width decreased at medial part. Recent study was able to show contact areas on both articular surfaces using dual fluoroscopic and magnetic resonance imaging techniques. That study showed that contact area was mainly distributed in lateral regions during the simulated stance phase of walking. However, Onodera et al. showed that SBD in the medial part was obviously higher than that in the lateral part (4). MRI study clarify aspects of total activity of daily life at just one time point, whereas their results reflect long-term physiological stress on the ankle, including walking stress. The cause of discrepancies between CT-OAM study results and MRI study results may be that CT-OAM reflects the dynamic stress pattern of a joint under long-term physiological conditions. Our study with normal subjects showed same results. We observed that the area of maximum density for subchondral bone across the articular surface of the tibia was located in the anteromedial part in most subjects. Therefore we observed that most highly SBD in weightbearing data was obtained in closer layer to articular surface than non-weightbearing data. We believed our data shows that stress concentration was increased in area of joint space narrowing especially. CT-OAM analysis may elucidate the pathology of primary OA of the ankle.

**Significance:** none
Figure: Distribution of Hounsfield unit of left talus

We observed that subchondral bone density in the medial part was obviously higher than that in the lateral part. (left: without weight bearing, right: with full weight bearing)