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Original Article

Change in the sub-sesamoid soft tissue thickness under different loading conditions

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Abstract. [Purpose] To measure the sub-sesamoid soft tissue thickness change from non-loading to self-weight loading conditions. [Participants and Methods] The study included 17 female participants for the study. A questionnaire was used to collect the demographic data and participant anamnesis, such as the presence of foot injuries and diabetes. The measured height and weight were used to calculate the body mass index. Participants were required to stand on an evaluation device from non-loading to 100% loading conditions to measure the sub-sesamoid soft tissue thickness. [Results] Significant differences were observed between the tibial and fibular sub-sesamoid soft tissue thicknesses under non-loading and all loading conditions. Significant soft tissue thinning was observed with a change from non-loading to 25% loading condition. However, no significant differences in the rate of change were observed between the tibial and fibular sub-sesamoid soft tissue thicknesses at 100% loading. [Conclusion] The sub-fibular sesamoid soft tissue was thicker than the sub-tibial sesamoid soft tissue in all loading conditions. The sub-sesamoid soft tissue thickness change was larger during initial loading stage than during the late loading stage, which may be normal in healthy females in their 20s.

Key words: Sub-sesamoid soft tissue, Loading condition, Loading device

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INTRODUCTION

The sesamoid bones are located under the first distal metatarsal and sustains 50% of the body weight while standing[1)]. The push-off motion further applies approximately 300% of the body weight, which causes sesamoid bone disorders, one of the causes of sesamoid pain[1)]. Sesamoid pain is one of the most common weight-bearing complaints, and it is generally felt on the tibial sesamoid bone[1, 2)].

The soft tissue beneath the sesamoid bone (sub-sesamoid soft tissue) includes the plantar aponeurosis, tendons of the flexor hallucis brevis muscle, and the fat pad[3)]. According to an anatomic study, the plantar fat pad contains a meshwork of fibroelastic septa that dissipate stress to maintain normal plantar pressure[4)]. The same function has been reported in the heel fat pads[5)]. Sub-sesamoid soft tissue has been presumed to dissipate stress and affect the position of sesamoid bones during loading. Therefore, the sub-sesamoid soft tissue form should be measured while standing to clarify the changing pattern. To date, few studies have evaluated the position of sesamoid bones[6–8)].

A previous study[6)] reported the use of a hole in the loading device, which was placed an ultrasound probe; the sesamoid bone area was placed over the probe and the sub-sesamoid soft tissue thickness with load changes was assessed using

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ultrasound. Other studies have reportedly used radiography[7] or magnetic resonance imaging[8] to assess the position of the sesamoid bone and sub-sesamoid soft tissue. However, techniques used in previous medical, and sports studies required considerable measuring time and could not reproduce loading changes when participants were standing on a plane. In 2022, Matsumoto used a polymethylpentene (PMP) resin plate loading device to reproduce loading conditions and measure the plantar soft tissue using ultrasound, and this device has shown high reliability in measuring sub-calcaneal soft tissues[9]. However, to our knowledge, the sub-sesamoid soft tissue form during weight-bearing remains unevaluated.

In this study, we evaluated the feasibility and reliability of the loading device for measurement, and subsequently measured the sub-sesamoid soft tissue thickness under non-loading condition and its changes under loading condition with self-weight, using a PMP plate loading device. The hypothesis is through this study clarify the sub-sesamoid soft tissue thickness changes when the loading conditions differ; furthermore, clarify the change pattern of the sub-sesamoid soft tissue thickness with loading change.

PARTICIPANTS AND METHODS

This was a cross-sectional observational study. Used G*Power 3.1.9.6 program (Heinrich Heine University, Düsseldorf, Germany) to calculate the number of participants. We initially recruited 36 female University students in their 20s without any training habits and who had not joined any sport circle or sports club. The inclusion criterion was that they do not have any foot symptoms. After excluding participants based on the following criteria: (1) those with a history of regular high-heel wear (≥2 days weekly), (2) those with a history of foot problems such as sesamoid disorders or hallux valgus[10], and (3) those with a history of illness, such as diabetes mellitus or peripheral circulatory disturbance that may influence sub-sesamoid soft tissue measurement[11]. A total of 34 feet of 17 females were finally assessed in this study. This study was conducted with the approval of the Ethics Review Committee for Research Involving Human Subjects at Waseda University (2021-305). Participants were informed in advance regarding the purpose of the study, methods, and ethical considerations, and all participants provided written informed consent.

Sub-sesamoid soft tissue thickness was assessed using an ultrasonography device equipped with a high-frequency (5–14 MHz) linear probe (Aplio a-series Verifia, Medical Systems Corporation, Tochigi, Japan). To set up the loading device, we used a general-purpose high-performance resin with a 79 millimetres (mm) diameter hole, which was first placed on a 400 mm steel evaluation table. A 5 mm PMP plate was fixed to the holes (Fig. 1). Non-loading and loading conditions were used to evaluate the tibial and fibular sub-sesamoid soft tissue changes. For the non-loading condition, the heel of the tested foot was lightly placed on a 1 centimeter (cm) wooden plate. The forefoot was positioned 1 cm from the PMP plate, and an adequate amount of gel was applied between the PMP plate and the first metatarsal head to measure the non-loading thickness of the tibial and fibular sub-sesamoid soft tissues (Fig. 2A).

To identify the sub-tibial and sub-fibular sesamoid soft tissue changes under each loading condition, we used measurement method from a previous study to design the measurement position, which used the participants' own weight (self-weight) to design the loading conditions[9], including 25% partial weight bearing (25% loading), 50% partial weight bearing (50%

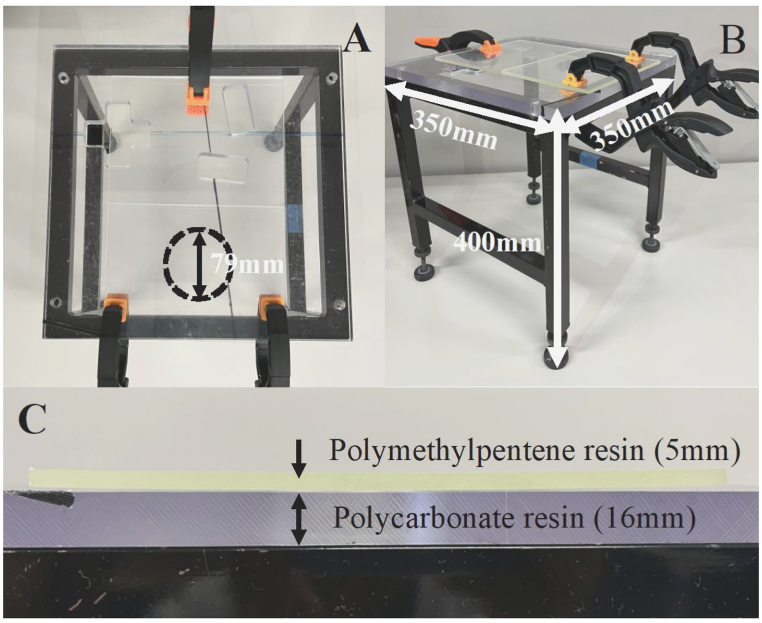

Fig. 1. The new loading device designed by Matsumoto et al[9]. A: aerial view B: lateral view C: setting of the resin plate.

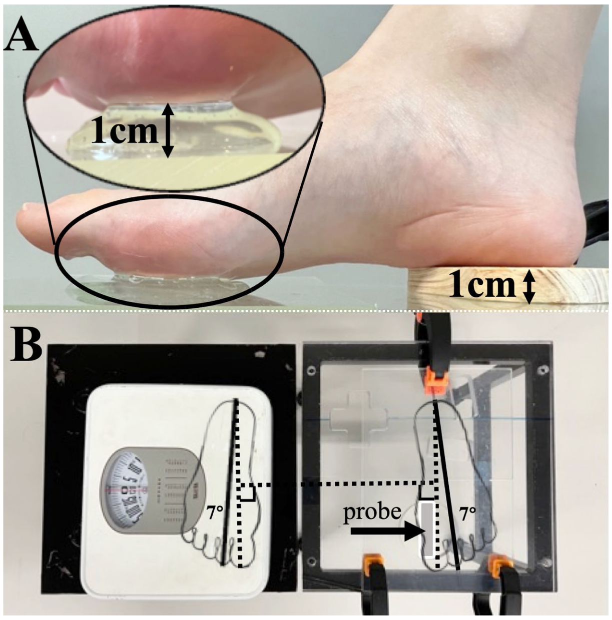

Fig. 2. Posture of the foot. A: Method of measurement under the non-loading condition. B: Method of measurement under the loading condition.

loading), 75% partial weight bearing (75% loading), and 100% full weight (100% loading), at their normal standing posture. To control the loading conditions, we set a weight meter above a steel device placed next to the loading device (Fig. 2B). To evaluate the loading condition, the distal first metatarsal of the tested foot was placed on the PMP plate and the contralateral foot was placed on the weight meter. A study of 60 adult participants showed that a normal human being's foot was externally rotated 7° to the sagittal plane during walking[12]. In our study, the entire foot was placed on the PMP plate and weight meter. Furthermore, both feet were externally rotated at 7°, with the base on the median sagittal plane (Fig. 2B).

A questionnaire was used to collect demographic data, age. And measured foot length, height, and weight, and calculated the body mass index. Tibial and fibular sub-sesamoid soft tissue thickness was evaluated using a loading device. The sub-sesamoid soft tissue thickness was measured by ultrasonography device. At first, the probe was slowly moved from the lateral side of the first distal metatarsal to its medial side. Using this method, images of the tibial sesamoid bone, tendon of flexor hallucis longus, and fibular sesamoid bone were sequentially captured. In addition, sub-tibial sesamoid soft tissue and sub-fibular sesamoid soft tissue were measured using ultrasonography under non-loading and loading conditions for each sesamoid bone. For each sesamoid bone, we took three images in each loading condition in the sagittal direction and horizontal plane. The thickness was measured from these images, and their average was calculated. In this study, we measured the sub-sesamoid soft tissue thickness vertically from the inferior margin of the sesamoid bone to the inferior margin of the skin (Fig. 3). The value of average thickness was used for further calculations; the rate of change in the sub-sesamoid soft tissue under 100% loading conditions were defined as rate of change (100% loading)=(non-loading thickness − 100% loading thickness) / (non-loading thickness)

SPSS software (version 28.0, SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Data such as age, foot length, height, weight, and BMI are represented as mean ± standard deviation (SD). Intrarater reliability was calculated by measurements repeated by a single examiner for each participant. Reliability thresholds for intraclass correlation coefficient (ICC) values were defined as poor (<0.50), moderate (0.50−0.75), good (0.75−0.90) and excellent (>0.90). In this study, ICC values were higher than 0.98 under all the loading conditions, showing excellent results (Table 1).

A Shapiro–Wilk test was used to verify normally distributed data. The data showing the soft tissue thickness does not follow the normal distribution curve, which was used to compare sub-sesamoid soft tissue thickness under all loading conditions, using a Kruskal–Wallis test. We also performed a Wilcoxon Signed-rank test to compare the difference between tibial and fibular sub-sesamoid thickness under each loading condition. A value of $p<0.05$ was considered statistically significant.

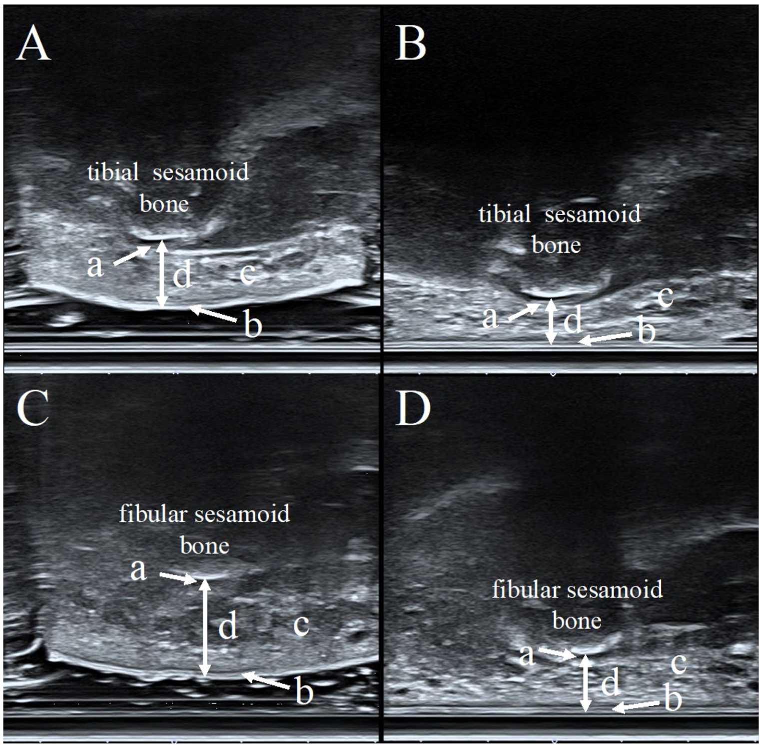

Fig. 3. Sub-sesamoid soft tissue thickness measurement using ultrasonography under loading and non-loading conditions.
A. Sub-tibial sesamoid soft tissue under a non-loading condition; B. Sub-tibial sesamoid soft tissue under a 50% loading condition; C. Sub-fibular sesamoid soft tissue under a non-loading condition; and D. Sub-fibular sesamoid soft tissue under a 50% loading condition.
a: flexor hallucis brevis muscle enthesis; b: skin/subcutaneous tissue; c: subcutaneous tissues (fat pad, plantar aponeurosis, and plantar interdigital ligament); and d: sub-sesamoid soft tissue thickness.

Table 1. Intrarater reliability for measuring the thickness of sub-sesamoid soft tissue

Loading conditions	Non-loading	25% loading	50% loading	75% loading	100% loading
Sub-sesamoid soft tissues	ICC1,1	ICC1,1	ICC1,1	ICC1,1	ICC1,1
Tibial	0.995	0.998	0.995	0.989	0.988
Fibular	0.993	0.997	0.982	0.985	0.988

ICC: intraclass correlation coefficient.

RESULTS

Age (24.5 ± 2.7 years), foot length (23.7 ± 0.8 cm), height (165.3 ± 0.04 cm), weight (52.0 ± 4.9 kg), and BMI (19.0 ± 1.6 kg/m^2) were calculated as mean ± SD.

Tibial and fibular sub-sesamoid soft tissues were significantly thinner under 25%, 50%, 75%, and 100% loading conditions than under the non-loading condition (p<0.001). However, no significant differences in sub-sesamoid soft tissue thickness were observed between the loading conditions from 25%−100%. During non-loading and all loading conditions, the sub-fibular sesamoid soft tissue thickness was greater than the sub-tibial sesamoid soft tissue thickness (p<0.001) (Fig. 4).

No significant differences were observed between the rate of change in tibial (47.1 ± 15.5%) and fibular (46.2 ± 9.8%) sub-sesamoid soft tissue thickness under the 100% loading conditions (p=0.49).

DISCUSSION

Our study demonstrated the feasibility of sub-sesamoid soft tissue thickness measurement using ultrasound under non-loading to 100% loading. A previous study reported changes in the position of the sesamoid bone in the frontal plane with or without loading[7, 8, 13]. The position and foot deformities such as hallux valgus had a higher correlation[7, 8]. Furthermore, the first metatarsophalangeal joint dorsiflexion can influence the position of sesamoid bone position[13]. However, these

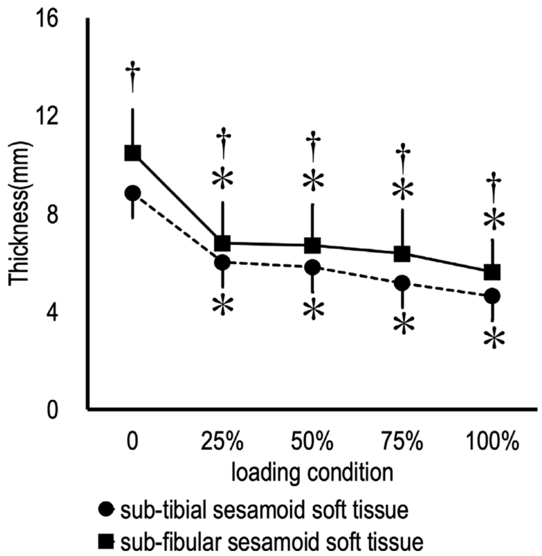

Fig. 4. Sub-sesamoid soft tissue thickness under each condition.
*Significantly thin sub-sesamoid soft tissue compared to non-loading condition.
†Significantly thin sub-sesamoid soft tissue compared to sub-tibial sesamoid tissue in all loading conditions.

studies were performed on cadavers[7] and patients with hallux valgus deformity[8, 13]. To our best knowledge, no studies have measured sub-sesamoid soft tissue thickness in a natural standing posture in participants without any foot deformity such as hallux valgus particularly. In this study, we measured sub-sesamoid soft tissue thickness in different conditions, from non-loading to 100% loading conditions, with high reliability. We discovered that the sub-sesamoid soft tissue (tibial and fibular) under all loading conditions was thinner than in the non-loading conditions. However, the tibial and fibular sub-sesamoid soft tissue thickness did not decrease significantly under loading conditions over 25%. This may have been due to the compression of the soft tissue to a maximum limit under the 25%loading condition.

Conversely, whilst we discovered no significant difference of rate of change in sub-tibial and sub-fibular sesamoid soft tissue thickness under 100% loading conditions, tibial sub-sesamoid soft tissue was significantly thinner than fibular sub-sesamoid soft tissue under all conditions. A previous study[14] reported the use of a sesamoid rotation angle to identify the horizontal position difference between the two sesamoid bones in a sitting position using radiography and found that when the two sesamoid bones are positioned differently under non-loading conditions, the tibial sesamoid bone was lower than the other, and another study reported simlar finding[15]. These results reflect our findings. However, to our knowledge, no study has reported sesamoid soft tissue thickness in loading conditions using self-weight. Our study revealed differences between the two sesamoid bones under any loading conditions and non-loading conditions. Furthermore, our results were in accordance with previous research results[7]. A previous study reported the obvious differences in soft tissue thickness between a group of participants with and without a history of heel pain[16]. Future studies can use the PMP plate to find differences in the sub-sesamoid soft tissue between those with sesamoid disorders and those without them. A previous study reported that the plantar fat pad was affected by age and sex[17]. Therefore, the form and tissue characteristics of sub-sesamoid soft tissue found in this study may have been influenced by the age and gender of the participants. Further studies are required to evaluate the role of a wide range of factors such as age, gender, and body composition in sub sesamoid soft tissue thickness.

Our study had some limitations. We included only healthy females in their 20s. Our study found the difference in tibial and fibular sub-sesamoid soft tissue thickness in loading conditions in healthy females in their 20s. Regarding the participation of individuals, this study recruited 20 year-old female University students. Previous studies have not examined soft tissue in females aged 20 years, and our study is the first of its kind. Therefore, the references appearing in this study can only be supported to a certain extent. This is an attempt to measure the thickness of the soft tissue. More participants were not recruited, and differences in sub-sesamoid soft tissue across age groups should be discussed in future studies with larger sample sizes will be required.

The method of measurement of sub-sesamoid soft tissue thickness using ultrasonography showed high reliability. Therefore, this method can be used to evaluate the sub-sesamoid soft tissue thickness in future medical and sports studies. The significant difference between the tibial and fibular sub-sesamoid soft tissue thicknesses that were found under non-loading conditions might have continued during loading conditions with the same rate of change. The sub-sesamoid soft tissue was mostly not compressed when the loading condition was beyond 25% of self-weight.

Funding and Conflict of interest

None.

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