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Original article

Differences in muscle attachment proportion within the most common location of medial tibial stress syndrome in vivo

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ABSTRACT

Introduction: The medial tibial stress syndrome is one of the most common causes of running-related injuries. The primary study objective was to observe the attachment proportion of flexor digitorum longus and soleus, at the most common location of medial tibial stress syndrome, using ultrasonography, on a large cohort of young males and females to evaluate for gender-based anatomical differences. The secondary objective of this study was to investigate the relationship between the anatomical features and medial tibial stress syndrome.
Methods: In this study, we observed whether or not flexor digitorum longus and/or soleus attached at the middle and distal thirds of the medial margin of the tibia (most common location of medial tibial stress syndrome) using ultrasonography. History of medial tibial stress syndrome was defined by inquiries.
Results: The Chi^2 tests showed that the attachment proportion of the soleus in female participants was significantly higher than that observed in male participants. In addition, Chi^2 testing showed that there were no significant differences between attachment proportion of soleus of legs with history of medial tibial stress syndrome and legs without history of medial tibial stress syndrome, in both male and female participants.
Conclusions: These results suggested that the anatomical features of flexor digitorum longus might be involved in medial tibial stress syndrome development, whereas the anatomical features of the soleus might not be involved in medial tibial stress syndrome development.
Level of evidence: III, cross-sectional study.

1. Introduction

The medial tibial stress syndrome (MTSS) is one of the most common causes of running-related injuries [1,2]. The pain of MTSS is localized to the middle and distal third of the medial margin of the tibia [3,4]. Previous studies found that females were at greater risk of MTSS than males [5,6]. Following onset, athletes with MTSS should stop competing for some time [7,8], which might lead to deconditioning. MTSS has a high recurrence rate [5], and it is an urgent problem requiring effective prevention methods and/or therapies.

The injury prevention model proposed by van Mechelen [9], states that it is necessary to identify the injury-related mechanisms and factors to prevent the injury, and this might be useful for constructing an injury prevention protocol. Previous studies have pointed out that the risk factors for MTSS development were body mass index and navicular drop, ankle plantarflexion range of motion, hip external ration range of motion, history of MTSS, and bone mineral density [10–13]. However, there was no consensus about the mechanisms underlying MTSS development. Therefore, Edama et al. used cadavers to understand the mechanisms of MTSS and reported that the attachment proportions to the middle and distal thirds of the medial margin of the tibia, the most common site affected by MTSS, were 97% for the flexor digitorum longus (FDL), 49% for soleus, and 0% for tibialis posterior [14], consistent with the subsequent study [15]. Interestingly, there was a significant gender difference in the proportion of soleus attachment to the middle and distal thirds of the medial margin of the tibia (females: 72.5%,

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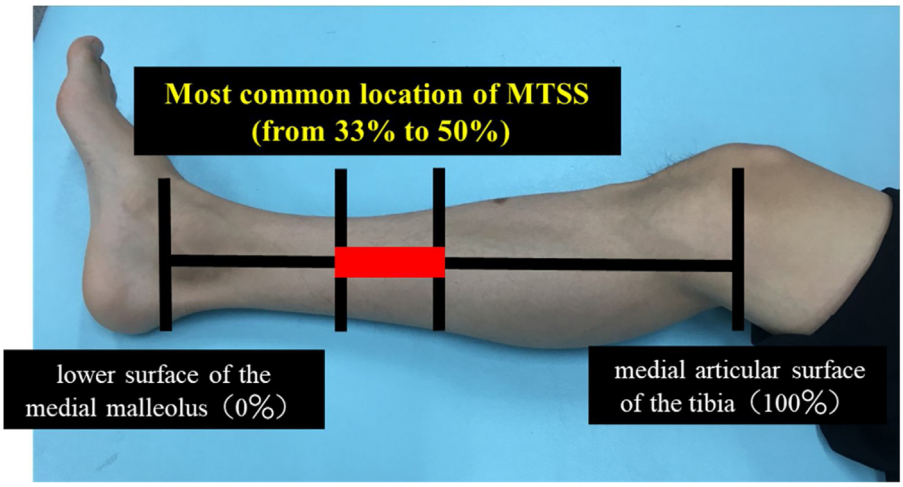

Fig. 1. Ultrasonographic measurement locations. The length of tibia was measured from the lower surface of the medial malleolus (0%) to the medial articular surface of the tibia (100%) by a digital caliper. We identified the most common location affected by MTSS as 33% to 50% from the lower surface of the medial malleolus.

males: 33.3%). Considered alongside previous studies [5,6,14], it appears likely that MTSS was involved in FDL in both sexes, and especially involved in the soleus, in addition to FDL, in females.

Many of the previous anatomical studies involved elderly cadavers [14,15], and there have been no in vivo anatomical studies. It is possible to observe the attachment of FDL and soleus at the most common location in patients with MTSS using ultrasonography in vivo. In addition, the previous study pointed out that most individuals who suffer from MTSS are young [16]. Therefore, it is necessary to examine the anatomical features of MTSS in young people to elucidate the mechanisms governing its occurrence. Moreover, MTSS has high relapse rate and a prior history of MTSS is a major risk factor for MTSS relapse [6,10,17]. Therefore, it is likely that runners with a history of MTSS possess physical factors that relate to MTSS development. However, since there have been no investigations of the relationship between anatomical features and MTSS, it is unclear if anatomical features are involved in MTSS development. Therefore, in order to clarify whether the attachments of the FDL and soleus, within the most common location of MTSS, are related to MTSS development.

MRI and ultrasonography imaging systems are available as methods to diagnose MTSS and evaluate the anatomical features of the muscles [11,18–20]. In addition, the development of 3D ultrasonography makes it possible to capture a wider picture. In recent years, with the development of 2D ultrasonography equipment, it has become possible to capture clear ultrasonography images more easily and inexpensively and to evaluate the anatomical characteristics of muscles in various situations. The primary study objective was to observe the attachment proportion of FDL and soleus, at the most common location of MTSS, using ultrasonography, on a large cohort of young males and females to evaluate for gender-based anatomical differences. The secondary objective of this study was to investigate the relationship between the anatomical features and a prior history of MTSS.

2. Material and methods

2.1. Participants

We examined 100 legs of 50 healthy participants [25 males (20.2 ± 2.1 years, 170.7 ± 4.4 cm, 64.0 ± 7.6 kg) and 25 females (20.9 ± 3.1 years, 156.7 ± 6.0 cm, 51.9 ± 6.3 kg)], all of whom volunteered to participate in this study. All subjects were fully informed of the procedures and purpose of the study, and all provided written informed consent. This study was approved by the ethics committee at the Niigata University of Health and Welfare in Niigata, Japan.

2.2. Ultrasonography

In this study, we observed whether or not FDL and/or soleus attached at the middle and distal thirds of the medial margin of the tibia (most common location of MTSS) using ultrasonography (Aplio 500, Toshiba Medical Systems, Tochigi, Japan) in vivo. The tibia length was measured from the lower surface of the medial malleolus (0%) to the medial articular surface of the tibia (100%) using a digital caliper (Mitutoyo Corp). As presented in Fig. 1, we identified the most common location affected by MTSS as 33%–50% from lower surface of the medial malleolus. After identifying the most common location of MTSS, we checked the location using the oil pen. In this study, we identified the lower surface of the medial malleolus and the medial articular surface of the tibia using ultrasonography (Fig. 2). As shown in Fig. 2, we investigated whether FDL or soleus was attached to the medial border of the tibia. In addition, we confirmed the measurement of the muscle by confirming the movement of muscle fibers during a B-mode ultrasonography examination of passive ankle or toe movement. Two observers investigated the presence or absence of attachment of FDL or soleus to the medial border of the tibia.

2.3. History of MTSS

History of MTSS was defined as per previous studies [21,22] as follows:

- experiencing exercise-induced pain on the posteromedial border of the tibia;
- experiencing pain along, or feeling discomfort on palpation of, the posteromedial border of the tibia;
- experiencing pain over an area of 5 cm along the posteromedial border of the tibia.

2.4. Statistical analyses

Statistical analyses were performed using SPSS (version 24.0, SPSS Japan INC., Tokyo, Japan). Differences between males and females for the attachment proportion of FDL and soleus, for most common location of MTSS, was assessed using the Chi^2 tests. In addition, to clarify the relationship between attachment proportion of FDL and soleus and MTSS history, the differences between

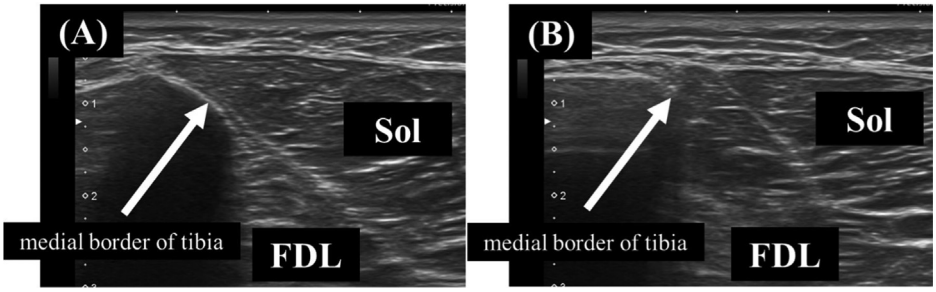

Fig. 2. Medial tibial border on ultrasound (transverse axis). We observed whether the flexor digitorum longus (FDL) and the soleus muscle (Sol) were attached to medial border of tibia, or not, at most common location affected by medial tibial stress syndrome (MTSS). A. Representative image depicting that both the FDL and soleus were attached to the medial border of the tibia. B. Representative image depicting that the FDL was attached to the medial border of the tibia, whereas the sol was not attached to the medial border of the tibia.

Table 1
The attachment portion of the FDL and soleus in both males and females.

	Both male and female		Male		Female	
	Legs	%	Legs	%	Legs	%
FDL	100	100	50	100	50	100
Soleus	31	31	7	14	24	48**

FDL: flexor digitorum longus.
** $p < 0.01$: significantly different between male and female.

legs with history of MTSS and legs without history of MTSS in each male and female participant for the attachment proportion of FDL and soleus were assessed using the Chi^2 tests. A p-value < 0.05 was considered to indicate statistical significance.

3. Results

The legs with a history of MTSS that were analyzed included males ($n = 14$, 28%) and females ($n = 16$, 32%). Table 1 presents the attachment proportion of FDL and soleus, for the most common location of MTSS, which was defined as 33%–50% from the lower surface of the medial malleolus. The attachment proportion of FDL was 100% in both males and females. The attachment proportion of the soleus was 14% (7 out of 50 legs) in male participants and 48% (24 out of 50 legs) in female participants. The Chi^2 tests showed that the attachment proportion of the soleus in female participants was significantly higher than that observed in male participants.

Findings of relationship between the attachment proportion of the FDL and soleus and MTSS history are shown in Table 2. In both male and female participants, the attachment proportion of FDL was 100% in both legs with, and without, a history of MTSS. In male participants, the attachment proportion of the soleus was 14.3% (2 out of 14 legs) in the legs with history of MTSS, and 13.9% (5 out of 36 legs) in the legs without history of MTSS. In female participants, the attachment proportion of the soleus was 50% (8 out of 16 legs) in the legs with history of MTSS and 47.1% (16 out of 34 legs) in the legs without history of MTSS. Chi^2 testing showed that there were no significant differences between attachment proportion of soleus of legs with history of MTSS and legs without history of MTSS, in both male and female participants.

4. Discussion

In this study, we observed the attachment proportion of the FDL and soleus, the most common location of MTSS, using ultrasonography for a large cohort of young males and females. Further, we investigated the relationship between anatomical features and MTSS history. The results of this study revealed that the attachment proportion of the soleus in female participants was significantly higher than that observed in male participants; however, there were no significant differences between the attachment proportion of the soleus in legs with, and without, a history of MTSS in both male and female participants. To the best of our knowledge, this is the first report to observe the attachment proportion of the FDL and soleus in a large cohort of both males and females. Additional examinations focused on the relationship between the attachment proportion of the FDL and soleus, and MTSS history.

Our results suggest that the attachment proportion of FDL, for the most common location of MTSS, was 100% in both male and female participants. A previous study reported that the attachment proportions of the FDL to the middle and distal thirds of the medial margin of the tibia were 95% in males and 100% in females, in a cadaver study [14], which was consistent with our results. FDL might be involved in MTSS development because the attachment proportion of the FDL, at the most common location of MTSS, was 100% in both male and female participants. Moreover, previous studies report a larger navicular drop and excessive pronation during running as risk factors for MTSS [5,17,23]. It is likely that a foot alignment abnormality, such as a larger navicular drop and excessive pronation during running, increases tension applied to the FDL, which can cause inflammation of the medial margin of the tibia, where the FDL is attached. Therefore, the results of this study suggest that reducing excessive tensile stress applied to the FDL could be useful as a preventive and therapeutic method for treating MTSS.

In addition, our observed gender differences show that the attachment proportion of the soleus in female participants was significantly higher than that observed in male participants, which

Table 2
Comparison of the attachment portion of the FDL and soleus between legs with a history of MTSS and those with no history of MTSS, in both males and females.

	Male				Female			
	Legs with a history of MTSS: 14 legs		Legs with no history of MTSS: 36 legs		Legs with a history of MTSS: 16 legs		Legs with no history of MTSS: 34 legs	
	Legs	%	Legs	%	Legs	%	Legs	%
FDL	14	100	36	100	16	100	34	100
Soleus	2	14.3	5	13.9	8	50.0	16	47.1

FDL: flexor digitorum longus; MTSS: medial tibial stress syndrome.

was consistent with a previous study [14]. The previous study reported that female sex was a risk factor for MTSS [5,6]. Therefore, it was likely that the occurrence of MTSS was involved in the soleus, in addition to the FDL, in females. However, there were no significant differences between attachment proportion of the soleus of legs with, and without, histories of MTSS in both male and female participants. Previous studies reported that a previous history of MTSS is a risk factor for MTSS relapse [6,17]. Taken together, it was assumed that the anatomical feature, which the higher attachment proportion of soleus at most common location of MTSS was female than male, might not be involved in MTSS development.

This study has some limitations. Because this was a cross-sectional study, future longitudinal studies are needed to clarify the role of the soleus in MTSS development. Recently, Akiyama et al. reported that shear elastic modulus of the lateral gastrocnemius, medial gastrocnemius, soleus, peroneus longus, and tibialis anterior were significantly higher in patients with MTSS and pain at the time of measurement, compared to healthy control subjects [24]. Moreover, Saeki et al. reported that the shear elastic moduli of the FDL and tibialis posterior, in subjects with a history of MTSS, were higher than in those without a history of MTSS [13]. In addition, our results showed that the attachment proportion of the FDL was 100% at the most common location of the MTSS in both males, and female. In summary, decrease in the shear elastic modulus of FDL might be effective for preventing or replacing MTSS. Thus, further study is needed to investigate the relationship between anatomical features and the shear elastic modulus to elucidate the mechanisms of MTSS development.

5. Conclusion

In this study, we observed the attachment of FDL and soleus at the most common location for MTSS by using ultrasonography. We also investigated the relationship between anatomical features and MTSS. The results of this study revealed that the attachment proportion of the FDL was 100% in both males and females and the attachment proportion of the soleus was significantly higher in female, than in male, participants. However, there were no significant differences between the attachment proportion of the soleus of legs with a history of MTSS and legs without a history of MTSS, in both male and female participants. These results suggested that the anatomical features of FDL might be involved in MTSS development, whereas the anatomical features of the soleus might not be involved in MTSS development.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contribution

MN contributed to study design and data correction, and drafted the manuscript; SO, TA, and DS contributed to data analysis and made critical revisions to the manuscript; RH, TK, EN, WI, and TT made critical revisions to the manuscript, ME was supervised the study, contributed to analysis and interpretation of data, and made critical revisions to the manuscript. All authors read and approved the final manuscript.

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