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Ankle-Dorsiflexion Range of Motion After Ankle Self-Stretching Using a Strap

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Context: A variety of ankle self-stretching exercises have been recommended to improve ankle-dorsiflexion range of motion (DFROM) in individuals with limited ankle dorsiflexion. A strap can be applied to stabilize the talus and facilitate anterior glide of the distal tibia at the talocrural joint during ankle self-stretching exercises. Novel ankle self-stretching using a strap (SSS) may be a useful method of improving ankle DFROM.

Objective: To compare the effects of 2 ankle-stretching techniques (static stretching versus SSS) on ankle DFROM.

Design: Randomized controlled clinical trial.

Setting: University research laboratory.

Patients or Other Participants: Thirty-two participants with limited active dorsiflexion (<20°) while sitting (14 women and 18 men) were recruited.

Main Outcome Measure(s): The participants performed 2 ankle self-stretching techniques (static stretching and SSS) for 3 weeks. Active DFROM (ADFROM), passive DFROM (PDFROM), and the lunge angle were measured. An independent *t* test was used to compare the improvements in these values before and after the 2 stretching interventions. The level of statistical significance was set at $\alpha = .05$.

Results: Active DFROM and PDFROM were greater in both stretching groups after the 3-week interventions. However, ADFROM, PDFROM, and the lunge angle were greater in the SSS group than in the static-stretching group ($P < .05$).

Conclusions: Ankle SSS is recommended to improve ADFROM, PDFROM, and the lunge angle in individuals with limited DFROM.

Key Words: limited ankle dorsiflexion, rehabilitation, injury prevention

Key Points

- Ankle self-stretching using a strap is a novel stretching technique used to improve ankle-dorsiflexion range of motion. It is more effective than static stretching and can be performed independently.
- For athletes with limited ankle range of motion, self-stretching with a strap can be recommended to improve their ankle-dorsiflexion range of motion and performance in functional and sports activities.
- The lunge angle was enhanced more with ankle self-stretching using a strap than with static stretching after 3-week interventions.

Ankle stretching has been considered an essential part of rehabilitation and physical fitness programs for injury prevention and improvement of ankle function.[1] Limited dorsiflexion range of motion (DFROM) may contribute to ankle, foot, and knee injuries, including plantar fasciitis,[2,3] ankle sprains,[4] Achilles tendinitis,[5] forefoot pain,[6] navicular stress fractures,[7] calf muscle tightness,[8] Achilles tendinopathy,[9] and anterior cruciate ligament injury.[10] Limited DFROM may be associated with various factors, such as tightness in the plantar flexors (gastrocnemius and soleus), soft tissue and capsular restriction, and loss of accessory motion at the tibiotalar, subtalar, tibiofibular, and midtarsal joints.[11] Posterior gliding of the talus should occur during ankle dorsiflexion (DF)[12,13]; reduced posterior gliding of the talus can contribute to limited DFROM.

Various interventions including static stretching,[14] runner's stretching,[15] mobilization with movement (MWM),[16,17] talus-stabilizing–taping (TST) techniques,[5,18] and orthoses[19] have been used to increase DFROM and prevent ankle and foot injuries in individuals with limited DFROM. Two mobilization techniques are available to improve DFROM. One traditional MWM technique is performed passively to glide the talus posteriorly in a non–weight-bearing position. Another MWM technique is performed in a weight-bearing position to improve DFROM, provide pain relief, and allow functional activities such as lunging and squatting.[17,18] Mobilization with movement can be applied with combined manual force by a therapist to glide the talus posteriorly and permit active DF in a weight-bearing position.[17] Previous authors[17,20] found that for individuals with limited DFROM, MWM techniques using weight-bearing exercises were more effective than techniques with a non–weight-bearing component. However, the MWM technique for ankle DF requires a therapist's hand to stabilize the ankle joint,[5,17] making it difficult for individuals to perform MWM independently.

Two methods have been introduced to facilitate posterior gliding of the talus during ankle DF exercises in a weight-

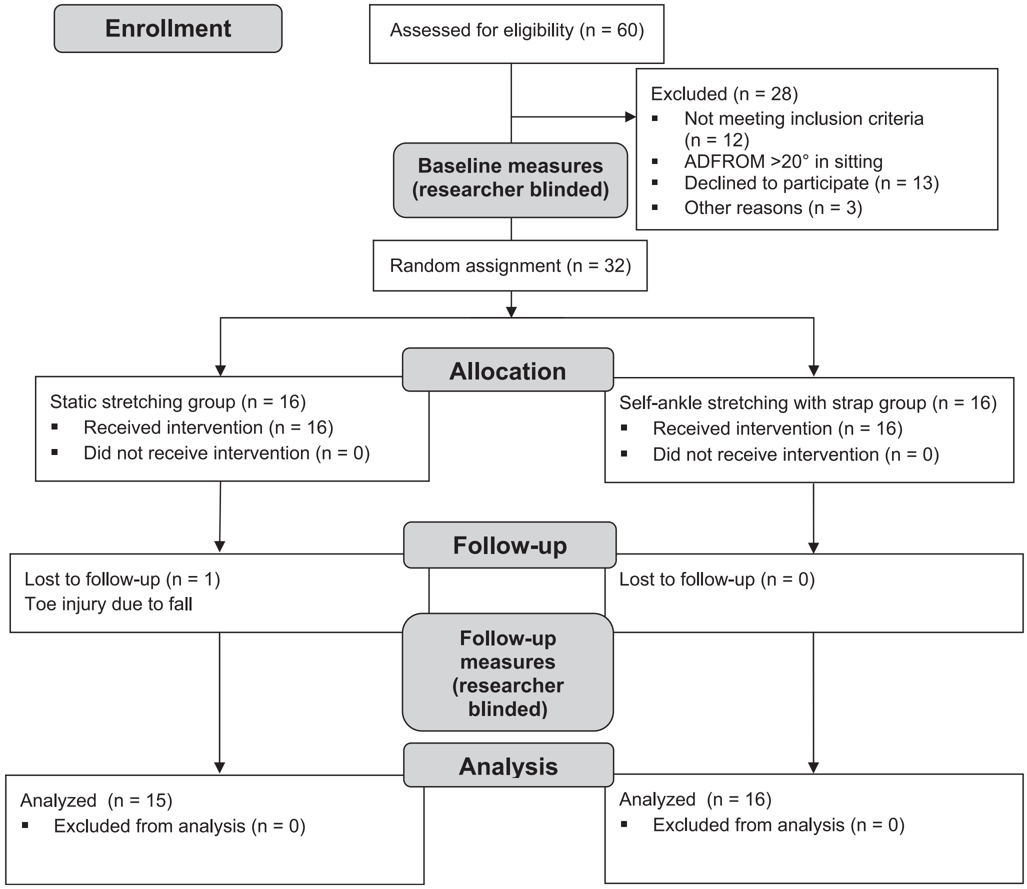

Figure 1. Flow chart of the participant-selection procedure. Abbreviation: ADFROM, active dorsiflexion range of motion.

bearing position.[5,18] Using the TST method during walking has also been suggested to increase DFROM.[5] Another ankle self-stretching DF exercise uses a towel to perform posterior glide of the talus during closed chain DF activity.[18] The MWM and TST methods, which use talar posterior gliding in the closed chain position, have been recommended for improving DFROM. Self-MWM towel- or strap-based techniques were introduced by Mulligan[21] to enable unrestricted movement without pain in the majority of joints in the body.[22] An additional ankle self-mobilization technique using a towel to provide posterior glide of the talus during closed chain DF activity has also been proposed.[18] Self-mobilization using a strap can increase wrist-extension range of motion and decrease wrist pain.[23] Therefore, we investigated whether strap-based stretching for talar posterior gliding was more effective than static stretching. To provide a self-stretching technique for facilitating gliding motion in the talocrural joint in the weight-bearing–lunge position, we designed the novel technique termed ankle *self-stretching using a strap* (SSS) for individuals with limited ankle DFROM.

To perform SSS, a strap approximately 30 cm long is tied to the anterior aspect of the talus on the front of the foot, which is on a 10° incline board, and the back of the strap is placed around the medial region of the plantar aspect of the foot on the ground to pull the talus in the posterior-inferior direction. The strap can be used to provide stability at the talus by pulling it during the lunge exercise.[5,18] Because the pulling force is applied during the lunge, SSS can affect both the musculotendinous tightness of the soleus and the arthrokinematic restriction of the talocrural joint, thereby improving DFROM. Additionally, during SSS, if the strap-pulling force is independently applied to specific regions of the ankle joint, SSS could be more effective than conventional static stretching.

In this study, we used conventional static stretching because it is among the most frequently self-applied static-position techniques.[24] However, SSS can be applied independently in the dynamic-lunge position using talar stabilization to improve ankle DFROM.[1,5,15] Thus, the aim of our study was to determine the effects of SSS on improvements in active DFROM (ADFROM), passive DFROM (PDFROM), and the lunge angle compared with static stretching. We hypothesized that SSS would increase ankle DFROM to a greater degree than static stretching would.

METHODS

Participants

In total, 32 participants (14 women and 18 men) with an ADFROM angle of <20° while sitting were recruited (Figure 1).[1] The mean age of the participants was 22.13 ± 1.64 years in the static group and 23.25 ± 2.65 years in the SSS group. The mean weight of participants was 58.6 ± 9.61 kg in the static group and 66.13 ± 11.96 kg in the SSS group. The mean height was 168.2 ± 9.35 cm in the static group and 170.56 ± 7.96 cm in the SSS group. The mean value for the ankle joint with limited ADFROM in the

Figure 2. Ankle self-stretching using a strap.

flexed-knee position was 15.75° ± 1.99° in the static group and 13.10° ± 5.95° in the SSS group ($P < .05$).

The following exclusion criteria were applied: (1) knee-flexion contracture; (2) neuromuscular disorder; (3) previous history of back, hip, knee, or ankle surgery; (4) hip, knee, or ankle injury in the previous 2 years; or (5) ankle fracture. Before this study, the investigator explained all procedures to the participants in detail. All participants provided written informed consent, and the study was approved by the Yonsei University Wonju Institutional Review Board.

Experimental Procedures

A randomized controlled trial design was used. The principal investigator (I.J.) administered the intervention. An assistant read and recorded the values from the measurement devices so that all examiners remained blind to the outcomes. The ADFROM inclusion criterion for both ankle joints while sitting was <20°. After baseline measurement of ADFROM, we also evaluated PDFROM and lunge angle. All participants were then randomly allocated into static-stretching (n = 16) and SSS (n = 16) groups using the Excel computer program (version 2007; Microsoft Corporation, Redmond, WA). One participant dropped out of the static-stretching group, resulting in a group size of 15 (7 right and 8 left ankles); 16 participants were included in the SSS group (8 right and 8 left ankles). Stretching exercises were performed 5 times per week for 3 weeks in the same location and under investigator supervision. The same examiner assessed the preintervention and postintervention outcomes for ADFROM, PDFROM, and lunge angle in the static-stretching and SSS groups.

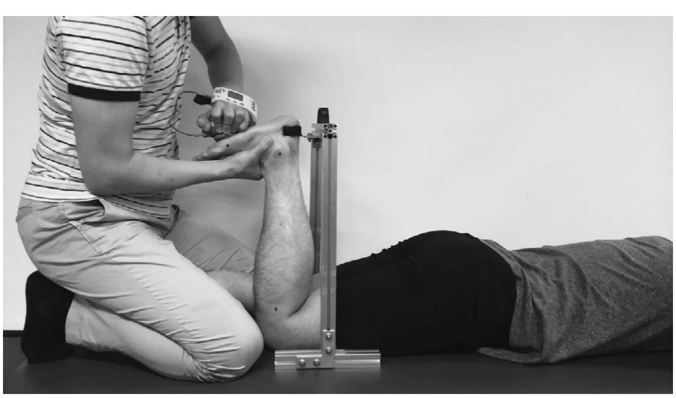

Figure 3. Measurement of passive dorsiflexion range of motion.

Figure 4. Measurement of lunge angle.

Static Stretching on the Incline Board

Each participant flexed the knee slightly while standing on a 10° incline board. The participant was asked to slightly flex both knees until a stretch was felt in the calf muscle. Stretching was performed for 20 seconds and repeated 15 times with the knee remaining slightly flexed. Between stretching exercises, we allowed 10 seconds of rest.

Ankle Self-Stretching Using a Strap

While lunging, the participant performed ankle self-stretching on the 10° incline board using a nonelastic strap approximately 30 cm long. The length and width of the incline board were approximately 30 and 10 cm, respectively (Figure 2). The tested foot was placed on the incline board. The opposite foot was then placed on the ground in the lunge position, and backward force was provided by pulling the strap. The front of the strap was placed around the anterior aspect of the talus of the test foot on the incline board, and the back of the strap was placed around the medial region of the opposite foot on the ground. The strap was positioned just inferior to the medial and lateral malleoli of the test foot. The incline board was used to control the pulling-force angle of the strap in the posterior-inferior direction on the test foot. The participant was asked to perform SSS with the strap pulled taut in the initial position; the knee of the front leg was subsequently moved forward along a straight line to effect a lunge during SSS. White tape (2-cm width) was attached to the middle of the incline board. The middle of the heel and second toe were placed on the taped line. To increase the strap's pulling force, the participant was required to perform a lunge while moving the knee forward without discomfort and pain until the soleus muscle of the front leg was stretched. This end position was then maintained by constantly applying pressure without lifting the heel for 20 seconds before the participant returned to the initial position. The strap was placed around the back foot to provide the posterior-inferior pulling force during SSS. These stretching interventions were performed 15 times, with 10 seconds of rest between exercises.

Table 1. Preintervention and Postintervention Active-Dorsiflexion Range of Motion in the Treatment Groups

Treatment Group	Active-Dorsiflexion Range of Motion, Mean ± SD, °		Mean Difference	*t* Value	*P* Value	Effect Size
	Preintervention	Postintervention				
Static stretching	15.75 ± 1.99	18.08 ± 2.46	2.33	−7.42	.001[a]	1.04
Ankle self-stretching using a strap	13.10 ± 5.95	19.91 ± 3.86	6.81	−6.58	.001[a]	1.36

[a] Independent *t* test: $P < .05$.

Active-DF Measurement

The DFROM was measured by 2 physical therapists who had a total of 3 years of clinical experience. The axis of the goniometer (Jamar, Jackson, MI) was placed on the lateral malleolus. The stationary arm was placed parallel to the center of the lateral side of the fifth metatarsal bone. The moving arm was placed parallel to the center of the fibular head, and the 3 axes were marked with a dot using a pen. The 3 marked dots were maintained at the same point until the end of the study. Before the examiners measured the ankle DFROM, the participant underwent preconditioning[20] by performing 4 active DF exercises for 5 seconds each. To measure ADFROM, the participant was placed in the prone position on the table and asked to flex the knee to 90°. The neutral subtalar-joint position was controlled by the examiner's hand, and the examiner measured the ankle-joint angle 3 times at maximum ADFROM.

Passive-DF Measurement

A handheld dynamometer (JTECH Medical, Midvale, UT) was used to constantly apply the moment of force (torque) to the sole while measuring PDFROM. The handheld dynamometer was positioned on the plantar surface of the forefoot at a distance of 8 cm from the lateral malleolus. The torque was controlled by applying 111 N of force perpendicular to the plantar surface of the forefoot (Figure 3).[25] Another examiner photographed the lateral side of the ankle. A camera was placed at the same height and in the same plane, 1 m from the sagittal plane of the ankle joint. A tripod was used to set the camera at 90° to minimize distortion. The ankle joint was positioned in the vertical plane using the guide (Figure 3). The measurement was performed 3 times. The image files were transferred to a personal computer for analysis using the ImageJ photographic-analysis software package (National Institutes of Health, Bethesda, MD). The ImageJ software package can analyze photographic images to provide an accurate measure of the angle,[26,27] and the PDFROM can be calculated by placing different markers on the exact point of the ankle axis at the lateral malleolus (ie, at the center of the lateral side of the fifth metatarsal bone and the fibular head).[26,27] This computer-assisted method has demonstrated good validity.[28] In a previous study,[29] the intraclass correlation coefficient (ICC [2,3]) was 0.92 to 0.99 for foot-arch–alignment measurements in ImageJ.

Lunge-Angle Measurement

An inclinometer (Baseline Inclinometer, White Plains, NY) was used to measure the tibial angle in the lunge position. The inclinometer was placed 15 cm below the center of the tibial tuberosity. The tibial tuberosity of the test foot was marked with a pen for consistent placement of the inclinometer. The ankle with limited DFROM underwent 3 trial measurements. During the lunge, the participant aligned the heel and second toe on a straight line on the ground. The second toe was placed against the edge of a wood stick. The participant lunged forward so that the patella pushed the wood stick as far away as possible with no heel lift (Figure 4).[30] The examiner confirmed that each participant's heel remained on the surface of the floor at all times during the measurements.[30] In addition, the direction of knee movement of the test foot was shifted forward and aligned over the second toe to minimize subtalar pronation.[31] The lunge angle was measured at the end point of tibial advancement.

Reliability of the Measurements

The intrarater reliabilities of ADFROM, PDFROM, and the lunge angle were assessed using the ICC ± SEM and the 95% confidence interval (CI). The intrarater reliabilities of the measurements were calculated for this study based on repeated trials of 5 healthy participants' outcome measures.[17] All experimental measurements had high intrarater reliability, with ICCs (3,1) of 0.97 (95% CI = 0.69, 0.99) for ADFROM, 0.99 (95% CI = 0.87, 0.99) for PDFROM, and 0.94 (95% CI = 0.39, 0.99) for the lunge angle. The SEM was 0.4° for ADFROM, 0.8° for PDFROM, and 2.0° for the lunge angle ($P < .05$).

Statistical Analysis

The data are expressed as mean ± standard deviation. The 1-sample Kolmogorov-Smirnov test was used to ensure normal distribution of the data collected through the measurements described earlier. To assess stretching effects, we calculated the Cohen d using mean ± standard deviation for the preintervention and postintervention data.[24,32] Cohen d values >0.8 indicated a *strong* effect, values >0.4 to ≤0.8 were regarded as *moderate*, and values ≤0.4 were rated as *weak*.[24,32] Independent *t* tests were used to compare initial differences in the ankle DFROM of the static-stretching and SSS groups. Paired *t* tests were used to

Table 2. Preintervention and Postintervention Passive-Dorsiflexion Range of Motion in the Treatment Groups

Treatment Group	Passive-Dorsiflexion Range of Motion, Mean ± SD, °		Mean Difference	*t* Value	*P* Value	Effect Size
	Preintervention	Postintervention				
Static stretching	20.75 ± 1.99	24.82 ± 3.80	4.07	−6.26	.001[a]	1.34
Ankle self-stretching using a strap	18.10 ± 5.95	25.98 ± 3.77	7.88	−7.41	.001[a]	1.58

[a] Independent *t* test: $P < .05$.

Table 3. Preintervention and Postintervention Lunge Angle in the Treatment Groups

Treatment Group	Lunge Angle, Mean ± SD, °		Mean Difference	*t* Value	*P* Value	Effect Size
	Preintervention	Postintervention				
Static stretching	37.75 ± 2.96	39.02 ± 5.32	1.27	−1.23	.24	0.30
Ankle self-stretching using a strap	37.27 ± 5.97	42.35 ± 6.03	5.08	−22.27	.001[a]	0.85

[a] Independent *t* test: $P < .05$.

compare the preintervention and postintervention dependent variables in both groups. Because differences between groups were identified at baseline, we used analysis of covariance for group comparison of postintervention dependent variables, with preintervention values as covariates. A value of $P < .05$ indicated statistical significance. The Statistical Package for the Social Sciences (version 18.0; SPSS Inc, Chicago, IL) was used for statistical analysis.

RESULTS

The groups did not differ in age ($P = .17$), height ($P = .45$), or weight ($P = .06$). Group differences were found in preintervention ADFROM and PDFROM. In both groups, the ADFROM and PDFROM scores were improved after the 3-week intervention (Tables 1 and 2). Lunge angle was greater postintervention in the SSS ($P < .001$) versus the static-stretching ($P = .24$) group (Table 3). Additionally, we observed differences in ADROM ($F_{1,28} = 14.13$, $P = .001$), PDROM ($F_{1,28} = 5.63$, $P = .025$), and lunge angle ($F_{1,28} = 13.30$, $P = .001$; Table 4).

Active DFROM was different between the SSS (preintervention = 13.10 ± 5.95, postintervention = 19.91 ± 3.86, $P < .05$) and static-stretching (preintervention = 15.75 ± 1.99, postintervention = 18.08 ± 2.46, $P < .05$) groups, as was PDFROM (SSS group: preintervention = 18.10 ± 5.95, postintervention = 25.98 ± 3.77, $P < .05$; static-stretching group: preintervention = 20.75 ± 1.99, postintervention = 24.82 ± 3.80, $P < .05$). Additionally, lunge angle differed between the SSS (preintervention = 37.27 ± 5.97, postintervention = 42.35 ± 6.03, $P < .05$) and static-stretching (preintervention = 37.75 ± 2.96, postintervention = 39.02 ± 5.32, $P = .24$) groups.

DISCUSSION

Insufficient DFROM has been considered a contributing factor to ankle and foot injuries.[5] Maintaining normal alignment of the ankle joint during ankle stretching is essential for improving DFROM.[33] To the best of our knowledge, this is the first study to elucidate the effect of ankle-stretching exercises on DFROM. The results of our study revealed improvements in ADFROM and PDFROM in both groups after 3 weeks of exercise interventions. However, compared with static stretching, SSS more effectively improved ADFROM, PDFROM, and lunge angle.

Various static-stretching interventions have been used to increase DFROM and prevent ankle and foot injuries in individuals with limited DFROM.[1,14,33,34] Knight et al[1] reported that static-stretching techniques applied for 6 weeks increased ADFROM and PDFROM by 4.1° (effect size = 0.93) and 6.1° (effect size = 1.02), respectively. A similar effect was observed in the static-stretching group in this study compared with previous studies[1,5,15,33,34]: static stretching increased ADFROM and PDFROM, which improved by 2.3° (effect size = 1.04) and 4.1° (effect size = 1.34), respectively. Ankle SSS improved ADFROM and PDFROM by 6.8° (effect size = 1.36) and 7.9° (effect size = 1.58), respectively. We also noted greater improvements in ADFROM and PDFROM after SSS than after static stretching.

In a previous study, the MWM technique with posterior talar gliding in a closed kinetic chain increased weight-bearing lunges by 0.6 cm (effect size = 0.39).[17] Lunge angle in the present study improved by 5.1° (effect size = 0.85) in the SSS group and by 1.3° (effect size = 0.30) in the static-stretching group. Although the results of these studies cannot be directly compared because those authors used different units of measurement, in our study, SSS improved ADFROM, PDFROM, and lunge angle. Two previous groups[11,16] investigated the immediate effects of MWM in participants with ankle sprains; however, the long-term effects of the MWM technique were not assessed. Therefore, direct comparison of our results with those of previous studies is not possible.

Several explanations are possible for the greater improvements in DFROM with SSS than with static stretching. First, Mulligan[21] stated that the MWM technique in the weight-bearing position for the posterior-inferior glide component can be used to minimize anterior talar displacement and restore normal ankle-joint kinematics for DFROM improvement. Posterior talar gliding is considered an accessory motion for ankle DF.[13] Reduced posterior talar gliding contributes to limited DFROM. In previous studies,[16,17] the MWM technique was applied with posterior-inferior gliding between the tibia and talus to increase limited DFROM, whereas we used an incline board for the SSS technique. The 10° incline board facilitates easy application of a posterior-inferior gliding force of the talus through the strap during SSS. This applied

Table 4. Postintervention Analysis of Covariance Results

Variable	Covariate	Treatment, Mean (95% Confidence Interval)		Adjusted R^2	*F* Value	*P* Value
		Static Stretching	Ankle Self-Stretching Using a Strap			
Active-dorsiflexion range of motion	14.39	17.36 (16.13, 18.60)	20.59 (19.39, 21.78)	0.53	−14.13	.001[a]
Passive-dorsiflexion range of motion	19.39	24.07 (22.49, 25.66)	26.68 (25.15, 28.21)	0.40	−5.63	.025[a]
Lunge angle	37.50	38.77 (37.23, 40.31)	42.59 (41.10, 44.08)	0.75	−13.30	.001[a]

[a] Independent *t* test: $P < .05$.

posterior-inferior gliding force may have contributed to the greater improvement in DFROM in the SSS group compared with the static-stretching group. Second, maintaining normal ankle-joint alignment during ankle stretching is essential for improving DFROM.[20] Each participant was asked to perform a lunge while bending the knee joint during SSS. In these procedures, both the middle of the heel and the second toe were aligned directly over a straight line to minimize subtalar pronation and other compensatory movements during stretching of the ankle joint.[30] Third, SSS was performed with the tested foot on the incline board in the lunge position, and the foot was moved forward to shift the participant's body weight. This may provide a greater stretching force than static stretching does. The greater stretching force produced by shifting the body weight forward may be another reason why DFROM was greater in the SSS group.

During performance of the traditional MWM technique in the lunge position, the therapist's hands provide a posterior-inferior gliding force. However, it may be difficult for the therapist's hands to contact the talus and maintain the posterior-inferior gliding force on the narrow joint surface between the talus and tibia, especially at the end of the lunge position. Therefore, we used a narrow strap to provide the posterior-inferior gliding force through the range of motion and for 20 seconds at the end of the lunge exercise. Although it was not directly measured, the continuous posterior-inferior gliding force provided by the strap may explain why SSS improved DFROM.

We did not directly measure the translation distance of the talus during SSS, but we can recommend the SSS technique to improve ankle DFROM. Indeed, SSS can be safely, simply, and independently applied with self-stretching exercises by individuals with limited ankle DFROM.

This study had several limitations. First, our results, which were obtained from young, healthy participants, cannot be generalized to adolescent and elderly populations. Second, follow-up studies may be needed to elucidate the lasting effects of the SSS technique. Third, the ADFROM of all participants in the sitting position was $<20°$, but the mean was 14.39°. Further investigations may be required to assess the effect of SSS in participants whose ankle ADFROM is more limited. Fourth, direct comparison of the conventional MWM and SSS techniques was not performed in this study. Further work may be required to directly compare the effects of the MWM and SSS techniques on limited ankle DFROM.

CONCLUSIONS

This study demonstrated greater improvements in ADFROM, PDFROM, and lunge angle in the SSS group than in the static-stretching group after 3-week interventions. We recommend ankle SSS to increase DFROM in individuals with limited DFROM.

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