The effects of dynamic stretching on plantar flexor muscle-tendon tissue properties.

1. INTRODUCTION

Athletes commonly use stretching in their warm-up routines to increase joint flexibility. The most common method is static stretching, which places muscles in their lengthened positions and maintains the positions for a certain period of time (Kisner, 2001). Static stretching may help increase flexibility and reduce injuries (Hartig and Wiktorsson-Möller, 1983; Hartig and Henderson, 1999; Witvrouw et al., 2003). Previous researches mentioned that passive static stretching also lengthened the muscle fascicle, and decreased the pennation angle of the plantar flexors (Morse et al., 2003; Abellaneda et al., 2009). However, static stretching has also been found to have negative effects on maximal muscle strength (Kokkonen et al., 1998; Fowles et al., 2000), leg power (Yamaguchi and Ishii, 2005), vertical jumping (Cornwell et al., 2001; Hough et al., 2009), balance and reaction times (Behm et al., 2004), and 20-m sprint performance (Fletcher and Jones, 2004).

By contrast, dynamic stretching consists of performing movements that take the limb through range of motion (ROM) by contracting the agonist muscles, which allows the antagonist muscles to relax and elongate due to reciprocal inhibition (Murphy, 1994). Recent studies indicate that dynamic stretching could increase such sports-related

performances as leg extension power (Yamaguchi and Ishii, 2005), vertical jump height (Hough et al., 2009), and golf swing performance (Moran et al., 2009). Although dynamic stretching is now gaining recognition as an effective exercise for improving sports performance, precisely what happens to the muscle-tendon unit (MTU) is still unclear.

Ultrasonography is a non-invasive tool that is useful for assessing musculoskeletal images. Different types of stretching are considered to have different effects on the MTU. Until now, the effects of static stretching modes on muscle-tendon tissues have been reported by use of ultrasonography (Mahieu et al., 2007; Mahieu et al., 2009), but previous researches on dynamic stretching have focused on how it affects performance, not MTU structure. Understanding how dynamic stretching affects the MTU structure may clarify how it improves sporting performance.

Therefore, the purpose of the present study was to determine the effects of dynamic stretching on the plantar flexors by use of ultrasonography. We hypothesized that dynamic stretching would increase ankle dorsiflexion ROM and lengthen the MTU.

2. METHODS

2.1. Subjects

Twenty healthy male university students (age = 22.5 ± 2.4 years; height = 171.5 ± 6.1 cm; body mass = 61.4 ± 5.6 kg) were recruited for the present study. Subjects with histories of lower-leg injuries on the right side were excluded from this research. All subjects were volunteers and provided written informed consent before participating in the present study, which was approved by the University's Committee of Ethics in Research.

2.2. Stretching protocol

The experiment was conducted entirely within the University laboratory room with the room temperature maintained at 23 degrees. Before commencing the stretching exercises, subjects rode a cycle ergometer for 5 minutes as their warm-up. The subjects performed dynamic stretching on their right legs only. Each subject was instructed to stand with his right knee fully extended and to raise the entire foot off the floor, which led to hip flexion. The subjects were then instructed to perform active dorsiflexion and plantar flexion of their right ankle joints to a rhythm of 60 beats per minutes provided

by a metronome. Movement was performed in each direction for one second. This stretching exercise continued for 30 seconds and was repeated 5 times. This exercise was performed on the right side only. Between the stretching sessions, 30-second rest periods were provided and ultrasonic measurements were performed during the breaks.

2.3. ROM measurement

Passive ROM of ankle joint dorsiflexion was measured prior to commencing the stretching and immediately after the 5th set of stretching exercises. The same investigator performed all measurements. Ankle dorsiflexion ROM was defined as the angle between the proximal axis (from the head of the fibula to the lateral malleolus) and the distal axis (from the base to the head of the 5th metatarsal). The subject lay supine and the fibular head, the lateral malleolus, the 5th metatarsal head, and the 5th metatarsal base were marked. A digital camera (Easy Share V570; Kodak Corporation, Tokyo, Japan) was used to take the pictures at the end range of passive dorsiflexion. Open source digital measurement software (Image J, NIH, USA) was utilized to quantify the angle of dorsiflexion from the images.

2.4. Ultrasonic measurement

The position and the changes in the MTU before and after the dynamic stretching were recorded using real-time ultrasound (MY LAB25, Hitachi Medico, Japan) from a 15-MHz linear type probe with a 38-mm wide field of view. Each subject stood upright with feet parallel, looking at the same point on the front wall. Prior to stretching, the middle of the monitor display was marked with a white string. A rectangular plastic foam frame (proximal frame) through which the ultrasound probe could pass was placed onto the right calf of each subject to obtain measurements from the same location, a quarter proximal to the distance between the popliteal crease and center of the lateral malleolus (Fig. 1). The myotendinous junction (MTJ) was defined as where the superficial and deep aponeuroses of medial gastrocnemius (MG) met (Fig. 2-a). Another rectangular plastic foam frame (distal frame) was put on the right calf where the middle of the MTJ of the MG aligned with the mid line of the ultrasound monitor (Fig. 1), which was defined as the base line of the MTJ (Fig. 2-a). After the dynamic stretching, the probe was set in the same place and the image was taken. The MTJ displacement was then calculated by measuring the distance between the white reference line and the new MTJ position (Fig. 2-b). The ultrasound image of Fig. 2-b

shows the proximal displacement of the MTJ. The pennation angle of the MG (α), and fascicle length (L_f) were also assessed from the images, which were taken at the proximal frame (Fig. 3). The pennation angle of MG (α) was measured as the angle of insertion of the muscle fiber fascicles into deeper aponeurosis (Fukunaga et al., 1997). Fascicle length (L_f) was defined as the length of the fascicular path between the insertions of the fascicle into the upper and deeper aponeuroses and was estimated by the following equation (Kumagai et al., 2000).

$$\text{Fascicle length } (L_f) = \frac{\text{muscle thickness}}{\sin \text{ pennation angle } (\alpha)}$$

The muscle thickness was defined as the distance between the deeper and upper aponeuroses and was measured at the MTJ.

2.5. Reliability

To determine the intrarater and interrater reliability of the MTJ displacement measurement with ultrasound and the ankle dorsiflexion measurement with ImageJ software, the intraclass correlation coefficient (ICC) was utilized. MTJ displacement by ultrasonography showed good intrarater ($ICC_{1,2}$ = 0.99; SEM, 0.69 mm) and interrater reliability ($ICC_{2,1}$ = 0.76; SEM, 0.61 mm). The ankle dorsiflexion measurement also

showed good intrarater reliability ($ICC_{1,2}$ = 0.99; SEM, 0.79 degrees) and interrater reliability ($ICC_{2,1}$ = 0.98; SEM, 1.55 degrees).

2.6. Statistical analyses

Values are expressed as means ± SD. A paired t-test was utilized to see the change of ankle dorsiflexion ROM before and after the dynamic stretching. One-way repeated measures analysis of variance (ANOVA) was used to determine if there were any significant changes in the displacement of the MTJ, pennation angle, and fascicle length with dynamic stretching. If a significant interaction was detected, Fisher's least significant difference (LSD) test was used as a post hoc test. The significance level was set at $p < 0.05$.

3. RESULTS

Ankle dorsiflexion ROM was significantly greater after dynamic stretching (22.7 ± 9.1 degrees) than before (15.4 ± 9.6 degrees; $p < 0.0001$; Fig. 4). The displacement in the MTJ of MG is shown in Fig. 5. There were significant changes in the displacement of the MTJ among the baseline (before stretching; 0 mm), the first set (4.0 ± 1.7 mm)

and the second set (5.2 ± 1.8 mm; $p < 0.0001$). However, no significant changes were found after the third set. There were no significant changes in pennation angle or fascicle length before and after stretching ($p > 0.05$; Fig. 6).

4. DISCUSSION

In this study, we used ultrasonography to determine the effects of dynamic stretching on the muscle-tendon properties of the plantar flexors. From the results of the present study, significant changes were found in ankle dorsiflexion ROM and in the proximal displacement of the MTJ after dynamic stretching.

Ankle dorsiflexion ROM was significantly greater after dynamic stretching compared with before in this research ($p < 0.0001$). The only two previous studies available to refer to examined the effects of static and dynamic stretching on flexibility, respectively (Bandy et al., 1998; O'Sullivan et al., 2009). One study indicated that both types of stretching were effective in increasing hamstring flexibility, but another study reported that knee ROM was increased more with static stretching than with dynamic stretching (Bandy et al., 1998). The second study on the other hand, indicated that dynamic stretching did not increase hamstring flexibility, whereas static stretching did

(O'Sullivan et al., 2009). As such, static stretching is considered an effective means of increasing flexibility whereas the role of dynamic stretching is unclear. In the present study, we applied dynamic stretching to the plantar flexors and found several significant changes in ROM and MTJ position, i.e. lengthening of the Achilles tendon. These results might differ from previous studies due to the method of stretching, as well as the area targeted for stretching, but the dynamic stretching used in this study was considered to be effective in improving ROM of ankle dorsiflexion.

To the best of our knowledge, this study is the first to describe how muscle-tendon tissue properties change with dynamic stretching. The present results showed that the MTJ moved proximally and no significant changes in pennation angle, or fascicle length were found. Pennation angle and fascicle length have been used to determine change in muscle architecture (Fukunaga et al., 1997; Kumagai et al., 2000; Kawakami et al., 2008; Abellaneda et al., 2009). With increasing ankle dorsiflexion, a linear decrease in pennation angle and a linear increase in fascicle length were indicated (Muraoka et al., 2002; Abellaneda et al., 2009). Therefore, the dynamic stretching exercises applied to the plantar flexors in the present study primarily affected the length of tendons, not of muscle tissues. Achilles tendon tissues are known to lengthen with

isometric contraction of the plantar flexors as well as with increasing ankle dorsiflexion (Kawakami et al., 2008; Abellaneda et al., 2009). It has also been shown that passive plantar flexion ROM from 30 degrees to 0 degrees at the ankle led primarily to the lengthening of Achilles tendon tissues (Kawakami et al., 2008). Further increases in range towards 30° of passive ankle dorsiflexion caused both the gastrocnemius muscle and Achilles tendon tissues to lengthen (Abellaneda et al., 2009). Moreover, the Golgi tendon organ is known to be sensitive to tension in the muscle-tendon complex, to shut off the agonist contractions, and to stimulate the antagonist muscles, all important components of dynamic stretching (Alter, 2004; Willmore et al., 2008). Tendons are believed to prevent or reduce muscle injury during high-velocity action or the application of sudden external force (Alter, 2004). Therefore, it is proposed that dynamic stretching applied to the plantar flexors worked to change the length of Achilles tendon tissue.

The other finding of the present study was that a significant improvement in MTJ displacement was evident until the second set of dynamic stretching ($p < 0.0001$). That is, tendon tissues responded to the first 2 sets. Although a previous study reported finding a significant change of ROM with the first 3 sets of static stretching (Taylor et

al., 1990), none of the studies investigating basic dynamic stretching protocols have addressed how many repetitions should be used or how long stretching should be maintained. However, ROM of ankle dorsiflexion was only measured before and after the 5th set of dynamic stretching in this study. We did not measure the ROM after each set of dynamic stretching. The change of ROM should have been measured between each set of stretching so as to see the relationship between ROM and the response of muscle-tendon tissue properties. Therefore, further investigation by measuring ankle dorsiflexion ROM after each set of dynamic stretching is needed.

There are several limitations to this study. Firstly, we did not measure the length of the MTU. Knowing how much the length of each tissue changes as well as the displacement of MTJ might allow us to quantify how each tissue is lengthened with dynamic stretching, which might be relevant in determining the mechanism. Secondly, only young male subjects were used in the present research. Different age groups and/or including female subjects might produce different results. Thirdly, the dynamic stretching used in the present study was applied within the active ROM so the results might have been affected by ankle ROM of the subjects. The protocol used here was based on one that had been proven effective in another study (Yamaguchi and Ishii,

2005). A different protocol of dynamic stretching might have led to different results. However, research to identify the most effective protocol for dynamic stretching has yet to be conducted. Lastly, the stretching intervention in this study revealed only short-term results. Further research is needed to identify any long-term effects of dynamic stretching on muscle-tendon tissue properties.

The findings of this research have several clinical implications. Dynamic stretching was effective in increasing ankle dorsiflexion ROM and in lengthening the Achilles tendon. These results might prove useful when devising warm-up exercises as well as in the treatment of Achilles tendon injuries in a clinical setting.

5. CONCLUSIONS

The effects of dynamic stretching on the plantar flexor muscle-tendon tissue properties were determined by use of ultrasonography. Dynamic stretching on MG affected ankle dorsiflexion ROM. Proximal displacement of the MTJ of MG was found but the pennation angle and the fascicle length were significantly unchanged after dynamic stretching compared with before, such that dynamic stretching was thought to primarily affect tendinous tissues.

REFERENCES

Abellaneda S, Guissard N, Duchateau J. The relative lengthening of the myotendinous structures in the medial gastrocnemius during passive stretching differs among individuals. Journal of Applied Physiology 2009; 106: 169-177.

Bandy WD, Irion JM, Briggler M. The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. Journal of Orthopaedic and Sports Physical Therapy 1998; 27: 295-300.

Behm DG, Bambury A, Cahill F, Power K. Effect of acute static stretching on force, balance, reaction time, and movement time. Medicine and Science in Sports and Exercise 2004; 36: 1397-1402.

Cornwell A, Nelson AG, Heise GD, Sidaway B. Acute effects of passive muscle stretching on vertical jump performance. Journal of Human Movement Studies 2001; 40: 307-324.

Fletcher IM, Jones B. The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. Journal of Strength and Conditioning Research 2004; 18: 885-888.

Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the

human plantar flexors. Journal of Applied Physiology 2000; 89: 1179-1188.

Fukunaga T, Ichinose Y, Ito M, Kawakami Y, Fukashiro S. Determination of fascicle length and pennation in a contracting human muscle in vivo. Journal of Applied Physiology 1997; 82: 354-358.

Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity over use injuries in military basic trainees. American Journal of Sports Medicine 1999; 27: 173-176.

Hough PA, Ross EZ, Howatson G. Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. Journal of Strength and Conditioning Research 2009; 23: 507-512.

Kawakami Y, Kanehisa H, Fukunaga T. The relationship between passive ankle plantar flexion joint torque and gastrocnemius muscle and achilles tendon stiffness: Implications for flexibility Journal of Orthopaedic and Sports Physical Therapy 2008; 38: 269-275.

Kisner C, Colby LA. Therapeutic exercise: Foundations and techniques. Fourth edition. Philadelphia: FA Davis company; 2002. p. 171-9.

Kokkonen J, Nelson AG, Cornwell A. Acute muscle stretching inhibits maximal strength

performance. Research Quarterly for Exercise and Sport 1998; 69: 411-415.

Kumagai K, Abe T, Brechue WE, Ryushi T, Takano S, Mizuno M. Sprint performance is related to muscle fascicle length in male 100-m sprinters. Journal of Applied Physiology 2000; 88: 811-816.

Mahieu NN, McNair P, De Muynck M, et al. Effect of static and ballistic stretching on the muscle-tendon tissue properties. Medicine and Science in Sports and Exercise 2007; 39: 494-501.

Mahieu NN, Cools A, Wilde De, Boon M, Witvrouw E. Effect of proprioceptive neuromuscular facilitation stretching on the plantar flexor muscle-tendon tissue properties. Scandinavian Journal of Medicine and Science in Sports 2009; 19: 553-560.

Moran KA, McGrath T, Marshall BM, Wallace ES. Dynamic stretching and golf swing performance. International Journal of Sports Medicine 2009; 30: 113-118.

Morse CI, Degens H, Seynnes OR, Maganaris CN, Jones DA. The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. Journal of Physiology 2008; 586: 97-106.

Muraoka T, Muramatsu T, Takeshita D, Kawakami Y, Fukunaga T. Length change of

human gastrocnemius aponeurosis and tendon during passive joint motion. Cells Tissues Organs 2002; 171: 260-268.

Murphy DR. Dynamic range of motion training: an alternative to static stretching. Chiropractic sports medicine 1994; 8: 59-66.

O'Sullivan K, Murray E, Sainsbury D. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. BMC Musculoskeletal Disorders 2009; 10: 37.

Taylor DC, Dalton JD, Seaber AV, Garrett WE. Viscoelastic properties of MTUs. The biomechanical effects of stretching. American Journal of Sports Medicine 1990; 18: 300-308.

Wiktorsson-Möller M, Öberg B, Ekstrand J, Gillquist J. Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. American Journal of Sports Medicine 1983; 11: 249-252.

Willmore JH, Costill DL, Kenney WL. Physiology of Sport and Exercise. Fourth edition. Champaign: Human Kinetics; 2008. p. 23-45.

Witvrouw E, Danneels L, Asselman P, D'Have T, Camber D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players.

American Journal of Sports Medicine 2003; 31: 41- 46.

Yamaguchi T, Ishii K. Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. Journal of Strength and Conditioning Research 2005; 19: 677-683.

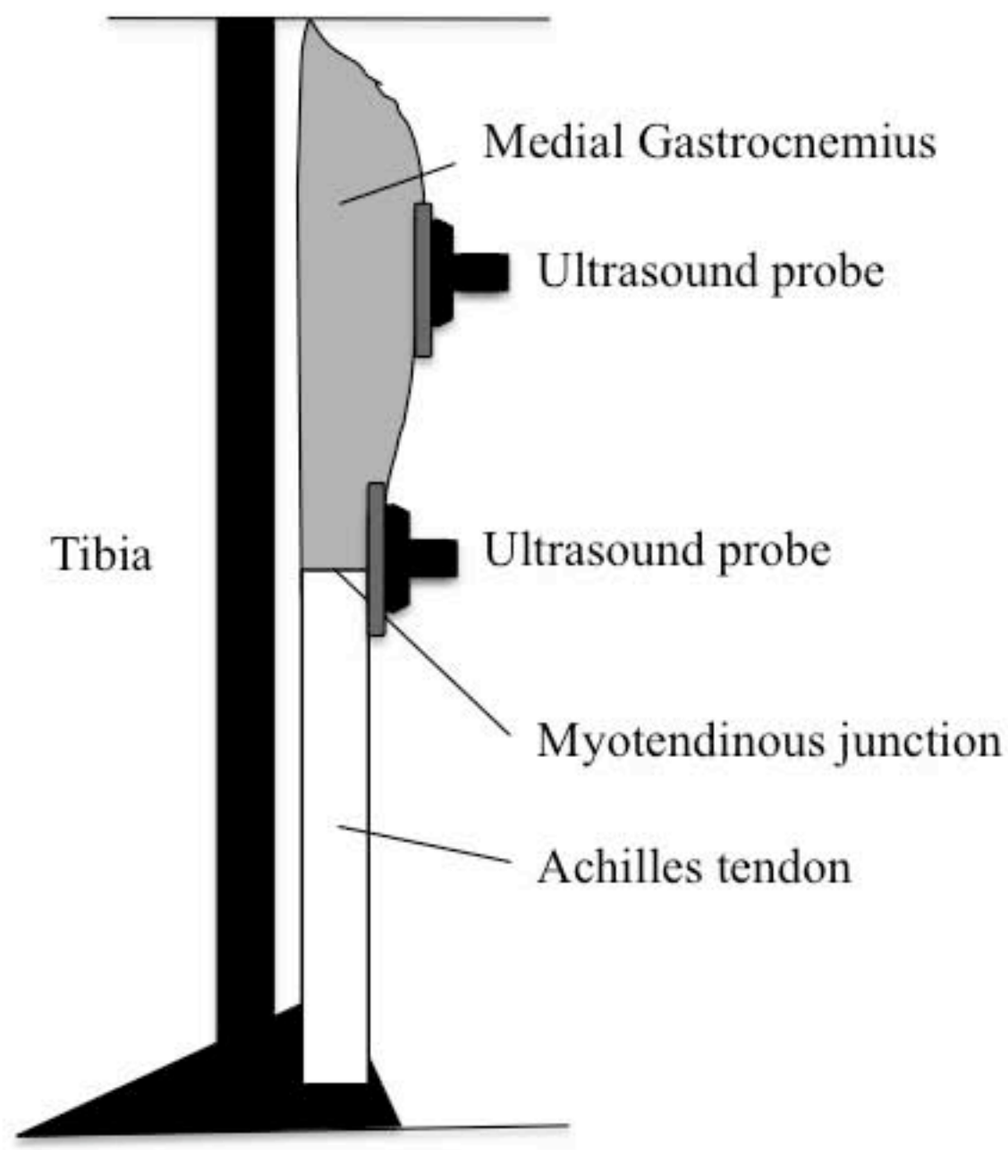

Fig 1. Ultrasound probe positioning.

(a) Before dynamic stretching

(b) After dynamic stretching

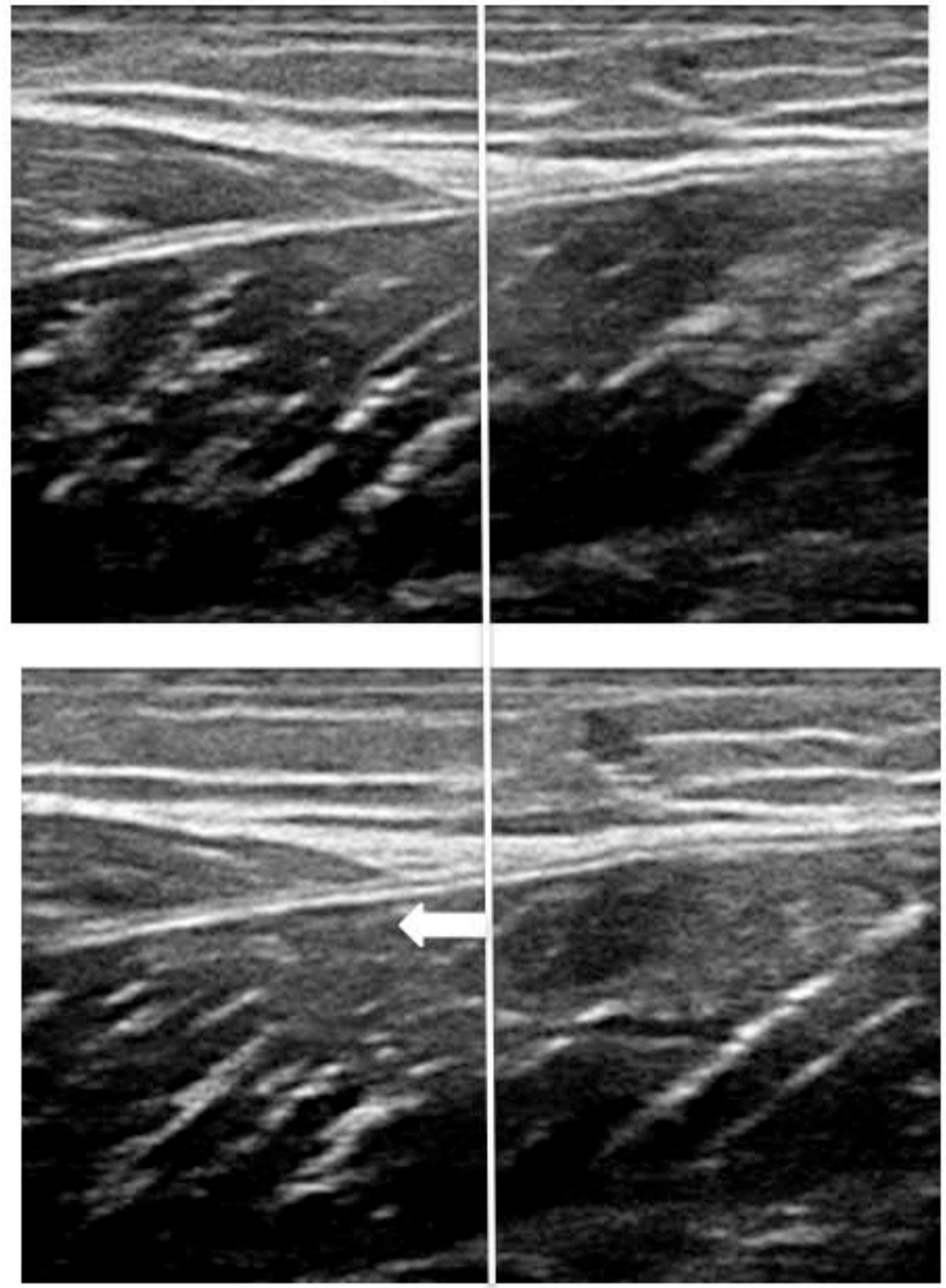

Fig. 2. Ultrasonographic images of the medial gastrocnemius myotendinous junction (MTJ). The white line indicates the location of the MTJ before dynamic stretching and the white arrow indicates the proximal displacement of the MTJ after dynamic stretching.

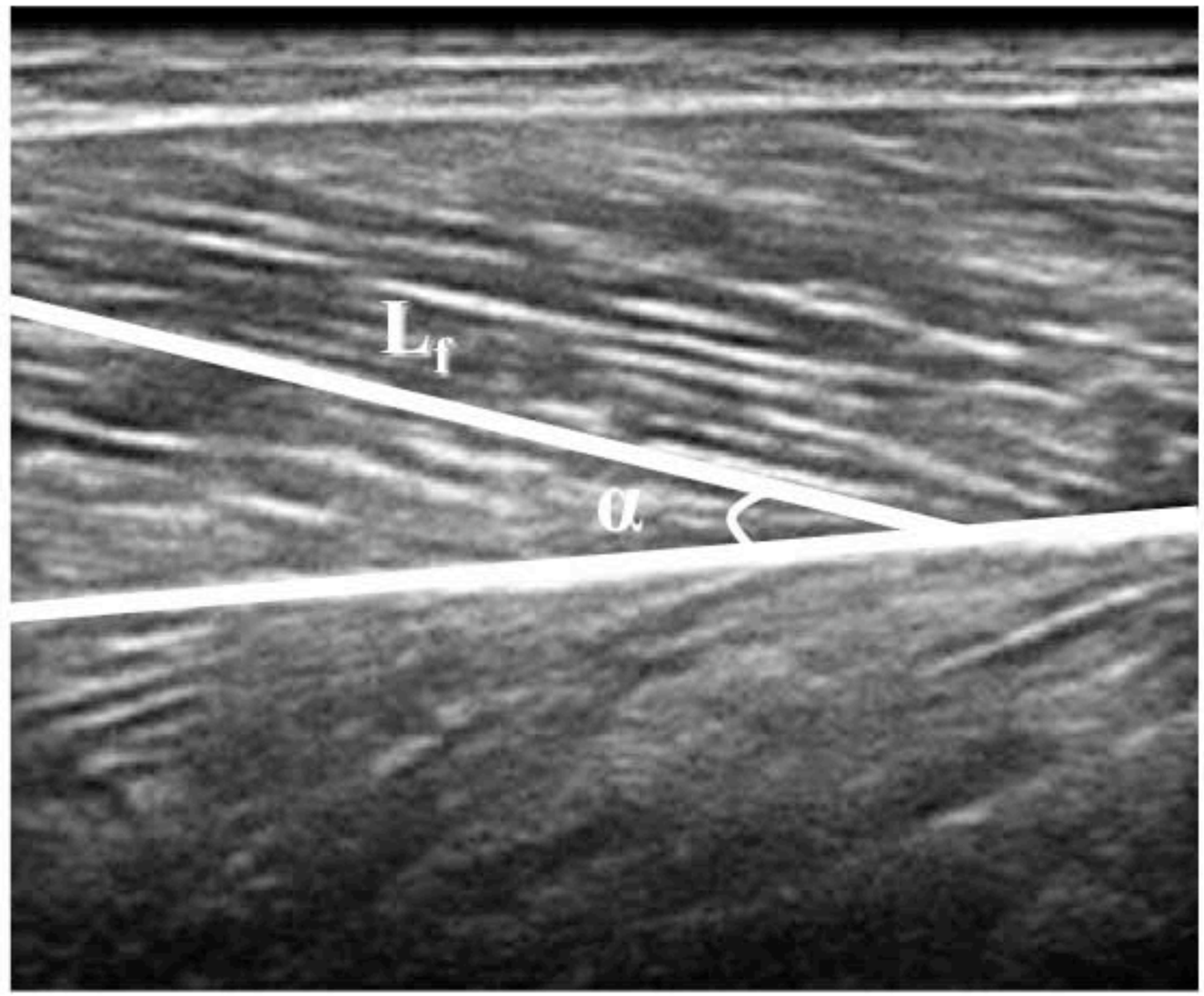

Fig. 3. Ultrasonographic images of the medial gastrocnemius. Lf indicates fascicle length and α indicates pennation angle.

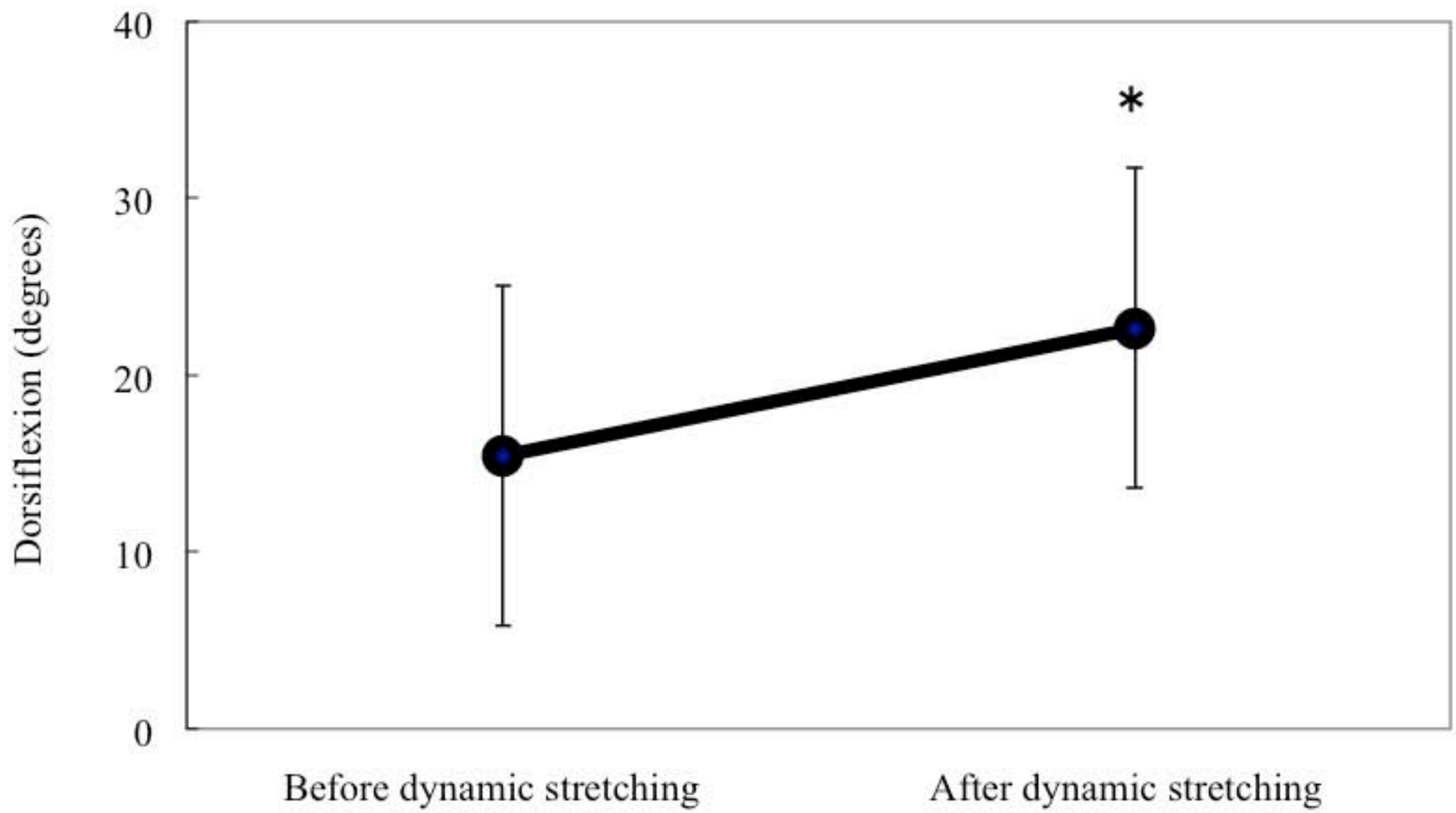

Fig. 4. Range of motion at ankle dorsi flexion before and after dynamic stretching.
* indicates a significant difference between before and after dynamic stretching ($p<0.0001$).

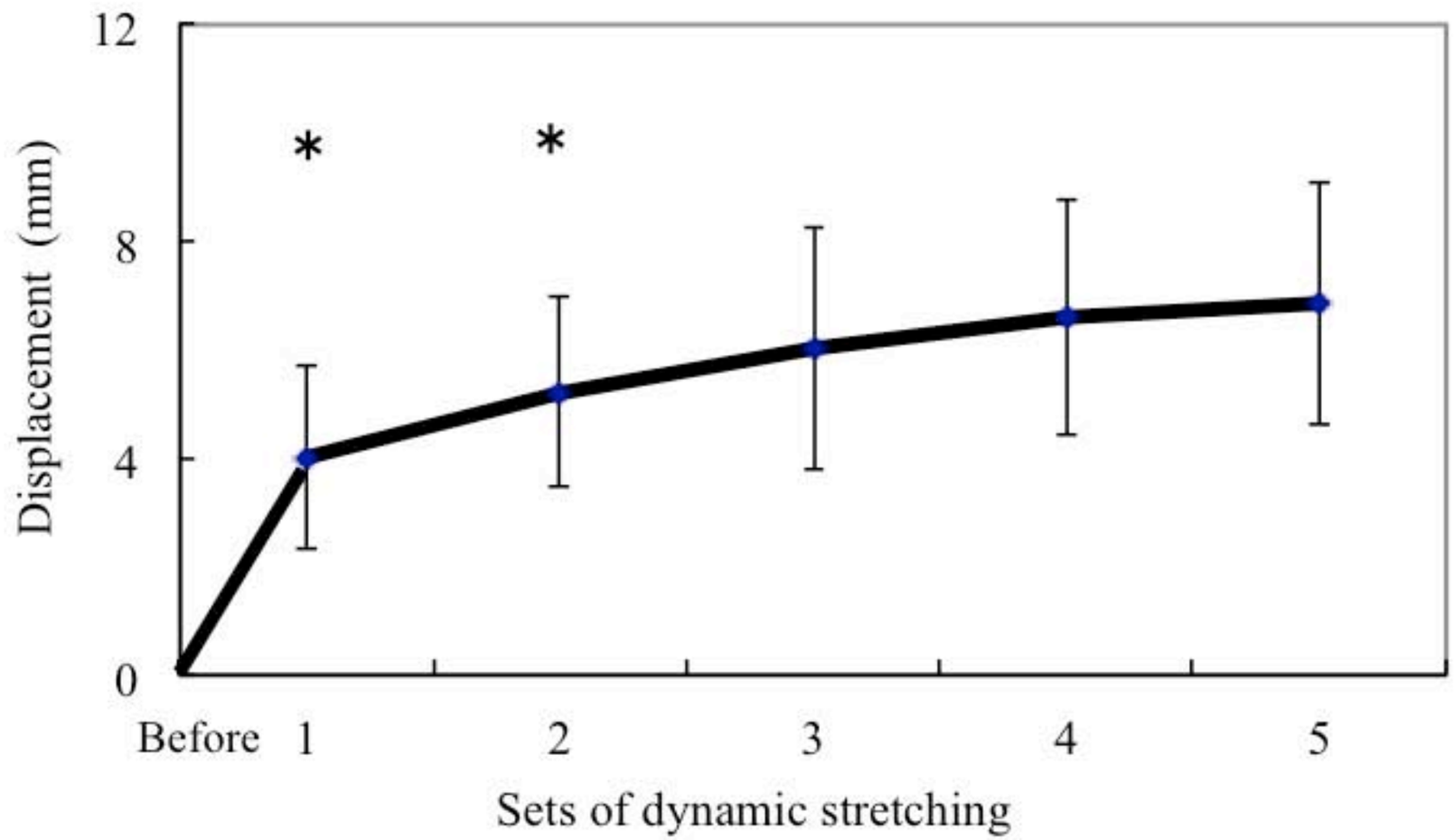

Fig. 5. The displacement of the myotendinous junction with dynamic stretching.
* indicates significant differences in the displacement of the MTJ among the baseline, the first set, and the second set ($p<0.0001$).

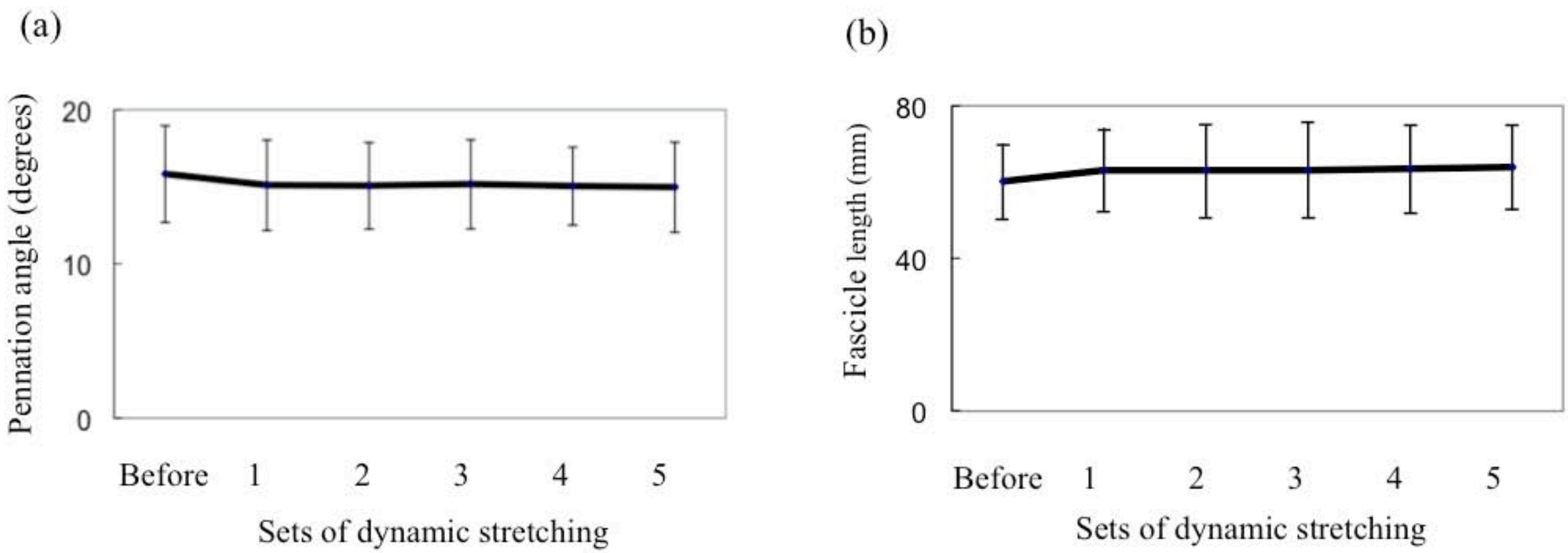

Fig. 6. Changes in the pennation angle (a) and the fascicle length (b) with dynamic stretching.

Table 1
Change in ankle dorsiflexion range of motion.

Variable	Before dynamic stretching	After dynamic stretching	p-value
Ankle dorsiflexion (°)	15.4 ± 9.6	22.7 ± 9.1	$p<0.0001$

All values are mean ± SD.

Table 2

Changes in the architectural parameters of medial gastrocnemius before and after dynamic stretching.

		Sets of dynamic stretching				
Variables	Before	1	2	3	4	5
Displacement of MTJ (mm)	0	4.0 ± 1.7 *,**	5.2 ± 1.8 *,**	6.0 ± 2.2 *	6.6 ± 2.2 *	6.8 ± 2.2 *
Pennation angle (°)	15.8 ± 3.1	15.1 ± 2.9	15.1 ± 2.8	15.2 ± 2.9	14.8 ± 2.9	15.0 ± 2.9
Muscle thickness (mm)	16.2 ± 3.2	16.3 ± 3.3	16.1 ± 3.4	16.3 ± 3.4	16.3 ± 3.4	16.3 ± 3.2
Fascicle length (mm)	60.2 ± 9.8	63.2 ± 10.9	62.9 ± 12.1	63.3 ± 12.7	63.4 ± 11.7	63.7 ± 11.2

All values are mean ± SD.

MTJ indicates myotendinous junction.

* Indicates significant difference was found compared with before DS.

** Indicates significant difference was found compared with 1 set before.