Relationship between degenerative change in the sesamoid-metatarsal joint and displacement of the sesamoids in patients with hallux valgus

Abstract

Background: To treat a patient with hallux valgus deformity, evaluating the congruency between the first metatarsal head and the sesamoids is important. Although tangential sesamoid view is used to visualize the sesamoid position relative to the first metatarsal head, correctly evaluating patients with advanced varus deformity of the first metatarsal is difficult. Computed tomography (CT) has a strong diagnostic power because it can show cross-sectional images in any plane. The purposes of this study were to evaluate the alignment of the tibial sesamoid and investigate the relationship between malalignment and degenerative change in the sesamoid metatarsal joint (SMJ) using simulated weight-bearing CT imaging in patients with hallux valgus.

Methods: The subjects included 269 feet from 142 patients with hallux valgus. The mean age was 63.7 years (range, 33–87 years). A dorsoplantar weight-bearing radiograph was taken, and the sesamoid position was divided into three grades (radiographic classification): grade 1, the tibial sesamoid is medial to the axis of the first metatarsal; grade 2, the tibial sesamoid exists below the first metatarsal axis; and grade 3, the tibial sesamoid exists lateral to the first metatarsal axis. The hallux valgus and intermetatarsal angles (HVA and IMA, respectively) were also investigated. CT coronal views of the forefoot were taken with the foot placed against a flat board, and pressure, equal to one third of the subject's weight, was applied to simulate weight bearing. The lateral shift of the tibial sesamoid relative to the first metatarsal was classified into three grades (CT classification): grade 1, cases wherein the tibial sesamoid is entirely medial to the intersesamoid ridge; grade 2, cases wherein the tibial sesamoid is subluxated laterally but located below the intersesamoid ridge; and grade 3, cases wherein the tibial sesamoid is located entirely lateral to the intersesamoid ridge. The differences of HVA and IMA in each grade were confirmed by using one-way analysis of variance with Bonferroni post-hoc corrections. Furthermore, a multiple linear regression analysis was used to predict the degenerative change in the SMJ for age, gender, sesamoid position determined by CT or plain radiography, HVA, and IMA. Chi-square test was used for descriptive statistics to analyze the agreement between radiography or CT classifications of sesamoid position against degenerative change in the SMJ.

Results: Based on the radiographic classification of the tibial sesamoid position, 7, 72, and 190 feet were classified as grades 1, 2, and 3, respectively. Based on the CT classification, 34, 116, and 119 feet were classified as grades 1, 2, and 3, respectively. Degenerative change in SMJ progressed according to the sesamoid shift relative to the first metatarsal evidenced by using either radiography or CT. In radiography, significant differences were recognized except for the difference in HVA between grades 1 and 2. In addition, significant differences were recognized between HVA and IMA, along with the grades in CT.

In multiple linear regression, degenerative change was correlated with age and sesamoid position in CT and radiographic classifications.

Conclusion: Our study showed that the lateral shift of the tibial sesamoid increased in association with progression of the hallux valgus deformity. Furthermore, increasing the lateral shift of the tibial sesamoid is suggested to be associated with worsening degenerative change within the SMJ.

Level of Evidence: Level III-Retrospective Comparative Study

Key word: sesamoid, hallux valgus, computed tomography

Introduction

Lateral displacement of the sesamoids has been reported to be strongly correlated with the severity of hallux valgus.[3,6] Okuda et al.[6] demonstrated that reduction of the sesamoids below the first metatarsal head could be an important component of hallux valgus surgery because postoperative incomplete reduction of the sesamoids may cause the hallux valgus deformity to recur. However, in some cases with bony erosion or degenerative change in the sesamoid metatarsal joint (SMJ), the sesamoids are unstable, and maintaining their position below the metatarsal head is difficult. Based on this knowledge, detailed assessment of the sesamoids is thought to be essential for choosing the appropriate treatment for hallux valgus.

The sesamoids of the first metatarsophalangeal (MTP) joint have several functions such as to absorb the majority of the weight of the first ray, to protect the tendon of the flexor hallucis longus, which courses over the rather exposed plantar surface of the first metatarsal head, and to help increase the mechanical advantage of the intrinsic musculature of the first ray.[2] The intersesamoid ridge, which is the ridge below the first metatarsal head, contributes to the intrinsic stability of the sesamoid complex.[2] However, when the sesamoids shift laterally, the intersesamoid ridge can erode. As a consequence of regression in the intersesamoid ridge, loss of stability in the SMJ may occur.

Hardy's classification[3] system was developed to assess displacement of the sesamoids by using dorsoplantar plain radiography. In clinical cases, evaluation of the sesamoid position and rotation of the first metatarsal is significant in deciding for an appropriate surgical procedure. Correlation between the hallux valgus and sesamoid position is well investigated in previous studies.[3,6] On the other hand, careful investigation proved that the sesamoids were in their normal position despite the adduction of the first metatarsal even in patients with hallux valgus.[12]

However, degenerative changes in the SMJ have not been well investigated regarding the correlation with hallux valgus. CT makes it possible to reconstruct the images in any plane, which allows a more detailed evaluation of the first MTP joint. This investigation was designed under the assumption that degenerative change in the SMJ would progress in accordance with the lateral shift of the sesamoid. The purposes of the present study were to evaluate alignment of the tibial sesamoid and investigate the relationship between malalignment and degenerative change in the SMJ by using simulated weight-bearing CT imaging in patients with hallux valgus.

Materials and Methods

The subjects included 142 patients (269 feet), who had hallux valgus deformity, with a mean age of 63.7 years. Patients with a history of forefoot surgery, hallux rigidus, a bone defect, or tibial sesamoid growth failure were excluded from this investigation.

Dorsoplantar weight-bearing radiographs were taken and used to measure the hallux valgus and intermetatarsal angles (HVA and IMA, respectively) for each case. The HVA was defined as the angle between the longitudinal axes of the first metatarsal and proximal phalanx, and the IMA, as the angle between the longitudinal axes of the first and second metatarsals. Subsequently, radiographs were classified based on the tibial sesamoid position relative to the axis of the first metatarsal (radiographic classification): grade 1, cases wherein the tibial sesamoid is medial to the axis of the first metatarsal (grades I to II in the Hardy and Clapham classification[3]); grade 2, cases wherein the tibial sesamoid exists below the first metatarsal axis (grades III to V in Hardy and Clapham classification); and grade 3, cases wherein the tibial sesamoid exists laterally to the first metatarsal axis (grades VI to VII in Hardy and Clapham classification) (Fig. 1).

Simulated weight-bearing CT images were taken as a preoperative evaluation of hallux valgus by following a procedure. The subject lay supine with the hip, knee, and ankle joints fixed in neutral positions, and a board with straps was placed against the plantar side of both feet. The subject was asked to pull the straps with both hands to apply a pressure equal to one third of their weight from the plantar side of the feet to simulate weight bearing. This pressure was carefully monitored using the TELOS system, whereas a CT image of the entire foot was taken (Fig. 2).

Images were taken using a 64-row helical CT and reconstructed in the plane perpendicular to the axis of the second metatarsal. The slice that revealed both sides of the sesamoids was used to assess the morphological characteristics of the intersesamoid ridge and dislocation of the tibial sesamoid (Fig. 3).[8]

Displacement of the tibial sesamoid was assessed using CT imaging and was then classified into three grades (CT classification). Grade 1 described cases wherein the tibial sesamoid is entirely medial to the intersesamoid ridge; grade 2, cases wherein the tibial sesamoid is subluxated laterally but located below the intersesamoid ridge; and grade 3, cases wherein the tibial sesamoid is located entirely lateral to the intersesamoid ridge (Fig. 4).[9,11,15]

In addition, degenerative change in the SMJ was evaluated as follows: cases with an intact intersesamoid ridge and no bony erosion or cystic lesions were identified as osteoarthritis (OA) (−), cases with evidence of erosive or cystic changes in the SMJ or disappearance of the intersesamoid ridge as OA (+) (Fig. 5).

HVA and IMA values were obtained from the dorsoplantar weight-bearing radiograph, and compared with the different grades of tibial sesamoid position. Differences of HVA and IMA in each grade were confirmed by one-way analysis of variance with Bonferroni post-hoc corrections. Furthermore, a multiple linear regression analysis was used to predict the degenerative change in the SMJ for age, gender, sesamoid position determined by CT or plain radiography, HVA, and IMA. Chi-square test was used for descriptive statistics to analyze the agreement between radiographic or CT classifications of sesamoid position against degenerative change in the SMJ. Statistical analysis was performed using SPSS (Statistics Premium Grad Pack Shrinkwrap Version 22.0), with the level of statistical significance set at $p < 0.05$.

Results

Based on radiographic classification, 7, 72, and 190 feet were classified as grades 1, 2, and 3, respectively (Table 1). From the results of the chi-square test, degenerative change in the SMJ progressed according to the sesamoid shift relative to the first metatarsal in radiography (χ^2 value, 73.23333; degree of freedom, 2; χ^2 (0.95); 5.991465, $p < 0.01$). The respective median of HVA/IMA values in each grade is shown in Figure 6A, B. Significant differences were recognized except for the difference in HVA between grades 1 and 2.

Based on the CT classification of the tibial sesamoid position, 34, 116, and 119 feet were classified as grades 1, 2, and 3, respectively (Table 2). Results of the chi-square test showed that degenerative change in the SMJ progressed according to the sesamoid shift relative to the first metatarsal in CT (χ^2 value, 171.4826; degree of freedom, 2; χ^2 (0.95); 5.991465, $p < 0.01$). The respective median of HVA/IMA values in each grade is shown in Figure 7A, B. These data showed that the HVA and IMA significantly increased with an increase in the sesamoid lateral shift.

In multiple linear regression, degenerative change was correlated with age and sesamoid position in CT and radiographic classifications. (Table 3).

Discussion

Hardy's classification[3] system was developed from dorsoplantar weight-bearing radiographs and is regularly used to assess displacement of the sesamoids. This assessment is performed by evaluating the amount of the lateral shift of the tibial sesamoid relative to the shaft of the first metatarsal, and classified cases into one of seven grades. Based on Hardy and Clapham,[3] 90% of normal feet are graded below grade III, and 88% of hallux valgus feet were graded above grade IV. In addition, Okuda et al.[6] reported that 83% of subjects with HVA less than 20° were classified as grade IV or below, whereas 100% of subjects with HVA greater than 25° were classified as grade V or above. Based on these investigations, a strong correlation has been proven between the severity of hallux valgus deformity and the degree of lateral displacement of the sesamoid.[3,6] Development of hallux valgus is caused by a functional failure of the medial collateral ligament and the tibial sesamoid, which provide medial support for the first MTP joint.[13] When the first metatarsal shifts medially, the tibial sesamoid comes into contact the intersesamoid ridge. If the tibial sesamoid starts to ride over the intersesamoid ridge, the medial portion of the ridge begins to erode. Over time, this will lead to loss of the ridge, degenerative change of the articular cartilage, and atrophy of the metatarsal head.[7] In our investigation, advanced deviation of the tibial sesamoid relative to the metatarsal head resulted in a higher rate of degenerative change in the SMJ.

Because the intersesamoid ridge of the first metatarsal head cannot be visualized on dorsoplantar weight-bearing radiographs, the tangential sesamoid view in plain radiography is required to assess the intersesamoid ridge.[3] The sesamoid position also can be assessed on tangential sesamoid view[5,10,15] with the hallux in hyperextension, without excessive exposure to radiation. However, it is difficult to perform a proper evaluation in cases with severe adduction of the first metatarsal, and the sesamoid position changes with hyperextension of the first MTP joint, which is required to take this view. Reports indicate that the sesamoids shift laterally with pronation of the first metatarsal.[1,4] In a patient with severe hallux valgus, the first metatarsal tends to adduct and pronate, and this prevents correct assessment of the position of the sesamoids. CT makes it possible to reconstruct the images in any plane, which allows a more detailed evaluation of the first MTP joint. For most purposes, CT images of the foot are taken under non-weight-bearing conditions by inserting the lower legs into the gantry. Based on Tanaka et al.,[12] the first metatarsal position shifts medially in weight bearing, which makes this condition preferable for the assessment of the sesamoid position. Therefore, simulated weight-bearing CT imaging is appropriate for evaluating sesamoid deviation in patients with severe hallux valgus.

The relationship between hallux valgus deformity and dislocation of the sesamoid has been well investigated in the past; however, most researches were composed of plain radiography, and the SMJ condition has not been investigated in detail. Kim et al.[14] used CT for evaluation of the first MTP joint and concluded that pronation of the first metatarsal had a correlation with sesamoid subluxation in patients with hallux valgus; however, degenerative change in the articular surface of the SMJ has not been documented. This study revealed that the relationship between the sesamoid lateral shift and degree of hallux valgus by using plain radiography and simulated weight-bearing CT. Furthermore, the lateral shift of the sesamoid led to degenerative changes in the SMJ. A mismatch in the prevalence of the three grades between radiographic and CT classification was presented in this study. Radiographic classification is based on the position of the tibial sesamoid relative to the metatarsal axis, which leads to advanced grading in the rotational deformity of the first metatarsal. However, using CT classification, congruency of the sesamoid metatarsal joint could be correctly assessed even with rotational deformity, resulting in the difference in patient distribution in these two classifications. Reduction of the sesamoid below the first metatarsal head is reported to be an important component of hallux valgus surgery. [6] For a case with dislocation of the sesamoids confirmed by CT, there is the erosion of the intersesamoid ridge which causes the instability of the SMJ. It is beneficial to reconstruct the medial metatarsosesamoid ligament to keep the sesamoids under the metatarsal head.

CT exposes a patient to a certain amount of radiation, and excessive exposure should be avoided; however, in our series, data were obtained to make the preoperative evaluation. Therefore, additional exposure of radiation has not been taken into consideration in this investigation.

Limitations of this study include uneven patient distribution for the level of hallux valgus severity and lack of control cases. In addition, the weight-bearing pressure was determined using pilot trials from healthy individuals as the safe level of pressure supply, and the validity of the weight-bearing simulation technique used in this study was not confirmed.

Conclusion

Based on radiographic classification, 7, 72, and 190 feet were classified having grades 1, 2, and 3, respectively. Based on the CT classification of the tibial sesamoid position, 34, 116, and 119 feet were classified as having grades 1, 2, and 3, respectively. HVA and IMA significantly increased with an increase in the sesamoid lateral shift. Multiple linear regression revealed that degenerative change was correlated with age and sesamoid position in the CT and radiographic classifications. This study found that the lateral shift of the tibial sesamoid increases in association with the advancement of the hallux valgus deformity. Furthermore, the increasing displacement of the tibial sesamoid is thought to be associated with worsening degenerative change within the SMJ.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

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LEGENDS

Fig. 1: Radiographic classification for tibial sesamoid position.
Grade 1: The tibial sesamoid is medial to the axis of the first metatarsal.
Grade 2: The tibial sesamoid exists below the first metatarsal axis.
Grade 3: The tibial sesamoid exists lateral to the first metatarsal axis.

Fig. 2: Simulated weight-bearing CT. Images were taken with the foot placed against a flat board, and pressure was applied from the plantar side with the ankle joint in the neutral position. The applied pressure was equal to one third of the patient's weight.

Fig 3: CT coronal view of the forefoot. The slice both fibular and tibial sesamoids was used for evaluation.

Fig 4: CT classification for tibial sesamoid position.
Grade 1: The entire tibial sesamoid is medial to the intersesamoid ridge.

Grade 2: The tibial sesamoid is subluxated laterally but located under the intersesamoid ridge.

Grade 3: The entire tibial sesamoid is located lateral to the intersesamoid ridge.

Fig 5: Degenerative changes in SMJ were divided into two categories by using CT images: OA (−), intact intersesamoid ridge without any bony erosion or cystic lesions (a) OA (+), contact of intersesamoid ridge with tibial sesamoid (b) or evidence of erosive, cystic changes in the SMJ, or disappearance of the intersesamoid ridge (c).

Fig 6: Mean HVA (A) and IMA (B) values in each grade of sesamoid shift based on radiographic classification. A significant difference was found between the HVA and IMA values between all grades except HVA grades 1–2.

Fig 7: Mean HVA (A) and IMA (B) values in each of the grades of sesamoid shift based on the CT classification criteria. Significant differences were found between the HVA and IMA measurements between all grades.

Table 1: Degenerative changes in SMJ according to the radiographic classifications.

	OA(-)	OA(+)
Radiographic Grade 1 (7 feet)	7	0
Radiographic Grade 2 (72 feet)	42	30
Radiographic Grade 3 (190 feet)	3	187

Table 2: Degenerative changes in SMJ according to the CT classifications.

	OA(-)	OA(+)
CT Grade 1 (34 feet)	34	0
CT Grade 2 (116 feet)	18	98
CT Grade 3 (119 feet)	0	119

Table 3: Multivariate linear regression analysis of SMJ OA change.

Variable	Regression Coefficient	P Value
HVA	0.099	0.154
IMA	0.042	0.480
Radiographic classification	0.520	<0.001※
CT classification	0.206	0.001※
Age	0.109	0.003※
Gender	-0.034	0.358
Right/Left	-0.034	0.343

※A significant association at $p < 0.05$

The decision variable R^2 was 0.665.

LEGENDS

Fig. 1: Radiographic classification for tibial sesamoid position.

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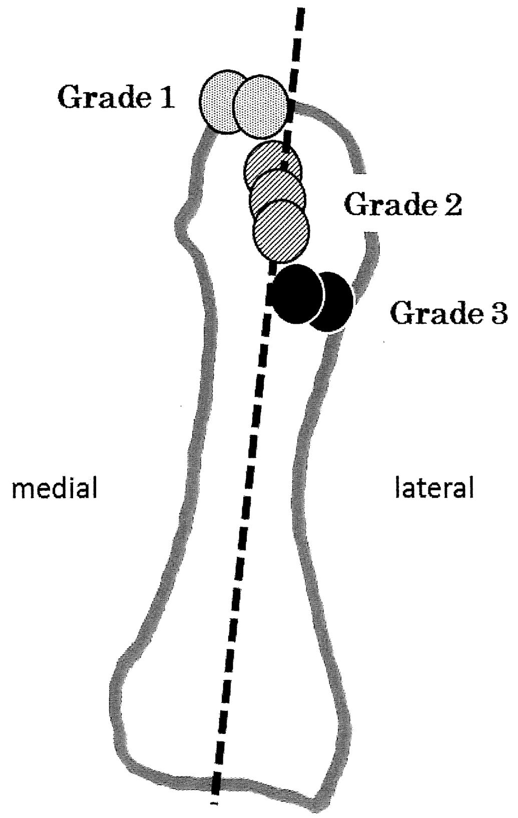

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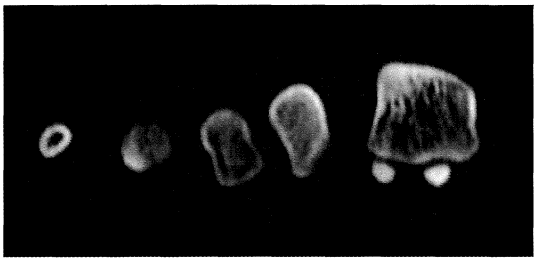
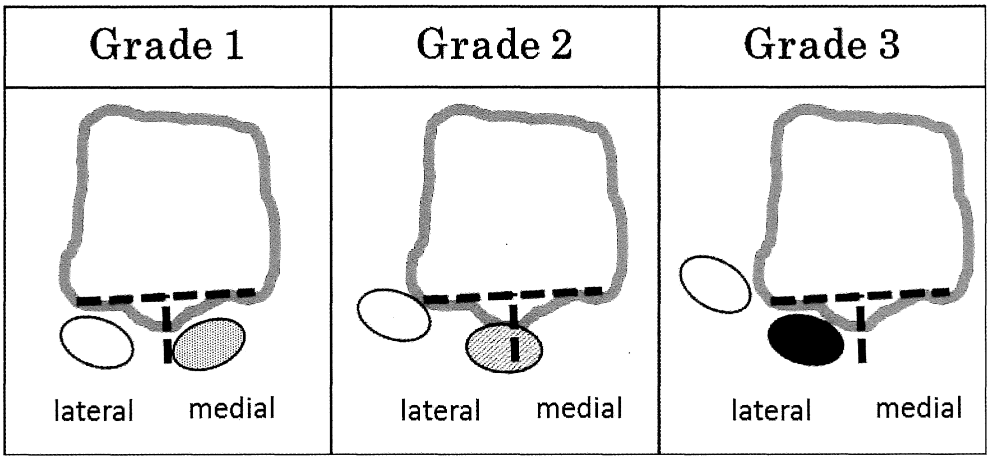


Fig 4: CT classification for tibial sesamoid position.
Grade 1: The entire tibial sesamoid is medial to the intersesamoid ridge.
Grade 2: The tibial sesamoid is subluxated laterally but located under the intersesamoid ridge.
Grade 3: The entire tibial sesamoid is located lateral to the intersesamoid ridge.



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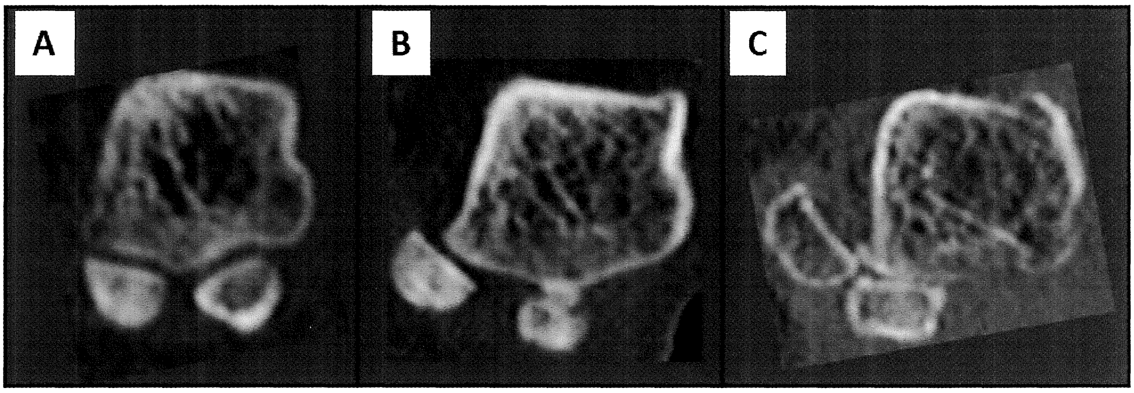

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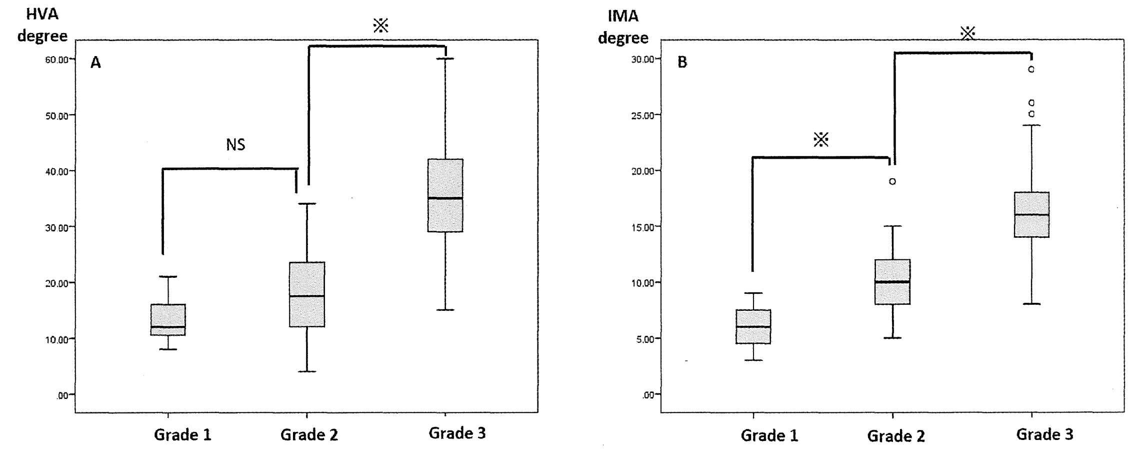

Fig 7: Mean HVA (A) and IMA (B) values in each of the grades of sesamoid shift based on the CT classification criteria. Significant differences were found between the HVA and IMA measurements between all grades.