Instrument-assisted soft tissue mobilization in healthy adults acutely changes the tissue stiffness

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Authors

Ryoichi Ema[1], Yuta Iino[2], Yuta Nomura[3], Tomoki Furusawa[3], Kosuke Hirata[4], Yasuhide Yoshitake[5], Ryota Akagi[2]

Affiliations
1 Faculty of Sport Science, Shizuoka Sangyo University, Iwata, Japan
2 College of Systems Engineering and Science, Shibaura Institute of Technology, Saitama, Japan
3 Graduate School of Engineering and Science, Shibaura Institute of Technology, Saitama, Japan
4 Institute of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan
5 Graduate School of Science and Technology, Shinshu University, Ueda, Japan

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Georg Thieme Verlag KG, Oswald-Hesse-Straße 50,
70469 Stuttgart, Germany

Correspondence
Dr. Ryota Akagi
College of Systems Engineering and Science, Shibaura Institute of Technology
307 Fukasaku, Minuma-ku
337-8570 Saitama-shi
Japan
rakagi12@sic.shibaura-it.ac.jp

ABSTRACT

This study clarified whether instrument-assisted soft tissue mobilization (IASTM) on the plantar surface changes abductor hallucis and plantar fascia stiffness at rest and medial longitudinal arch height under low- and high-loading conditions. IASTM was performed to one foot of the twenty-eight young men (IASTM condition), and the other foot of them was assigned to the control condition. Using ultrasonography, the resting shear wave propagation velocity of the abductor hallucis and plantar fascia and navicular height in a seated posture were determined. The foot contact area during quiet standing was measured using a foot-scan system. The shear wave propagation velocity of the plantar fascia significantly decreased by 10.8 % in the IASTM condition but did not change significantly in the control condition. The magnitude of change in the shear wave propagation velocity of the plantar fascia was negatively correlated ($r = -0.660$) with the shear wave propagation velocity of the plantar fascia before IASTM. The interaction of time and condition was not significant for the shear wave propagation velocity of the abductor hallucis, navicular height, or foot contact area. The current study revealed that IASTM on the plantar surface affected tissue stiffness but did not change the structure of the foot.

Introduction

In basic human activities such as standing and locomotion, the foot plays a role in sustaining balance, absorbing shock, and generating forceful propulsion against the ground [1]. These foot functions are closely linked to the arch structure. The abductor hallucis [2] and plantar fascia [3] are one of the important support elements for the medial longitudinal arch. The volume of the abductor hallucis is the largest among the intrinsic foot muscles [4], and fatigue of the muscle was accompanied by acute changes in the medial longitudinal arch height [5]. Thus, investigating whether an intervention reduces the stiffness of the abductor hallucis is useful, considering that muscle tissue can be stiffened due to fatigue [6]. Regarding the plantar fascia, it undergoes dynamic elongation and shortening, thereby modifying the windlass effect during human locomotion [7]. The plantar fascia that is excessively stiff might potentially impair this effect. In addition, plantar fascia stiffness was higher in patients with type II diabetes than in healthy individuals, which was associated with a slower gait speed and higher fall risk [8]. A computational modeling study [9] indicated that increased stiffness of the plantar fascia was accompanied by corresponding changes in the contact force through the metatarsophalangeal and tarsometatarsal joints, which could result in metatarsalgia. Certainly, elucidating methods that decrease the stiffness of the abductor hallucis and plantar fascia would be beneficial.

Instrument-assisted soft tissue mobilization (IASTM), which has been reported to have a larger effect on joint range of motion compared to foam rolling [10] and has been advocated in sports [11] and rehabilitation [12], would have the potential to change the medial longitudinal arch height by altering the stiffness of the tissue supporting the arch. The impact of IASTM on tissue stiffness is not well-documented, and to the best of our knowledge, there are no studies available on its effect on the tissue stiffness of the foot. Because a study conducted on the infraspinatus [13] reported a decrease in muscle stiffness, this method can be applied to the foot region. In contrast, a cross-sectional study observed that the stiffness of the abductor hallucis and plantar fascia did not differ between normal and flat feet in an unloaded position [14]. Schuster et al. [15] investigated plantar fascia stiffness and foot shape changes under low (sitting) and 100 % (standing while supporting a mass equal to body mass) body mass loading conditions. They showed that load-induced change in plantar fascia stiffness was not a good predictor of corresponding changes in foot structure. Based on these findings, despite potential alterations in the stiffness of the abductor hallucis or plantar fascia, IASTM may not be sufficiently effective to cause a change in the height of the medial longitudinal arch.

Therefore, the purpose of the present study was to examine the effects of IASTM on tissue stiffness and structure of the foot. We hypothesized that IASTM on the plantar surface would decrease resting abductor hallucis and plantar fascia stiffness without changes in medial longitudinal arch height under low- and high-loading conditions.

Materials and Methods

Participants

Twenty-eight healthy young men (age, 21 ± 1 year; height, 173.5 ± 5.4 cm; body mass, 69.9 ± 8.7 kg; mean ± standard deviation [SD]) participated in this study. The inclusion criteria consisted of healthy young men, while the exclusion criterion was defined as the presence of injuries or diseases affecting the lower limbs and feet. Consequently, the level of physical activity of the participants ranged from sedentary to active. The participants were requested to avoid high-intensity exercise the day before and on the day of the experiment. It was verified that there were no muscle pains in their lower legs and feet immediately before the experiment. This study was approved by the Ethics Committee of the last author's institution and conducted in agreement with the ethical guidelines of the International Journal of Sports Medicine [16]. Participants were informed of the purpose and potential risks of the study and provided written informed consent before participation.

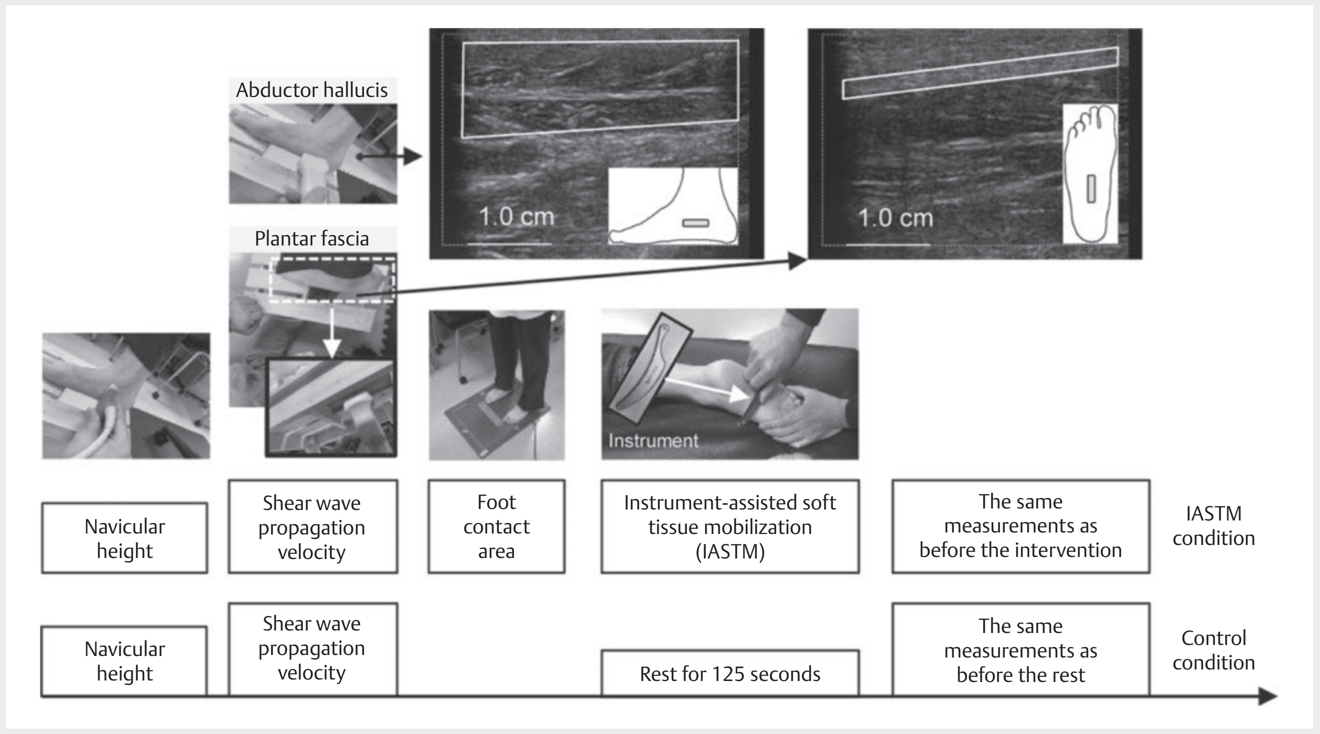
The sample size estimation (G*Power 3.1.9.4, Kiel University, Germany) indicated that 26 participants (52 feet) were necessary for a small-to-medium effect size ($f = 0.20$) with $\alpha = 0.05$ and statistical power = 0.80 to detect the changes in shear wave propagation velocity of the tissues over time between conditions. Ikeda et al. [17] investigated the effect of IASTM on musculoskeletal properties and reported a medium effect size for the difference in the changes in joint stiffness between the IASTM and control conditions. Because it was assumed to have larger variability in the tissue stiffness than in the joint stiffness [17], the expected effect size of the current study was set slightly lower than medium. Anticipating potential dropouts, two more participants were recruited.

Study design

The experimental procedure is illustrated in ▶ **Fig. 1**. Dependent variables were measured before and after the IASTM intervention or while maintaining a relaxed position with the same time interval as in IASTM. Among the participants (n = 28), 24 participants were right-dominant, and others were left-dominant, which was defined as that used for kicking a ball. One of the feet was assigned to the IASTM condition and the other to the control condition, which was counterbalanced between the dominant feet among the participants. Because the effect of IASTM on the contralateral foot was unclear, we selected a between-participant design in statistical analyses to examine the effect of condition on dependent variables. The two conditions were conducted in a random order. As for dependent variables that represent tissue stiffness, the resting shear wave propagation velocity of the abductor hallucis and plantar fascia was measured. Changes in navicular height during sitting and foot contact area while standing on both feet were evaluated as indices of the corresponding change in medial longitudinal arch height under low- and high-loading conditions, respectively. We did not obtain navicular height during standing because of poor repeatability in a pilot study. Before and after the intervention, measurements were conducted in the following order: navicular height, shear wave propagation velocity (in a random order between the two tissues), and foot contact area. All measurements after IASTM were completed as expeditiously as possible. Data collection and image analyses were conducted by the same investigator, who was familiar with the measurements and blinded to the hypothesis outlined in the introduction.

IASTM

The participant lay prone on a treatment table, and a single session of IASTM was performed on their feet (▶ **Fig. 1**). The target for mobilization was the plantar surface within 20 %–80 % of the foot length, focusing on the plantar fascia. A specialized apparatus with an upper arc was used for mobilization. The procedure was performed by a single, well-practiced examiner. To directly apply the specialized tool to the skin, a water-soluble gel was used to enhance its smoothness. One repetition was defined as a single round-trip movement within the range of 20 % to 80 % of the foot length, and four sets of 30 repetitions were performed. Each set lasted for 20 s with a 15-second interval between sets. To maintain a consistent speed, a metronome was set at 90 beats/min. During the control condition, a rest period of 125 s, which is the same time as the IASTM, was implemented.



▶ **Fig. 1** Time course of the experimental procedure, typical examples of ultrasound images, and schematic illustrations of ultrasound probe placements. Each image shows the experimental setting for the measurements or intervention. The area surrounded by the white line on each ultrasound image represents the region of interest for shear wave velocity analysis.

Shear wave propagation velocity

The shear wave propagation velocity of the abductor hallucis and plantar fascia was determined using a B-mode ultrasound apparatus (ACUSON S2000, Siemens Medical Solutions, USA) with a 45-mm linear probe (▶ **Fig. 1**). Participants sat on a chair with ankle and knee joint angles of 0 ° and 90 ° (anatomical position = 0 °), respectively [14]. An ultrasound image of the abductor hallucis was acquired at a point equidistant from the apex of the medial malleolus, where a line perpendicular to the ground was divided into two equal parts. To measure the plantar fascia, an image was acquired at a position 40 % proximal to the foot length. Measurements were performed randomly across tissues.

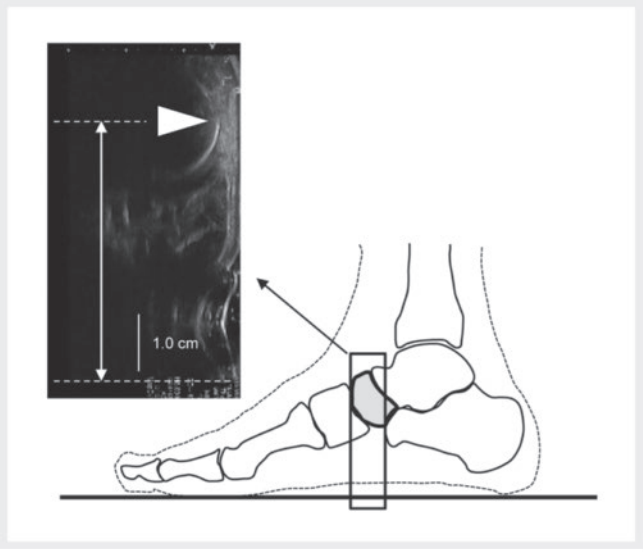
The images were analyzed in the same manner as previously described [18, 19]. Briefly, the region of interest (ROI) on the tissue was delineated to maximize its size within the color-coded area of the elastography image, with the explicit exclusion of non-target tissues (e. g. subcutaneous adipose tissues, aponeuroses, and non-target muscles) using image processing software (Image J, NIH, USA). The average shear wave propagation velocity value across the ROI was subsequently computed for each image using proprietary analysis software developed in MATLAB (MATLAB R2018a, Math Works, USA) [18]. This software can transform the red-green-blue color model values of individual pixels within the ROI into corresponding shear wave propagation velocity values, aligned with the color scale of the elastography images. The mean of the three images was used for further analysis. The velocity was used as an indicator of tissue stiffness.

Navicular height

In the same participant's posture for the shear wave propagation velocity measurement, navicular height was determined by ultrasonography [20]. The participants placed their feet on the pedestal without intentional inward or outward movements. After palpating and identifying the approximate location of the navicular tuberosity, a 60-mm linear ultrasound probe was positioned perpendicular to the medial aspect of the foot to obtain a B-mode image visualizing the navicular tuberosity (▶ **Fig. 2**). The edge of the probe-imaging range was aligned with the surface where the sole of the foot touched the ground. Measurement was performed three times. Navicular height was calculated on the ultrasound image as the distance between the navicular tuberosity and surface. The mean of the three images was used for subsequent analysis.

Foot contact area

Before and after IASTM, the foot contact area while standing at rest was measured using a foot pressure distribution scan system with a 578 × 418 mm plate (footscan USB, RS scan international, Belgium) [21]. The data obtained from the foot subjected to IASTM were utilized as the IASTM condition data, whereas the data from the opposite foot were employed as the control condition. The participant stood barefoot on the scanning mat and was asked to stand with equal weight distribution on both legs. A linear mixed model analysis demonstrated that the mean peak foot pressure was not significantly different between feet and before and after intervention in each foot ($P = 0.145–0.948$). The participants gazed at a



▶ **Fig. 2** Schematic illustration of the foot and an example of an ultrasound image obtained for navicular height measurement. The navicular bone was gray with a thick frame. The vertex of the white triangle in the ultrasound image indicates the navicular tuberosity. The navicular height (two-direction arrow) was calculated on the ultrasound image as the distance between the navicular tuberosity and the plantar surface.

landmark 2 m in front of them to control their gaze and minimize body sway during measurement. Foot pressure distribution data were automatically obtained, and the foot contact area was determined using the software.

Repeatability of dependent variables

The day-to-day repeatability of measurements was tested on five participants (ten feet). No significant differences were found between the days for all variables using paired *t*-tests. The coefficient of variation (CV) and intraclass correlation coefficient (ICC [1,1]) for each variable were as follows: shear wave propagation velocity of the abductor hallucis, 3.5 ± 2.6 %, 0.780; shear wave propagation velocity of the plantar fascia, 3.1 ± 2.8 %, 0.899; navicular height, 1.3 ± 1.1 %, 0.968; and foot contact area, 3.0 ± 2.6 %, 0.736. The CVs values were lower than the usual repeatability in biological systems (10–15 %, [22]). The ICCs ranged from good to excellent [23].

Statistical analyses

Statistical analyses were performed using SPSS (version 28.0, IBM, USA). Normality of the data distribution was investigated using the Shapiro-Wilk test. If the distribution was skewed, data were log-transformed. To facilitate interpretation, all data are presented as mean ± SD of the raw data. A linear mixed model analysis was conducted for dependent variables with condition (IASTM, control) and time (before, after) as fixed factors and participants as the random factor. When a significant interaction was evident, Bonferroni multiple comparisons were performed. For variables that showed a significant interaction of condition × time, relationships between variables at baseline and changes in them were tested using Pearson product moment correlation coefficient (r). The significance level was set at $P<0.05$. In addition, Cohen's d (d) in between-subject designs [24] was calculated using the mean and SD of the change scores. The d was interpreted as 0.20–0.49, 0.50–0.79, and ≥ 0.80 representing small, moderate, and large, respectively [25]. We considered the effect of IASTM to be substantial, if d showed moderate or large with a significant interaction of condition × time.

Results

▶ **Fig. 3** shows the changes in shear wave propagation velocity in the tissues. A main effect of time ($P=0.010$) was significant for the abductor hallucis (Before > After; Control: Before, 2.89 ± 0.41 m/s; After, 2.85 ± 0.35 m/s; IASTM: Before, 3.04 ± 0.43 m/s; After, 2.87 ± 0.36 m/s) without an interaction of condition × time ($P=0.130$) or main effect of condition ($P=0.355$), with a small effect size ($d=0.38$). For the plantar fascia, there was a significant condition × time interaction ($P<0.001$). The 10.8 % decrease ($P<0.001$) was found in IASTM condition (Before, 3.59 ± 0.48 m/s; After, 3.16 ± 0.34 m/s; Control: Before, 3.44 ± 0.58 m/s; After, 3.55 ± 0.74 m/s) with a large effect size ($d=1.24$).

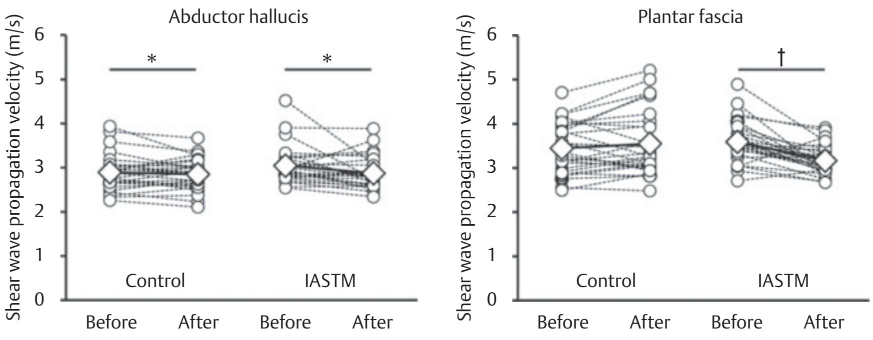
The individual changes in navicular height and foot contact area are shown in ▶ **Fig. 4**. There was no significant interaction ($P=0.262$) or main effect (time: $P=0.292$; condition: $P=0.645$) for navicular height (Control: Before, 4.18 ± 0.49 cm; After, 4.17 ± 0.45 cm; IASTM: Before, 4.18 ± 0.48 cm; After, 4.28 ± 0.44 cm), with a small effect size ($d=0.30$). Similarly, no significant interaction or main effects ($P=0.332$–0.769) were found for the foot contact area (Control: Before, 163.6 ± 15.0 cm^2; After, 160.9 ± 16.7 cm^2; IASTM: Before, 163.6 ± 10.9 cm^2; After, 163.0 ± 14.8 cm^2, $d=0.16$).

▶ **Fig. 5** shows the relationship between the shear wave propagation velocity of the plantar fascia before IASTM and its relative changes. There was a negative correlation between the variables ($r=-0.660$, $P<0.001$).

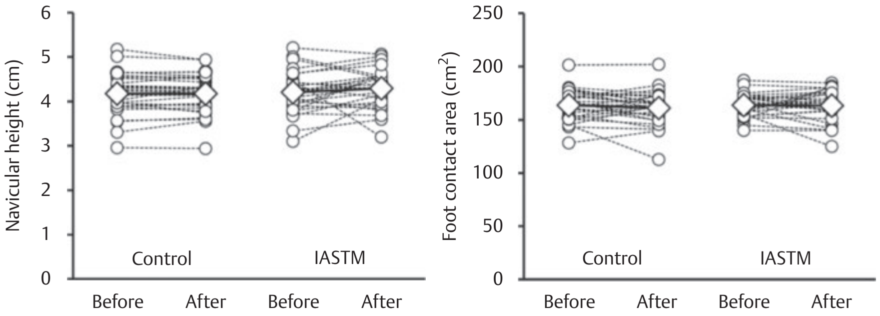
Discussion

To the best of our knowledge, this is the first study that clarified the acute effects of IASTM on the stiffness of the abductor hallucis and plantar fascia comprising the medial longitudinal arch and foot structure. The present study revealed that IASTM on the plantar surface substantially decreased the resting plantar fascia stiffness. The decrease was greater in individuals with a higher stiffness of the plantar fascia. In contrast, the effects of IASTM on resting abductor hallucis stiffness, navicular height during sitting, and foot contact area while standing on both feet were not substantial. The present results demonstrated that IASTM on the plantar surface affected tissue stiffness but did not change the structure of the foot.

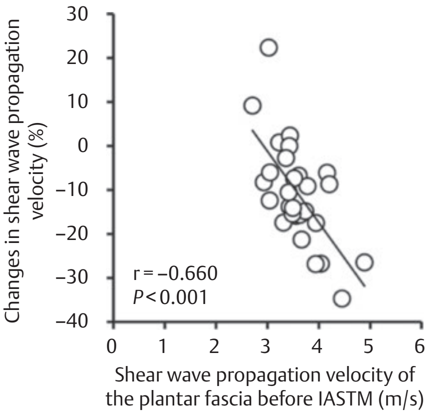
IASTM significantly reduced plantar fascia stiffness (▶ **Fig. 3**). While the mechanism by which IASTM alters tissue stiffness remains unclear, a review [12] suggests potential influences such as fascial release, increased blood flow, and desensitization of pain receptors, which might be related to the current results. Brandl et al. [26] demonstrated an increase in bioimpedance following IASTM, likely attributed to a decrease in water content within the targeted tissues. This alteration could potentially affect the viscoelastic properties of the treated tissues, as indicated by the reduced plantar fascia stiffness observed in the current study. In contrast, the effect



▶ **Fig. 3** Individual (circle plots) changes in the shear wave propagation velocity of the abductor hallucis and plantar fascia under control and instrument-assisted soft tissue mobilization (IASTM) conditions. The rhombus indicates the mean value. *Significant change after intervention with a significant main effect of time. † Significant change after intervention with a significant interaction of time and condition.



▶ **Fig. 4** Individual (circle plots) changes in navicular height and foot contact area under control and instrument-assisted soft tissue mobilization (IASTM) conditions. The rhombus indicates the mean value.



▶ **Fig. 5** Relationship between the shear wave propagation velocity of the plantar fascia before instrument-assisted soft tissue mobilization (IASTM) and change in shear wave velocity in IASTM condition.

of IASTM on abductor hallucis stiffness was unclear (▶ **Fig. 3**). An increase in the sample size may result in a significant interaction; however, the expected effect is anticipated to be small. Hence, the likelihood of obtaining a practically meaningful effect is low. These results are consistent with those of previous studies [13, 17]. Bailey et al. [13] reported a decrease in stiffness of the infraspinatus through IASTM. They specifically mentioned conducting IASTM sessions to reduce muscle stiffness. Conversely, Ikeda et al. [17] did not observe a decrease in muscle stiffness when using IASTM. They performed a wide range of IASTM not only on muscles such as the gastrocnemius and soleus but also on surrounding tissues and muscle-tendon junctions. The muscle lengths and sizes of the medial gastrocnemius and soleus [27] are greater than those of the infraspinatus [28] and foot region, and the area beneath the skin is limited in the case of the soleus muscle. Within limited instrument sizes or time frames, the effectiveness of mobilization may vary depending on the length and size of the targeted muscle, which might have posed challenges in observing the effects of IASTM in the previous study [17]. In the current study, IASTM was applied to the plantar surface by a well-practiced practitioner, without direct intervention on the skin above the abductor hallucis, which would be related to the substantial effect of IASTM on plantar fascia stiffness but not on abductor hallucis stiffness. Taken together, to reduce stiffness using IASTM, it may be necessary to directly apply it to targeted tissues.

No significant changes in navicular height during sitting and foot contact area during standing were observed following IASTM (▶ **Fig. 4**), despite the substantial decrease (*d* = 1.24) in plantar fascia stiffness. Theoretically, reduced stiffness would result in a corresponding alternation of the medial longitudinal arch height. The present results suggest that although sufficient reduction in plantar fascia stiffness was achieved through IASTM, inducing changes in the medial longitudinal arch height proved to be challenging. Consistent with the results of the present study, load-induced changes in plantar fascia stiffness were poorly associated with changes in the foot shape [15]. Previous cross-sectional studies showed that plantar fascia stiffness was not different between individuals with normal foot and flat foot in unloading [14] and standing positions on both feet [29]. Furthermore, a modeling study [30] demonstrated that a decrease in the medial longitudinal arch height associated with a reduction in plantar fascia stiffness was less likely in stiffer plantar fascia. In the current study, it was found that individuals with a stiffer baseline demonstrated a greater reduction in the stiffness of the plantar fascia (▶ **Fig. 5**). Combining the findings of the present study with those of previous research suggests that individuals with initially higher plantar fascia stiffness are more prone to experiencing a reduction in stiffness; conversely, a decrease in medial longitudinal arch height is less likely to occur in these individuals. Collectively, the impact of stiffness changes in the plantar fascia on the medial longitudinal arch height would be small.

For the lack of significant change in the foot contact area, another possible factor is the potential improvement in neuromuscular activation of the intrinsic foot muscles under loading conditions. Osailan et al. [31] reported an increase in muscular power after a single session of IASTM. These findings imply that IASMT can enhance neuromuscular activation of the mobilized muscle. Fiolkowski et al. [2] showed that the reduced neuromuscular activation of the abductor hallucis due to the tibial nerve block was accompanied by increased navicular drop, implying that the abductor hallucis activation prevents the load-induced decrease in the medial longitudinal arch height. This suggests that the facilitation of intrinsic foot muscle activities by IASTM may counteract a decline in the medial longitudinal arch height induced by a decrease in plantar fascia stiffness. As we did not obtain any neuromuscular activation data in the current study, further research is necessary to clarify this matter.

The present study has some limitations. First, we evaluated the dependent variables in resting and static conditions. Careful attention is required to associate the role of the investigated tissues during dynamic movements with the results of the current study. Second, the participants in this study were limited to young males; thus, it is uncertain whether similar results would be obtained in females or older individuals. A previous study reported that the stiffness of the plantar fascia was similar between females and males [32], whereas another study demonstrated lower stiffness in males [33]. Older individuals have been reported to exhibit lower stiffness in muscle and fascia tissues than young individuals [18]. These may suggest the effectiveness of IASTM may be smaller in males and older individuals. Finally, we measured only the shear wave propagation velocity of the abductor hallucis and plantar fascia from one region. It was reported the regional differences in the plantar fascia stiffness along the foot [33]. Future research should investigate whether IASTM affects other muscles or tissues constructing the medial longitudinal arch, and whether such effects are similar among the different regions of the tissues within the foot.

The current study provides some practical implications. The present results indicated for the first time that IASTM can be applied to the foot region. Considering the different magnitudes of the IASTM effect on the plantar fascia and abductor hallucis stiffness, IASTM should be directly applied to tissues to achieve a substantial effect on their stiffness. A key finding is that the greater the stiffness of the plantar fascia, the more significant the reduction in stiffness by IASTM (▶ **Fig. 5**). This suggests that stiffness at baseline can be useful in predicting the IASTM effect, which would help the use of IASTM in sports and rehabilitation situations (e. g. in type II diabetes patients who have stiff plantar fascia [8]).

In conclusion, the present study revealed that instrument-assisted soft tissue mobilization (IASTM) on the plantar surface decreased plantar fascia stiffness. The effect was greater in individuals with higher stiffness of the plantar fascia, suggesting the practical usefulness of IASTM in the foot region. In contrast, the effects of IASTM on abductor hallucis stiffness, navicular height, and foot contact area were not significant. These results might be related to the lack of direct IASTM intervention on the skin above the abductor hallucis and potential improvement in neuromuscular activation of the intrinsic foot muscles by IASTM. The findings provide robust evidence that IASTM affects tissue stiffness without affecting foot structure.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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