Effects of Self–Ankle Stretching Using a Strap on the Ankle Dorsiflexion Range of Motion

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ABSTRACT

Effect of Self–Ankle Stretching Using a Strap on the Ankle Dorsiflexion Range of Motion

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Normal range of motion (ROM) of ankle dorsiflexion plays as important role in postural control and functional activities such as lunging and gait. The purpose of this study was to compare the effects of three different types of stretching techniques: static stretching, self–ankle stretching using a strap (SASS), and SASS plus active dorsiflexion (Active SASS) on ankle dorsiflexion ROM (DFROM), and the strength of the tibialis anterior.

Forty–eight volunteer subjects with limited (<20°) active dorsifexion in a sitting position (18 females, 30 males) were recruited for this study. The subjects were allocated randomly to three groups (static stretching, SASS, Active SASS). Static

stretching was performed while standing with knee flexion on an incline board (10°). SASS was performed while lunging, and the subjects lunged with a strap to stabilize the talus. Active SASS consisted of active dorsiflexion and SASS. Stretching exercises were performed for three weeks. A universal goniometer was used to measure active DFROM (ADFROM). Photographic analysis was used to measure passive DFROM (PDFROM). PDFROM was measured in 111 N pressures using a handheld dynamometer (HHD) in a prone knee flexion position. An inclinometer was used to measure the lunge angle. The HHD was used to measure the strength of the tibialis anterior. All of the dependent variables were measured three times and averaged. One–way analysis of variance was employed to compare the differences between pre– and post– values among three different stretching interventions (static stretching/SASS/Active SASS) on ADFROM, PDFROM, the lunge angle, and the strength of the tibialis anterior. The level of significance was set at $a = 0.05$.

The findings of this study showed that the ADFROM and PDFROM were significantly increased in all stretching groups after three–week interventions. However, the ADFROM, PDFROM, and the lunge angle were more increased in SASS and Active SASS groups than the static stretching group. There were no significant differences in DFROM data between SASS and Active SASS groups ($p>0.05$). The strength of the tibialis anterior was significantly increased in Active SASS.

In conclusion, SASS and Active SASS can be recommended for improving

DFROM, and Active SASS can be applied to improve both ankle DFROM and the strength of the tibialis anterior in individuals with limited DFROM

Key words: Ankle dorsiflexion, Limited ankle dorsiflexion, Self–ankle stretching using a strap.

Introduction

Ankle stretching has been considered as an essential part of rehabilitation and physical fitness programs for injury prevention and ankle function improvement (Knight et al. 2001). Limited dorsiflexion of range of motion (DFROM) may contribute to ankle and foot injuries such as plantar fasciitis (Kibler, Goldberg, and Chandler 1991; Riddle et al. 2003), ankle sprains (Willems et al. 2005), Achilles tendinitis (Kang et al. 2013), forefoot pain (DiGiovanni et al. 2002), navicular stress fractures (Agosta, and Morarty 1999), Patella tendinopathy (Malliaras, Cook, and Kent 2006), and Achilles tendinopathy (Angermann, and Hovgaard 1999).

Many factors, such as for the limitation of DFROM could be involved with various factors such as tightness in the plantar flexors (gastrocnemius and soleus), soft tissue and capsular restrictions, and the loss of accessory motions at the tibiotalar, subtalar, tibiofibular, and midtarsal joints (Denegar, Hertel, and Fonseca. 2002). Posterior gliding of the talus should occur during ankle dorsiflexion (DF) (Pope, Herbert, and Kirwan 1998; Williams 1980). Reduced posterior gliding of the talus can contribute to limited DFROM.

Various interventions, such as static stretching (De Vries 1962), runner's stretch (Williford et al. 1986), mobilization with movement (MWM) (Collins, Teys, and Vicenzino 2004; Vicenzino et al. 2006), talus–stabilizing taping techniques (TST) (Kang et al. 2013, Sahrmann 2010), and orthosis (Selby–Silverstein et al. 1997), have been used to increase DFROM and to prevent ankle and foot injuries in individuals with limited DFROM.

There are the two mobilization techniques for improving DFROM. One traditional mobilization 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 for functional activities such as lunging and squatting (Sahrmann 2010; Vicenzino et al. 2006). MWM can be applied with combined manual force by a therapist to glide the talus posteriorly and permit active DF in a weight–bearing position (Vicenzino et al. 2006).

Previous study has found that MWM techniques using weight–bearing exercises were more effective than techniques with a non–weight–bearing component for individuals with limited DFROM (Trevino, Davis, and Hecht 1994; Vicenzino, Prangley, and Martin 2004). Because the MWM technique for ankle DF requires a therapist's hand, it is impossible to perform MWM independently (Kang et al. 2013; Vicenzino et al. 2006).

Some methods were introduced to facilitate the posterior gliding of the talus during ankle DF exercises in a weight–bearing position. TST method during walking has also been suggested to increase DFROM (Kang et al. 2013). Another self–ankle DF exercise using towel to provide a posterior glide of talus during closed chain DF activity has been suggested (Sahrmann 2010).

However, the method involving a towel can increase excessive lumbar flexion loads and cause muscle fatigue in the upper extremities. Therefore, in this study, to provide the techniques to mobilize ankle joint as a self–intervention in weight–bearing lunge position, self–ankle stretching using a strap (SASS) and SASS plus active DF (Active SASS) have recently been recommended as new methods for individuals with limited DFROM.

To perform SASS, a strap is applied to the talus in the anterior to posterior with the superior to inferior direction in a diagonal manner while lunging is performed with the inclined tibia forward. The strap can also be used to help provide stability in the talus by pulling the strap placed on the talus during a close chain activity requiring tibial advancement on the foot (Sahrmann 2010; Kang et al. 2013). The technique using the application of the strap would be pulled with talus to posterior–inferior direction by the other foot for talus posterior gliding during lunge.

Vicenzino (2001) reported that posterior gliding of the talus during weight–bearing activities can be combined with active DF to improve DFROM. To perform Active SASS, a technique that used active contraction of the tibialis anterior with SASS was recommended to improve limitations of DFROM. These elements can improve the DFROM and functional activities such as lunging.

Thus, the aim of the current study was to determine the effects of SASS and Active SASS on improving active DFROM (ADFROM), passive DFROM (PDFROM), the lunge angle, and the strength of the tibialis anterior. It is hypothesized that (1) SASS would increase ankle DFROM more than static stretching; (2) Active SASS would increase ankle DFROM more than the other interventions.

Methods

1. Subjects

For this study, 48 subjects (18 females, 30 males) with an angle of less than 20° of ADFROM were included (Williford et al. 1986) after 60 subjects living in Won ju city underwent a screening test.

Exclusion criteria were if they had 1) impaired sensation; 2) a previous neuromuscular disorder; 3) a previous surgery to the back, hip, knee, or ankle; 4) hip, knee, or ankle pathologies (within the past two years); or 5) a fracture to the ankle. Before this study, the investigator explained all of the procedures to the subjects in detail. All subjects signed an informed consent form approved by Yonsei University Wonju Institutional Review Board. The subjects' age, weight, height and the mean value of ADFROM are shown in Table 1.

Table 1. General characteristics of the subjects. (N=48)

Parameter	Mean ± [a]SD	Range
Age (years)	22.94 ± 2.73	20–30
Weight (kg)	63.15 ± 10.84	44–93
Height (cm)	170.43 ± 8.37	153–183
Mean value of [b]ADFROM (°)	13.96 ± 4.24	9.72–18.2

[a]SD: Standard Deviation.
[b]ADFROM: Active Dorsiflexion Range of Motion.

2. Experimental Equipment

2.1 Universal Goniometer

The angle of ankle joint was measured using a universal goniometer (Jamar, Jackson, MI, USA), which is 14–inch with 360° stainless steel goniometer (Figure 1).

Figure 1. Universal goniometer.

2.2 Inclinometer

An inclinometer (Baseline Inclinometer, Irvington, NY, USA) was used to measure the tibia angle from the ground while each subject lunged. The shape of the inclinometer was circular with a two–point contact surface at its base (Figure 2).

Figure 2. Inclinometer.

2.3 Photographic Analysis

Two–dimensional photographic analysis was performed using ImageJ image analysis software (National Institutes of Health, USA) to measure the PDFROM. The ImageJ method can provide accurate outcome analysis, as it has obtained good validity as a computer–assisted method (Tran et al. 2003). In a previous study, the ICC (2, 3) obtained with ImageJ was 0.92–0.99 for foot arch alignment measurements (Rao, and Bell 2013).

2.4 Hand– Held Dynamometer (HHD)

A PowerTrack II™ Commander dynamometer (JTECH Medical, Salt Lake City, USA) was used to measure the muscle strength of the tibialis anterior (Figure 3). The unit of measurement was Newtons (N) generated while each subject performed an isometric contraction. A PowerTrack II^{TM} Commander dynamometer can provide force records for intervals of 0.1N.

Figure 3. PowerTrack II^{TM} Commander dynamometer.

3. Ankle Dorsiflexion Measurement Using a Goniometer

The DFROM was measured by clinical physical therapists with three years of experience. The axis of the goniometer 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, respectively, and the three axes were expressed with a dot using a pen. During the study, the three marked points were maintained to record the constant region. Before the examiners measured ankle DFROM, the subjects performed four 5–second active DF to differentiate between temporary and lasting effects before the DFROM was measured, which was called “preconditioning” (Zito et al. 1997). To measure the ADFROM, subjects were positioned in prone on the table and asked to perform knee flexion at 90°. The neutral subtalar joint position was controlled by the examiner’s hand, and the examiner measured the ankle joint angle three times while each subject performed full ADFROM in a neutral subtalar joint position. All measurements were performed in the single–blinded design, and the goniometer was replaced between measurement trials (Figure 4A). To measure the PDFROM, each subject’s knee was positioned at 90° in the prone position. To apply pressure constantly on the sole while measuring the PDFROM, a hand–held dynamometer (HHD) was used.

The HHD was positioned on the plantar surface of the forefoot 8 ㎝ away from the lateral malleolus. The examiner pressed the HHD until 111N of pressure was obtained

(Wilken et al. 2011). Another examiner took pictures of the lateral side of the ankle. The pressure value was confirmed using the HHD, and the examiner performed the measurement three times for the PDFROM using the ImageJ photographic analysis program (National Institutes of Health, USA).

The photographic measures were taken while the calf muscles were completely relaxed with firm resistance felt, and the pressure from the HHD reached 111N. The ankle joint of all subjects was photographed from 1 m behind them from the sagittal plane of the ankle joint (Figure 4B). The DFROM in the knee–flexed 90° in prone position was collected for data. Three trial measurements were averaged for ADFROM and PDFROM data analysis.

ADFROM PDFROM

Figure 4. Measurement of active (A) and passive dorsiflexion range of motion (B)

4. Lunge Angle Measurement

A lunge was performed to measure the angle between the anterior border of the tibia and the vertical line using the inclinometer (Baseline Inclinometer, Irvington, New York), which was placed over the region 15 ㎝ below the center of the tibial tuberosity.

To measure the angle, the unilateral side of the ankle with limited DFROM was measured with three trial measurements. During the lunge, subjects placed their heel and big toe aligned directly on a tape measure and perpendicular to the wood prop. In addition, the top of the big toe was placed against the edge of the wood prop. This process was required to prevent ankle compensation, such as subtalar pronation, which could alter the neutral subtalar joint position (Munteanu et al. 2009). Subjects lunged forward while looking forward during all of the tests so that the top of their patella could push the wood prop as far away as possible with no heel lift. The examiner confirmed that each subject's heel remained on the surface of floor all the times during the measurements (O'Shea, and Grafton 2013). In addition, the moving direction of the patella of the tested ankle was moved forward and aligned over the second toe to measure precise DFROM without subtalar pronation (Munteanu et al. 2009). The spot 15 ㎝ below the center of the tibial tuberosity was marked using a marker to apply the center of the inclinometer. Three separate measurements were averaged. The angle measurements were performed three times with 15 seconds of resting time between trials to prevent fatigue, which could affect ankle flexibility because of the repeated measurements (O'Shea, and Grafton 2013). The DFROM while lunging was measured at the end point of tibial advancement with heel contact on the ground (Figure 5).

Figure 5. Lunge angle measurement.

5. Measurement of Strength of Tibialis Anterior

To measure strength of tibialis anterior, each subject was tested while sitting with one knee flexed to 90°. Then, subjects leaned their upper body back comfortably with both arms supporting the upper body. To test subjects' strength of tibialis anterior, ankle DF was performed without extension of the great toe and with inversion of the foot (Kendall, McCreary, and Provance. 1993). The strength of the muscle was measured with the HHD. Peak force was measured for all of the subjects using a dynamometer (0.1N unit). The dynamometer was placed over the dorsal surface of the foot, 8 ㎝ away from the lateral malleolus and in the direction of plantar flexion of the ankle joint. The subjects were required to maintain ankle DF for three seconds while downward pressure was applied by the examiner (Docherty, Moore, and Arnold 1998) (Figure 6). The measurements were performed three times with 15 seconds of resting time between trials to prevent fatigue (O'Shea, and Grafton 2013). All three trial data values were averaged.

Figure 6. Measurement of strength of tibialis anterior.

6. Experimental Procedures

All subjects were evaluated for experimental participation at the initial visit. Each ankle was measured using the universal goniometer with 90° of knee flexion on the table. An angle of less than 20° of ADFROM was collected for 48 limited ankles, and 15 samples were assigned to static stretching, 16 samples to SASS, and 17 samples to Active SASS. Randomized controlled trials, examiner single–blind, repeated measurements were used for this study. Three exercise interventions consisted of (1) static stretching with an incline board, (2) SASS, (3) Active SASS. After the collection of suitable subjects, the examiner measured the angle of the each limited ankle pre–intervention. Following the three–week intervention, the post–intervention was performed.

6.1 Static Stretching on the Incline Board

Each subject performed slight knee flexion in standing on the incline board. The angle of the incline board was adjusted to 10°, as the PDFROM angle should be at least 10° to prevent ankle injuries (Johanson et al. 2006b; Kang et al. 2013). So, the angle of incline board in this study was used at least for functional angle with weight–bearing activities, which could be prevented from ankle injuries. Slight knee flexion while standing was slowly progressed until the end feel was felt in the calf muscles as the soleus muscle was stretched on the 10° incline board (Figure 7). Stretching was performed for 20 seconds and repeated 15 times in the posture with slight knee flexion. Ten seconds of resting time was given between the repetitive trials.

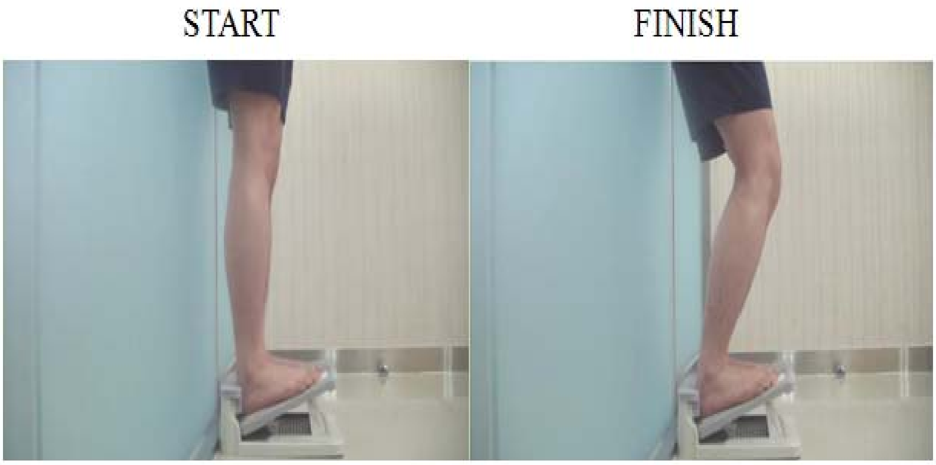

Figure 7. Static stretching technique.

6.2 Self–Ankle Stretching Using a Strap (SASS)

While lunging, subjects performed self–ankle stretching on the 10° incline board using a strap. The limited target foot was placed on the incline board. Then, the opposite foot was placed on the ground to support weight bearing and provide backward force by pulling the strap, which was non–elastic. The strap was located on the talus region of the limited target foot on the incline board and located on the middle of the opposite foot on the ground to provide strong force in opposing directions. The self stretching was performed as one side of the strap was pulled to either side. During stretching while lunging, the direction of the patella of the ankle on the incline board was maintained while moving forward as knee flexion was slightly increased. Slight knee flexion in standing was slowly progressed until it was felt in calf muscles as the soleus muscle was stretched on the 10° incline board. Then, the other side of foot was placed behind the incline board to sustain a pulling force. The top of the heel and big toe were aligned directly in a straight line, and the patella was moved forward exactly in the same straight line. Additionally, the direction of the pulling force from the other foot was maintained in the same line (Figure 8). These stretching interventions were performed for 20 seconds and repeated 15 times with 10 seconds of resting time between trials.

Figure 8. Self–ankle stretching using a strap.

6.3 Self–Ankle Stretching Using a Strap Plus Active Dorsiflexion (Active SASS)

Subjects performed the same procedure as for SASS. Active DF, which could provide a small contraction of the tibialis anterior, was performed during SASS as well. During this intervention, active DF was performed where the patella moved slightly backward from the final range of lunging to lift the foot superiorly. Active DF was maintained for five seconds for each muscle contraction and repeated five times, which could be defined as one set. Then, five sets were performed with 10 seconds of resting time between each set. The space between the top surface of the incline board and the sole of the foot was determined to confirm the movement of ankle DF. During the Active SASS, the top of the heel and the big toe were maintained in a straight line. In addition, not only the forward moving direction of the patella while lunging, but also the backward pulling direction of the strap should be aligned parallel to the straight line (Figure 9).

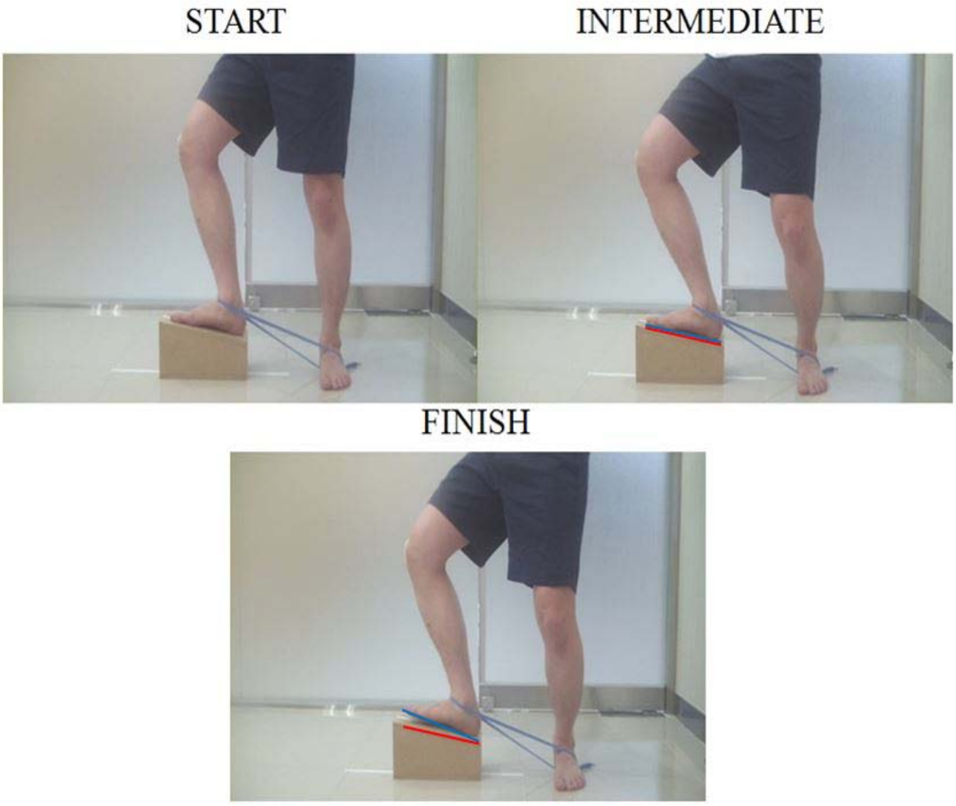

Figure 9. Self–ankle stretching using a strap plus active dorsiflexion.

7. Statistical Analysis

The data are expressed as means ± standard deviations. One–sample Kolmogorov–Smirnov test was employed to ensure the normal distribution of the data collected through the measurements. Paired *t*–tests were used to assess the statistical significance between pre– and post–stretching exercises. One way analysis of variance was employed to compare the effects among the three different exercises (static stretching/SASS/Active SASS) for dependent variables, such as the ADFROM, the PDFROM, the lunge angle, and the strength of the tibialis anterior. In the case of significant differences among the three exercises, Scheffe's post hoc test was performed. *P*–values <0.05 were considered to indicate statistical significance. The statistical package for the Social Sciences for Windows version 18.0 (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis.

8. Reliability of the Measurements

The intra-rater reliability of the experimental procedures of the examiner responsible for all of the measurements performed in this study was calculated from repeated trials (resulting from a single session of the experimental measurements) of five healthy subjects' outcome measures before the main examiner commence the main experiment (Vicenzino et al. 2006). The intra–rater reliability for ADFROM, PDFROM, lunge angle, and the strength of the tibialis anterior was tested using the intra–class correlation coefficient (ICC), the standard error of the measurement (SEM), and a 95% confidence interval (CI). All of the experimental measurements had high intra–rater reliability with an ICC (3,3) of 0.97 (95% CI, 0.69~0.99) in ADFROM, an ICC (3,3) of 0.99 (95% CI, 0.87~0.99) in PDFROM, an ICC (3,3) of 0.94 (95% CI, 0.39~0.99) in lunge angle, and an ICC (3,3) of 0.99 (95% CI, 0.97~0.99) in the strength of the tibialis anterior. The SEM was 0.4° for ADFROM, 0.8° for PDFROM, 2.0° for the lunge angle, and 3.4 Nm for the strength of the tibialis anterior ($P < 0.01$).

Results

1. Active Dorsiflexion Range of Motion (ADFROM)

The different pre– and post– values for static stretching, SASS, and Active SASS groups indicate significant differences in ADFROM (*p*<0.01) (Table 2). A comparison of the differences in the ADFROM among the three groups is shown in Table 3. The effect sizes for the ADFROM between the groups are shown in Table 4. Post hoc analysis of the differences in the ADFROM of static stretching, SASS, and Active SASS is shown in Table 4.

Table 2. Differences on active dorsiflexion range of motion between pre– and post – exercise program.

Variables	Mean±[d]SD(°)		Mean difference	*t* value	*P* value
	Pre–Intervention	Post–Intervention			
[a]STATIC (°)	15.75 ± 1.99	19.82 ± 3.40	4.07 ± 2.43	–6.48	<0.01*
[b]SASS (°)	13.10 ± 5.95	22.92 ± 4.00	9.81 ± 5.02	–7.81	<0.01*
[c]Active SASS (°)	13.18 ± 3.44	21.38 ± 2.96	8.20 ± 3.51	–9.63	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self– ankle stretching using a strap.
[c]Active SASS: Self– ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
*$p<0.05$, by Paired *t*– test.

Table 3. Comparison of the differences on active dorsiflexion range of motion among three groups.

Variables	Mean±[d]SD(°)			f value	P value
	[a]STATIC group (N = 15)	[b]SASS group (N = 16)	[c]Active SASS group (N = 17)		
Change	4.07 ± 2.43	9.81 ± 5.02	8.20 ± 3.51	9.25	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation
*p<0.05, by One way analysis of variance.

Table 4. Post hoc comparison of the difference in Active Dorsiflexion Range of motion between groups. (N = 48)

Variables	Intervention Condition compared	Difference between pre and post (95% [e]CI)	*P* value	Effect size (*d*)
[f]ADFROM	[b]SASS vs [a]STATIC	5.75 (2.27 to 9.23)	<0.01*	1.31
	SASS vs [c]Active SASS	1.61 (–1.76 to 4.99)	0.49	0.36
	Active SASS vs STATIC	4.13 (0.70 to 7.56)	0.02*	1.37

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
[e]CI: Confidence Intervals.
[f]ADFROM: Active Dorsiflexion Range of Motion.
*$p<0.05$, by One way analysis of variance.

2. Passive Dorsiflexion Range of Motion (PDFROM)

The different pre– and post– values for static stretching, SASS, and Active SASS groups indicate significant differences in PDFROM (p<0.01) (Table 5). A comparison of the differences in the PDFROM among the three groups is shown in Table 3. A comparison of the differences in the PDFROM among the three groups is shown in Table 6. The effect sizes for the PDFROM between the groups are shown Table 7. Post hoc analysis of the differences in the PDFROM of static stretching, SASS, and Active SASS is shown in Table 7.

Table 5. Differences on passive dorsiflexion range of motion between pre– and post– exercise program.

Variables	Mean±[d]SD(°)		Mean difference	*t* value	*P* value
	Pre–Intervention	Post–Intervention			
[a]STATIC (°)	20.75 ± 1.99	23.09 ± 1.77	2.33 ± 1.17	–7.72	<0.01*
[b]SASS (°)	18.10 ± 5.95	28.98 ± 3.92	10.88 ± 5.04	–8.62	<0.01*
[c]Active SASS (°)	18.71 ± 3.60	29.44 ± 2.93	10.73 ± 3.23	–13.69	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self– ankle stretching using a strap.
[c]Active SASS: Self– ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation
[*]$p<0.05$, by Paired *t*– test.

Table 6. Comparison of the differences on passive dorsiflexion range of motion among three groups.

Variables	Mean±[d]SD(°)			*f* value	*P* value
	[a]STATIC group (N = 15)	[b]SASS group (N = 16)	[c]Active SASS group (N = 17)		
Change	2.33 ± 1.17	10.88 ± 5.04	10.73 ± 3.23	29.31	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
[*]$p<0.05$, by One way analysis of variance.

Table 7. Post hoc comparison of the difference in passive dorsiflexion range of motion between groups. (N = 48)

Variables	Intervention Condition compared	Difference between pre and post (95% [d]CI)	*P* value	Effect size (*d*)
[f]PDFROM	[b]SASS vs [a]STATIC	8.54 (5.31 to 11.77)	<0.01*	1.87
	SASS vs [c]Active SASS	1.61 (–2.99 to 3.28)	0.99	0.03
	Active SASS vs STATIC	4.13 (5.21 to 11.58)	<0.01*	3.05

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]CI: Confidence Intervals.
[f]PDFROM: Passive Dorsiflexion Range of Motion.
*$p<0.05$, by One way analysis of variance.

3. Lunge Angle

The different pre– and post– values for static stretching, SASS, and Active SASS groups indicate significant differences in lunge angle (p<0.01) (Table 8). A comparison of the differences in the lunge angle among the three groups is shown in Table 9. The effect sizes for the lunge angle between the groups are shown Table 10. Post hoc analysis of the differences in the lunge angle of static stretching, SASS, and Active SASS is shown in Table 10.

Table 8. Differences on lunge angle between pre– and post– exercise program.

Variables	Mean±[d]SD(°)		Mean difference	*t* value	*P* value
	Pre–Intervention	Post–Intervention			
[a]STATIC (°)	37.75 ± 2.96	39.02 ± 5.32	1.27 ± 4.02	–1.23	0.24
[b]SASS (°)	37.27 ± 5.97	42.35 ± 6.03	5.08 ± 0.91	–22.27	<0.01*
[c]Active SASS (°)	36.85 ± 4.85	41.07 ± 5.17	4.21 ± 1.44	–12.03	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
$^{*}p<0.05$, by Paired *t*–test.

Table 9. Comparison of the differences on lunge angle among three groups.

Variables	Mean±[d]SD(°)			*f* value	*P* value
	[a]STATIC group (N = 15)	[b]SASS group (N = 16)	[c]Active SASS group (N = 17)		
Change	1.27 ± 4.02	5.08 ± .91	4.21 ± 1.44	10.15	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
$^{*}p<0.05$, by One way analysis of variance.

Table 10. Post hoc comparison of the difference in lunge angle between groups. (N = 48)

Variables	Intervention Condition compared	Difference between pre and post (95% [d]CI)	*P* value	Effect size (*d*)
Lunge angle	[b]SASS vs [a]STATIC	3.80 (1.57 to 6.04)	<0.01*	1.08
	SASS vs [c]Active SASS	0.86 (–1.30 to 3.03)	0.60	0.71
	Active SASS vs STATIC	2.94 (.74 to 5.14)	<0.01*	0.86

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]CI: Confidence Intervals.
*p<0.05, by One way analysis of variance.

4. Strength of Tibialis Anterior

The different pre– and post– values for static stretching, SASS, and Active SASS groups indicate significant differences in the strength of the tibialis anterior (p<0.01) (Table 11). A comparison of the differences in the strength of the tibialis anterior among the three groups is shown in Table 12. The effect sizes for the strength of the tibialis anterior between the groups are shown in Table 13. Post hoc analysis of the differences in the strength of the tibialis anterior for static stretching, SASS, and Active SASS is shown Table 13.

Table 11. Differences on strength of tibialis anterior between pre– and post– exercise program.

Variables	Mean±[d]SD(°)		Mean difference	*t* value	*P* value
	Pre–Intervention	Post–Intervention			
[a]STATIC (°)	333.07 ± 58.38	352.89 ± 62.17	19.82 ± 45.08	–1.70	0.11
[b]SASS (°)	323.67 ± 51.10	348.94 ± 49.39	25.27 ± 12.41	–8.14	<0.01*
[c]Active SASS (°)	320.14 ± 57.92	410.47 ± 54.60	90.33 ± 64.70	–5.76	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
*p<0.05, by Paired t–test.

Table 12. Comparison of the differences on strength of tibialis anterior among three groups.

Variables	Mean±[d]SD(°)			*f* value	*P* value
	[a]STATIC group (N = 15)	[b]SASS group (N = 16)	[c]Active SASS group (N = 17)		
Change	19.82 ± 45.08	25.27 ± 12.41	90.33 ± 64.70	11.64	<0.01*

[a]STATIC: Static stretching.
[b]SASS: Self– ankle stretching using a strap.
[c]Active SASS: Self– ankle stretching using a strap plus active dorsiflexion.
[d]SD: Standard Deviation.
*$p<0.05$, by One way analysis of variance.

Table 13. Post hoc comparison of the difference in strength of tibialis anterior between groups. (N = 48)

Variables	Intervention Condition compared	Difference between pre and post (95% [d]CI)	*P* value	Effect size (*d*)
strength of tibialis anterior	[b]SASS vs [a]Static	5.45 (–36.96 to 47.85)	0.95	0.14
	SASS vs [c]Active SASS	–65.06 (–106.16 to –23.97)	<0.01*	1.13
	Active SASS vs Static	70.51 (28.71 to 112.30)	<0.01*	1.27

[a]STATIC: Static stretching.
[b]SASS: Self–ankle stretching using a strap.
[c]Active SASS: Self–ankle stretching using a strap plus active dorsiflexion.
[d]CI: Confidence Intervals.
*$p<0.05$, by One way analysis of variance.

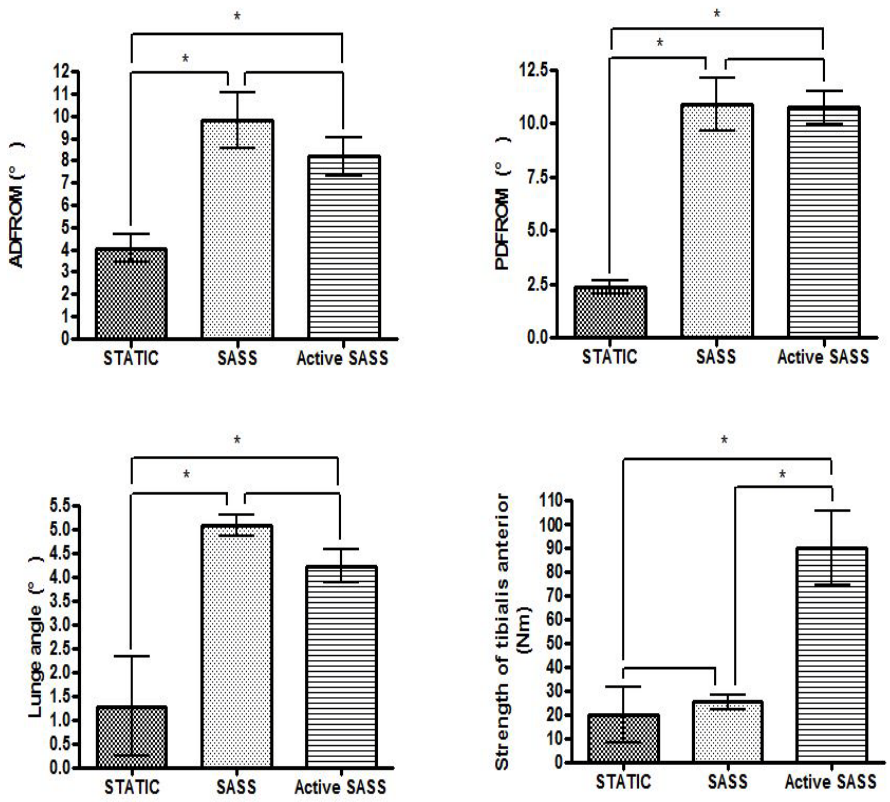

Figure 10. Comparison of the changes in the ankle range of motion and strength of the tibialis anterior among the different stretching groups. Abbreviation: DFROM, Dorsiflexion Range of Motion; STATIC, Static Stretching; SASS, Self– Ankle Stretching using a Strap. (**p* <0.05)

Discussion

Insufficient DFROM has been contributed to ankle and foot injuries (Kang et al. 2013) by the lack of posterior talar glide as well as tightness in the plantar flexors, capsular restrictions (Denegar, Hertel, and Fonseca. 2002). The element for the effective ankle stretching can be to maintain normal alignment of ankle movement while ankle stretching was being performed (O'Shea, and Grafton 2013). The talus, which is included both ankle joints and feet structures, is important in the function of the feet as well as the lower extremity (Sahrmann 2010). Posterior talar glide is considered an accessory motion for ankle DF (Williams 1980). The results of this study revealed improvements in ADFROM and PDFROM in all of the stretching groups for three week self–exercise interventions. However, SASS and Active SASS were more effective for improvements in ADFROM, PDFROM and lunge angle than static stretching. Strength of tibialis anterior in the Active SASS group was greater than static stretching and SASS groups.

Various interventions, such as conventional static stretching (De Vries 1962), runner’s stretch (Williford et al. 1986), and orthosis (Selby–Silverstein et al. 1997), have been used to increase the DFROM and to prevent ankle and foot injuries in individuals with limited DFROM. Additionally, MWM has been commonly used to improve ankle DFROM by gliding the talus posteriorly using a manual approach of experienced physical therapist (Vicenzino et al. 2006). In the recent study, TST was applied independently using the tape to improve DFROM and gait pattern by stabilizing talus (Kang et al. 2013; Sahrmann 2010).

This study shown that posterior talar gliding using a SASS technique was more effective to increase DFROM than only static stretching without talus gliding. Lunge angle of the effect sizes for the SASS and Active SASS were large (0.85 and 0.84, respectively) compared to the small effect size 0.30 for the static stretching. As similarly, another previous study applied posterior talar gliding in closed kinetic chain using MWM technique, resulting 0.8 effect size (Vicenzino et al. 2006). Although the results of this study and previous study showed similar effect, SASS and Active SASS can be applied independently as a home exercise program, compared to MWM technique in weight bearing position by physical therapist. The greater improvement in lunge angle more than MWM technique may be explained by using a strap which can be effectively applied to a narrow gap in ankle joint.

Previous studies have shown that the effect of stretching positions in a closed kinetic chain could significantly correlate to ankle DFROM improvements in an open kinetic chain (Rabin, and Kozol 2012; Kang et al. 2013). The findings of this study, which indicate improvements in DFROM following posterior talar gliding using a strap could reinforce previous findings (Vicenzino et al. 2006; Williams 1980). Thus, it is possible that the stretching to improve the DFROM of functional activities such as lunging can influence the ADFROM and PDFROM which have the improvement of 43%, 38%, respectively in SASS group and 38%, 36%, respectively in Active SASS group. And the ADFROM and PDFROM have the improvement of 21%, 10%, respectively in static stretching group. Moreover, SASS and Active SASS described in this study were easily applied after simple exercise educations. The techniques can be independently applied by individuals with easy training, and cost–effectiveness as home exercises to improve the DFROM using weight bearing and the pulling force using a strap.

The techniques used in this study, SASS and Active SASS, could both be used because there was no significant difference in ADFROM, PDFROM, and lunge angle improvements. Condon and Hutton (1987) found that different types of stretching, such as hold and relax and agonist contraction, showed no significant differential improvement in DFROM. Indeed, volitional active muscle contractions could produce active contractile components. While muscles are stretched, volitionally induced inhibition could decrease active resistance, which has been attributed to improvements in the DFROM with a specific technique of stretching (Condon, and Hutton 1987; Sady, Wortman, and Blanke 1982). These components are not significantly effective for DFROM, which was proven by our findings.

This study demonstrated a significant increase in the strength of the tibialis anterior in the Active SASS group (22%) compared to static stretching and SASS groups (6% and 7%, respectively). Previous studies showed that ankle isometric exercise for six weeks improved the strength of ankle muscles such as the dorsiflexor and evertor (Docherty, Moore, and Arnold 1998; Smith et al. 2012). Our study showed that Active SASS for three week interventions has the similar effect in improving strength of tibialis anterior with the previous study. The strap may play a role in maintaining an axis of subtalar joint (Kang et al. 2013), when training tibialis anterior in this study, resulting more improvement in strength of tibialis anterior than conventional static stretching, SASS techniques. Therefore, Active SASS can be recommended for the individuals with limited DFROM to strength tibialis anterior.

Each subject was required to perform a lunge while bending knee joint over the second toe parallel to the straight tape during SASS and Active SASS. In these procedures, the strap, which has a backward pulling force from an anterior to superior and posterior to inferior direction in the ankle, plays an important role in gliding the talus posteriorly to improve limited DFROM. In this study, both the top of the heel and big toe were aligned directly over the straight tape to restrict subtalar pronation and prevent ankle compensation such as midtarsal joint DF, which could alter the normal alignment of ankle movements (O'Shea, and Grafton 2013). Therefore, the prevention of subtalar pronation may help to perform DF in the talocrural joint, while SASS and Active SASS were being applied to glide talus posteriorly. Moreover, the position of SASS and Active SASS techniques can replicate lunge position. It can be possible explanation that increases in the lunge angle in SASS and Active SASS may reflect our results.

This study had several limitations. First, our results, which were obtained from young and healthy subjects, cannot be generalized to adolescent and elderly populations. Second, single–blinded measurement might lack the accuracy required to reduce the potential bias of examiners using universal goniometer and photo graphic analysis techniques. Further research is required involving repetitive, double–blinded measurements for precise data collection. Third, the subjects in this study for the ADFROM measure were collected with ankle DFROM < 20°, and the mean values in this study were 13.96°. Further research essential to perform all the measurements with subjects with limited ankle DFROM < 10° to investigate the effects of stretching in individuals with severely limited ankle DFROM

Conclusion

This study demonstrated significantly improved DFROM of SASS and Active SASS compared to static stretching, and the increase in the strength of the tibialis anterior as a result of using the Active SASS technique after three weeks of SASS and Active SASS interventions. SASS and Active SASS can be applied to increase the DFROM, and Active SASS is recommended to improve both the DFROM and strength of tibialis anterior in individuals with limited DFROM.

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국문 요약

스트랩을 이용한 자가 발목 스트레칭이 발목 들기 각도에 미치는 영향

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발목 들기의 정상적인 관절가동범위는 자세적인 조절 그리고 런지(lunge)나 보행과 같은 기능적인 활동에서 매우 중요한 역할을 한다. 본 연구의 목적은 (1) 정적인 스트레칭 운동(static stretching)과, (2) 스트랩을 이용한 자가 발목 스트레칭 운동(self ankle stretching using strap; SASS) 그리고, (3) 능동적인 발목 들기가 병행된 SASS (self ankle stretching using strap plus active dorsiflexion; Active SASS) 이 세가지 다른 형태의 스트레칭 운동의 효과를 비교하는 것이다.

앉은 자세에서 능동적인 발목 들기 각도 제한 (20 도 미만)이 있는 48 명 (여자 18 명과 남자 30 명)의 대상자들이 이 연구에 참여하였다. 모든 대상자들은 무작위로 세 집단 (static stretching, SASS 그리고 Active SASS)으로 할당되었다. Static stretching 은 발목 관절에서 견고한 저항의 끝 느낌이 느껴질 때까지 무릎 관절을 살짝 구부리며 경사대 (10 도) 위에 서서 수행되었다. SASS 는 대상자가 런지 자세에서 전방에 있는 무릎을 앞으로 구부리는 동안 스트랩을 이용한 자가 발목 스트레칭 운동을 하며 수행된다. Active SASS 는 SASS 를 진행하면서, 능동적인 발목 들기를 추가하여 수행된다. 스트레칭 운동은 3 주간 수행되었다. 능동적인 발목 들기 각도를 측정하기 위해 각도계를 사용하였다. 수동적인 발목 들기 각도를 측정하기 위해 이차원 사진 분석을 사용하였다. 엎드려 무릎 굽힌 자세에서 도수용 근력 측정기를 사용하여 111 N 에서 수동적인 발목 들기 각도가 측정 되었다. 런지 자세에서 발목 들기 각도를 측정하기 위해 경사측정기를 사용하였다. 앞정강근의 힘을 측정하기 위하여 도수용 근력 측정기를 사용하였다. 모든 종속변수들은 3 번씩 측정되어 평균을 내었다. 3 주간의 세 가지 다른 스트레칭 운동 (static stretching/SASS/Active SASS)이 능동적인 발목 들기 각도, 수동적인 발목 들기 각도, 런지 각도 그리고 앞정강근의 힘에

대하여 미치는 효과를 비교하기 위하여 반복 측정된 일요인 분산 분석을 실시하였고, 통계학적 유의수준은 $\alpha = 0.05$ 로 정하였다.

이 연구에서 3 주간의 서로 다른 스트레칭 운동을 적용한 집단에서 모두 능동적인 발목 들기와 수동적인 발목 들기 각도가 크게 증가하였다. 그러나, SASS 와 Active SASS 집단이 static stretching 집단에서 보다 능동적인 발목 들기, 수동적인 발목 들기 그리고 런지 각도가 스트레칭 운동 전과 비교하였을 때, 3 주간의 스트레칭 운동 후 유의하게 증가하였다($p<0.05$). SASS 와 Active SASS 집단 간에는 능동적인 발목 들기, 수동적인 발목 들기 그리고 런지 각도가 스트레칭 운동 전과 비교하였을 때, 3 주간의 스트레칭 운동 후 유의한 차이가 없었다. Active SASS 에서는 static stretching 과 SASS 집단보다 3 주간의 스트레칭 운동 동안 앞정강근의 발목 들기 힘에 유의한 증가를 보였다.

결과적으로, DFROM 각도에 제한이 있는 대상자에게 DFROM 의 증가를 위한 스트레칭 운동으로 SASS 와 Active SASS 가 추천될 수 있다. 그리고, 발목의 DFROM 뿐만 아니라 앞정강근의 힘의 개선을 위해 Active SASS 방법이 적용될 수 있다.

핵심 되는 말: 발목 들기, 발목 들기의 제한, 스트랩을 이용한 자가 발목 스트레칭 운동.