Research Report

Effect of Superficial Heat, Deep Heat, and Active Exercise Warm-up on the Extensibility of the Plantar Flexors

Background and Purpose. Warm-up prior to static stretching enhances muscle extensibility. The relative effectiveness of different modes of warm-up, however, is unknown. The purpose of this study was to evaluate the effectiveness of superficial heat, deep heat, and active exercise warm-up prior to stretching compared with stretching alone on the extensibility of the plantar-flexor muscles. **Subjects.** Ninety-seven subjects (59 women, 38 men) with limited dorsiflexion range of motion (ROM) were randomly assigned to 1 of 5 groups. Female subjects had a mean age of 27.6 years (SD=7.68, range=17–50), and male subjects had a mean age of 26.8 years (SD=6.87, range=18–48). **Methods.** The first group (group 1) was a control group and did not perform the stretching protocol. The 4 experimental groups (groups 2–5) performed a stretching protocol 3 days per week for 6 weeks. Group 2 performed the static stretching protocol only; group 3 performed active heel raises before stretching; group 4 received 15 minutes of superficial, moist heat to the plantar-flexor muscles before stretching; and group 5 received continuous ultrasound for 7 minutes before stretching. Dorsiflexion ROM measurements were taken initially and after 2, 4, and 6 weeks. **Results.** All experimental groups increased active and passive range of motion (AROM and PROM). The mean AROM/PROM differences at 6 weeks were 1.11/1.39 degrees for group 1, 4.10/6.11 degrees for group 2, 4.16/4.21 degrees for group 3, 4.38/4.90 degrees for group 4, and 6.20/7.35 degrees for group 5. The group receiving ultrasound before performing the stretching protocol (group 5) displayed the greatest increase in both AROM (6.20°) and PROM (7.35°). **Discussion and Conclusion.** Among the modalities tested, the use of ultrasound for 7 minutes prior to stretching may be the most effective for increasing ankle dorsiflexion ROM. [Knight CA, Rutledge CR, Cox ME, et al. Effect of superficial heat, deep heat, and active exercise warm-up on the extensibility of the plantar flexors. *Phys Ther.* 2001;81:1206–1214.]

Key Words: *Exercise, Plantar flexors, Range of motion, Stretching, Thermal modalities.*

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Stretching is used as part of physical fitness and rehabilitation programs because it is thought to positively influence performance and injury prevention. Numerous studies[1–14] have been conducted to investigate the effectiveness of stretching. Shortness and contractures of the plantar flexors may cause limitations in range of motion (ROM) that restrict the normal action of muscle.[1] This potentially harmful condition may be managed with a stretching program, which may positively influence an individual's functional activities of daily living and decrease risk of injury.[2] Regardless of the type of program, a goal of stretching is often to change the physical characteristics of connective tissue. Data to support this goal, however, are lacking. Connective tissue is classified into 4 groups: loose (eg, subcutaneous tissue), dense (eg, fascia and muscle sheaths), organized (eg, ligaments and tendons), and specialized (eg, cartilage and bone). Some authors argue that stretching programs focus on affecting the dense and organized connective tissues.[2]

Connective tissue is a viscoelastic structure capable of plastic and elastic changes.[3] The viscous properties of connective tissue allow it to go through a permanent change in structure.[15–18] *Elastic properties* refer to the connective tissue's ability to regain its original length.[15–18] When an applied stretch to a connective tissue is removed, the elastic components recover their original length and the viscous components remain deformed.[15–18] The amount of elastic and viscous defor-

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All authors provided concept/research design, writing, fund procurement, and facilities/equipment. Ms Knight, Ms Rutledge, and Mr Cox provided data collection, subjects, and clerical/secretarial support. Julia O Bader provided data analysis. Dr Hall provided project management and consultation (including review of the manuscript before submission). Ms Acosta provided institutional liaisons.

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mation can vary considerably, depending on the amount of applied force, duration of applied force, and tissue temperature.[3] Theoretically, stretching protocols produce deformational changes that lengthen the connective tissue and increase joint ROM.

Ballistic stretching, so-called low-load static stretching, and proprioceptive neuromuscular facilitation techniques (PNF) are all techniques that have been used to accomplish the goal of stretching.[3–8] *Ballistic stretching* refers to a technique that uses a repetitive bouncing motion that lengthens the muscle quickly and immediately returns it close to the starting point.[8] Ballistic stretching may be beneficial for clients who want to return to competitive sports. These authors[8] further suggested that ballistic stretching should be performed in a controlled manner, thereby decreasing the possibility of injury to the musculotendinous unit.

The static stretching protocol requires that the stretch be performed in a slow, gradual manner and held at end-range just before the point that causes discomfort to the patient.[8] De Vries[5] contended that static stretching is preferred over ballistic stretching because it is energy efficient, thus requiring less energy to perform than the ballistic stretch, and because the probability of injury may be lower than with ballistic stretching.

Proprioceptive neuromuscular facilitation includes another stretching technique that purportedly is used to aid the neuromuscular responses through proprioceptive stimulation.[9] These techniques utilize different combinations of alternating contraction and relaxation of the agonist and antagonist muscle groups to increase joint ROM.[5,7,8,10,11] In these techniques, the muscle to be elongated (the agonist) is passively moved to end-range and isometrically contracted, which is followed by an eccentric contraction of the antagonist muscle.[4,8] Proprioceptive neuromuscular facilitation techniques, however, may be difficult for the subject to understand and typically require another person to perform. Lower-load, static stretching exercises are used in most settings because of their simplicity and the decreased potential for injury.[8]

Studies have produced conflicting results as to the optimal duration of static stretch necessary to achieve the viscoelastic changes to increase ROM. As research by Bandy et al,[10] Borms et al,[12] and Gajdosik[13] shows, the optimal time for maintaining the stretch varies. The use of a 30-second stretch, 10-second stretch, and 15-second stretch resulted in an increase in ROM of the hamstring musculature, as demonstrated by Bandy et al,[10] Borms et al,[12] and Gajdosik,[13] respectively. In the majority of these studies,[10,12–14] however, the hamstring muscle's flexibility was studied, and we believe the findings cannot necessarily be generalized to other muscle groups.

Thermal agents also play a role in determining the amount of elongation obtained from a static stretch. Studies[15–17] have shown that an elevated tissue temperature increases the amount of elongation obtained from a stretch. The clinician may use superficial heat or deep heat, or the patient may perform active exercise to warm up the muscles. Superficial heat may be applied in the form of hot packs, paraffin, Fluidotherapy, and infrared radiation.[18] Some physical therapists commonly use hot packs because they are easy to apply and economical. Studies[19,20] have shown that applying superficial heat simultaneously with a low-load static stretch improves the flexibility of shoulder and hip muscles compared with stretching alone.

Ultrasound is a method of applying deep heat to connective tissue.[18] The extensibility of nonhuman tendons has been shown to increase with the application of ultrasound.[15,21] To obtain increases in the viscoelastic properties of collagen, an elevation in tissue temperature of greater than 3° to 4°C is indicated.[22,23] Draper and colleagues[23,24] found that continuous ultrasound with a frequency of 1 MHz at an intensity of 1.5 W/cm^2 for 7 to 8 minutes was sufficient to increase the tissue temperature of the triceps surae muscle in humans as measured by a needle thermistor and resulted in viscoelastic changes of collagen.

Another way the muscle can be warmed is by performing active exercise. Safran et al[25] conducted studies on rats in which the gastrocnemius muscles were stretched until the tendon ruptured. Muscles performing isometric exercises prior to stretching were able to withstand more elongation before failure than the muscles in the control animals. Williford et al[26] investigated the effects of jogging prior to stretching compared with stretching alone on shoulder, trunk, hamstring, and ankle flexibility. They concluded that both methods were effective at increasing ROM and flexibility.

The plantar-flexor muscles play an important role in the gait cycle and in postural control. Lack of extensibility in this muscle group may cause or be related to decreases in ankle dorsiflexion, and it has also been hypothesized to contribute to Achilles tendinitis,[2] shin splints,[27] plantar fasciitis,[28] muscle strains, and joint sprains.[28] There is, however, no research to support the idea that stretching or a specific exercise program reduces or prevents specific injuries. Although researchers[11,28–31] have investigated stretching the plantar-flexor muscles, it is still unclear which stretching protocol should be used to obtain optimal flexibility. Zito et al[31] reported that one bout of two 15-second passive stretches was not sufficient for increasing ankle dorsiflexion ROM, and Worrell et al[28] found increases in dorsiflexion ROM after four 20-second stretches were repeated over 10 treatment sessions. There is, however, no known research investigating the effects of the application of superficial heat to the plantar-flexor muscles prior to stretching. In addition, no research-based information concerning the effects of active exercise on the temperature of these muscles prior to stretching was found.

The purpose our study was to determine the effects of superficial heat, deep heat, and active exercise warm-up on the extensibility of the plantar-flexor muscles. The research hypotheses were: (1) All stretching protocols with heat prior to stretching would provide increases in ankle dorsiflexion ($P \leq .05$) compared with that obtained with stretching alone, and (2) a stretching protocol with deep heat prior to stretching would provide a greater increase in ankle dorsiflexion ($P \leq .05$) than that obtained with all other stretching protocols.

Methods

Subjects

One hundred thirty volunteers in the local community who were between 17 and 50 years of age volunteered to participate after signing an informed consent statement. To be eligible for this study, the volunteers had to have an ankle dorsiflexion active range of motion (AROM) of less than 20 degrees.[26] Subjects were excluded from the study if they were pregnant; had impaired sensation; had bleeding disorders; had any previous neuromuscular disorders or hip, knee, or ankle pathologies (ie, within the past 2 years); or had lower-extremity malignancies. Ninety-seven subjects (59 women, 38 men) met the prerequisites and completed the study. The female subjects had a mean age of 27.6 years (SD=7.68, range=17–50), and the male subjects had a mean age of 26.8 years (SD=6.87, range=18–48).

Screening and Pretest

Prior to the collection of data, all volunteers completed a demographic and general health screening survey, and their ankle dorsiflexion AROM and passive range of motion (PROM) were measured with a universal goniometer* using the standard protocol described by Norkin and White.[32] According to Norkin and White,[32] the standard deviation of ankle dorsiflexion ROM is 4.4 degrees. Subjects were positioned sitting at the edge of a plinth with the knee in at least 30 degrees of flexion. One author (MEC) performed all goniometric measurements and did not know subjects' group assignments. Following the screening and pretest measurements, the subjects were randomly assigned to 1 of 5 groups. Table 1 presents the demographics and characteristics of the groups.

* Sammons Preston, 4 Sammons Ct, Bolingbrook, IL 60440.

Table 1.
Demographics[a]

Group No.	n	Sex: Female	Sex: Male	Mean Age (y)	Mean Weight (kg)	Mean Height (cm)
1	18	13	5	26.17	66.30	165.66
2	19	11	8	27.37	70.13	170.59
3	19	13	6	29.11	70.13	171.73
4	21	11	10	26.52	70.54	167.64
5	20	11	9	27.20	64.08	166.19

[a] Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

Familiarization Session

A familiarization session was conducted prior to initiating the stretching protocol in order to instruct each subject on how to correctly perform a runner's stretch. To perform a proper runner's stretch,[26] the subject stood approximately 91.44 to 137.16 cm (3–4½ ft) from the wall with his or her hands placed flat against the wall at shoulder level and with elbows extended. The subject stepped forward, flexing the left knee, and then shifted their body weight forward onto the left leg. The right heel remained flat on the floor with the right knee extended. The subject continued to shift weight forward until the right heel began to rise off the floor. The stretching exercises were performed gently and slowly until tightness, not pain, was felt. This position was maintained for 20 seconds. To reinforce proper stretching technique, a visual aid was placed on the wall in front of each stretching station.

Experimental Treatments

All subjects performed their stretching exercises in a controlled laboratory environment, with the researchers (CAK and CRR) observing the sessions. Group 1 did not perform the static stretching protocol and served as the control group. The subjects in group 2 performed the static stretching protocol only. Group 3 performed active heel raises to warm up the muscle prior to stretching. Before beginning the study, we conducted a pilot study to determine the maximal number of repetitions of heel raises needed to effectively increase plantar-flexor ROM. Subjects were assigned to 1 of 3 groups performing 20, 40, or 60 heel-raise repetitions, respectively. The group performing 40 repetitions demonstrated the greatest increases in ROM. Temperature was not measured, as this would have required performing an invasive procedure. We based our efforts on improvements in ROM only. Based on the results of the pilot study, each subject was encouraged to perform a minimum of 40 repetitions plus as many additional repetitions as the subject felt were necessary to warm up the plantar-flexor muscles.

Group 4 received superficial, moist heat to the plantar-flexor muscles in the prone position for 15 minutes prior to performing the static stretching. Superficial heat was administered by hot packs[†] consisting of silica gel encased in a canvas cover. The moist hot packs were heated and maintained at 73.88°C (165°F) throughout the study and were contoured to the subject's plantar-flexor muscles. Nine layers of terry cloth padding were placed between the hot pack and the subject. Another author (CAK) administered the moist heat. Group 5 received continuous ultrasound with a frequency of 1 MHz and an intensity of 1.5 W/cm^2 for 7 minutes prior to performing the static stretching.[11,31] A Sonopuls 434 ultrasound unit[‡] was used to administer the deep heat. The generator operated at a frequency of 1.0 MHz±0.2%. The transducer head was 6.2 cm in diameter, and the beam nonuniformity ratio of the crystal was a maximum of 5.0. The effective radiating area of the sound head was 5.0 cm^2±20%. Calibration and an electrical safety inspection were performed prior to testing. Ultrasound treatments were administered to the plantar-flexor muscles and were performed by another researcher (CRR).[11]

Stretching Protocol

Subjects in groups 2 through 5 performed four 20-second runner's stretches with a 10-second rest period between stretches.[33] The subjects were instructed to stretch 3 times per week every other day at approximately the same time of day for 6 weeks. This protocol was followed with the exception of the fifth week in which the subjects stretched only 2 times because of a holiday. In addition, subjects who were not exercising at the beginning of this study agreed to abstain from lower-extremity stretching or stretching exercises other than those included in the research protocol. Subjects in a concurrent exercise program agreed not to increase their level of activity during the 6-week stretching protocol. Two researchers (CAK and CRR) monitored each stretching session to ensure that proper stretching procedures were followed. After completing weeks 2, 4, and 6, measurements of ankle dorsiflexion AROM and PROM were obtained. Subjects who missed more than 3 stretching sessions were eliminated from the study to maintain the level of consistency for the study and not skew data.

[†] Henley International Inc, 120 Industrial Blvd, Sugar Land, TX 77478.
[‡] Chattanooga Group Inc, 4717 Adams Rd, PO Box 489, Hixson, TN 37343.

Table 2.
Means, Standard Deviations, and Mean Differences Between Pretest and Posttest Measurements (in Degrees) for Dorsiflexion Active Range of Motion (AROM) for Baseline and Weeks, 2, 4, and 6[a]

	Group No.				
AROM	**1**	**2**	**3**	**4**	**5**
Baseline					
$\bar{X}$	9.72	9.79	10.42	9.52	9.20
SD	4.24	4.16	5.12	4.81	5.54
Mean difference	—	—	—	—	—
Week 2					
$\bar{X}$	9.56	11.79	12.53	11.33	10.95
SD	3.54	4.21	4.62	4.82	5.61
Mean difference	−0.16	2.00	2.11	1.81	1.75
Week 4					
$\bar{X}$	10.78	13.58	13.84	12.95	13.75
SD	3.72	4.50	5.68	4.78	4.94
Mean difference	1.06	3.79	3.42	3.43	4.55
Week 6					
$\bar{X}$	10.83	13.89	14.58	13.90	15.40
SD	4.12	4.63	5.47	5.20	5.69
Mean difference	1.11	4.10	4.16	4.38	6.20

[a] Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

Table 3.
Means, Standard Deviations, and Mean Differences Between Pretest and Posttest Measurements (in Degrees) for Dorsiflexion Passive Range of Motion (PROM) for Baseline and Weeks, 2, 4, and 6[a]

	Group No.				
PROM	**1**	**2**	**3**	**4**	**5**
Baseline					
$\bar{X}$	17.67	17.05	19.05	18.62	18.30
SD	6.27	6.20	7.47	5.70	6.78
Mean difference	—	—	—	—	—
Week 2					
$\bar{X}$	16.61	18.63	19.37	19.00	20.75
SD	5.11	6.00	7.23	5.27	8.14
Mean difference	−1.16	1.58	0.32	0.80	2.45
Week 4					
$\bar{X}$	18.00	21.58	22.37	21.76	22.90
SD	5.32	5.59	7.02	5.33	6.74
Mean difference	0.33	4.53	3.32	3.14	4.60
Week 6					
$\bar{X}$	19.06	23.16	23.26	23.52	25.65
SD	5.72	5.77	6.21	4.96	7.90
Mean difference	1.39	6.11	4.21	4.90	7.35

[a] Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

Data Analysis

Adherence rates were calculated for each group. A multivariate analysis of variance (MANOVA) was performed on the baseline data to determine whether any differences existed between groups prior to beginning the stretching protocols. Intraclass correlation coefficients (ICCs) (*df*=2,1; fixed effect) were calculated on the control group data to assess intratester reliability of ankle dorsiflexion measurements. The ICC equation used in this study was:

$$r_I = \frac{(MS_{\text{among classes}} - MS_{\text{within classes}})}{(MS_{\text{among classes}} + [(n-1)\ MS_{\text{within classes}}])}$$

The control group's ICC values for pretest and final week AROM and PROM measurements were .91 and .97, respectively. The mean attendance for the 5 groups was 16.06 days, which resulted in a 94.48% adherence rate. The means, standard deviations, and mean differences between pretest and posttest measurements for weeks 2, 4, and 6 are presented in Tables 2 and 3.

A general linear mixed model analysis was used to evaluate the repeated-measures data on AROM and PROM separately. This type of analysis allows data comparison across different models to determine which model provides the best fit. The Tukey-Kramer multiple-comparison procedure for unbalanced data (unequal group sizes) was used as a *post hoc* test. Significance for all statistical tests was accepted at the .05 level of probability.

Results

The multivariate ANOVA performed on the baseline data for both AROM and PROM indicated that there were no differences among the 5 groups in mean age, height, weight, pretest AROM, and pretest PROM. A chi-square test indicated the same ratio of men to women across groups.

The model incorporating an unstructured variance-covariance matrix supplied the best fit for both data sets in the statistics program used (Statistical Analysis System[§]). Because an interaction was found, a reduced model was fitted to the data with sources of variation. Group, week, and group × week interaction were the fixed effects. A general linear mixed model analysis indicated a difference for the PROM group × test interaction ($F=2.61$; *df*=12,92; $P<.0049$) and for the AROM group × test interaction ($F=2.66$; *df*=12,92; $P<.0041$). Further testing with the Tukey-Kramer multiple-comparison procedure was used to determine the interaction for group × week. Results are presented in Tables 4 and 5.

[§] SAS Institute Inc, PO Box 8000, Cary, NC 27511.

Table 4.
Effects of Different Warm-up Methods on Active Range of Motion (AROM) Over 6 Weeks[a]

Group No.[b]	Baseline	Week 2	Week 4	Week 6
1	9.7 (A, X)	9.6 (A, X)	10.8 (A, X)	10.8 (A, X)
2	9.8 (A, X)	11.8 (B, X)	13.6 (C, X)	13.9 (C, XY)
3	10.4 (A, X)	12.5 (B, X)	13.8 (C, X)	14.6 (C, Y)
4	9.5 (A, X)	11.3 (B, X)	13.0 (C, X)	13.9 (C, XY)
5	9.2 (A, X)	11.0 (B, X)	13.8 (C, X)	15.4 (D, Y)

[a] Average of the means of dorsiflexion AROM (in degrees) for each of the 5 groups. A, B, C, and D are used for comparing means in a row. X and Y are used for comparing means in a column. Significant changes are indicated when a letter changes. Mean separation by Tukey-Kramer test ($P<.05$).
[b] Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

Table 5.
Effects of Different Warm-up Methods on Passive Range of Motion (PROM) Over 6 Weeks[a]

Group No.[b]	Baseline	Week 2	Week 4	Week 6
1	17.7 (A, X)	16.6 (A, X)	18.0 (A, X)	19.1 (A, X)
2	17.1 (A, X)	18.6 (A, XY)	21.6 (B, XY)	23.2 (C, Y)
3	19.1 (A, X)	19.4 (A, XY)	22.4 (B, Y)	23.3 (B, Y)
4	18.6 (A, X)	19.0 (A, XY)	21.8 (B, XY)	23.5 (C, Y)
5	18.3 (A, X)	20.8 (B, Y)	22.9 (B, Y)	25.7 (C, Y)

[a] Average of the means of dorsiflexion PROM (in degrees) for each of the 5 groups. A, B, C, and D are used for comparing means in a row. X and Y are used for comparing means in a column. Significant changes are indicated when a letter changes. Mean separation by Tukey-Kramer test ($P<.05$).
[b] Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

AROM

No differences were found between the control group measurements over time. An increase in AROM was noted in all 4 experimental groups between baseline and week 2 and between weeks 2 and 4. After weeks 2 and 4, however, all of the experimental interventions produced similar results, and groups 3 through 5 did not differ from group 2. Group 5 was the only group that had increased AROM between weeks 4 and 6. At the conclusion of the study, group 5 had the largest overall mean difference between pretest and posttest measurements (6.2°). Biweekly changes are presented in Figure 1.

There were no differences among AROM values for the 4 experimental groups after 4 weeks. At 6 weeks, groups 3 and 5 had greater AROM values than group 1. However, AROM values for the 4 experimental groups were

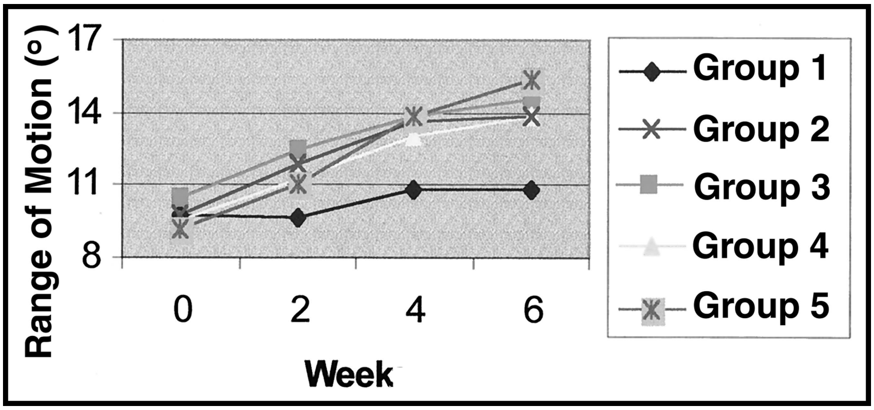

Figure 1.
Biweekly changes in active range of motion (in degrees) between groups. Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

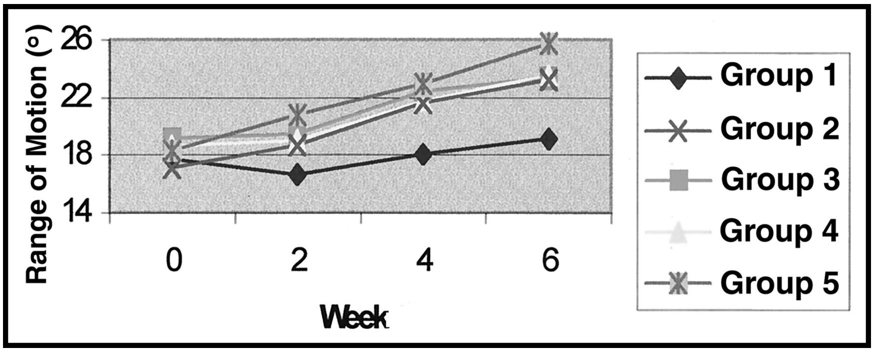

Figure 2.
Biweekly changes in passive range of motion (in degrees) between groups. Group 1 was the control group and did not perform the stretching protocol, group 2 performed the stretching protocol only, group 3 performed active heel raises to warm up the muscle prior to stretching, group 4 received superficial, moist heat from hot packs for 15 minutes before performing the stretching protocol, and group 5 received 7 minutes of continuous ultrasound before performing the stretching protocol.

not different compared with each other. In addition, the AROM values for groups 2 and 4 were not different from the AROM values for group 1.

PROM

No changes were noted in group 1 PROM measurements over time. Group 5 was the only experimental group that demonstrated an increase in PROM after 2 weeks. At week 4, groups 2 through 4 had gains in PROM compared with week 2. Group 5's PROM, however, did not change during this time. Groups 2, 4, and 5 had increased PROM between weeks 4 and 6, whereas group 3 remained the same. Group 5 had greatest overall mean difference between pretest and posttest PROM measurements, a mean of 7.35 degrees.

At week 2, group 5 had greater PROM than group 1. No differences in PROM were noted at week 2 among the other groups as compared with the control group. At week 4, all group PROM measurements remained the same as those for week 2, with the exception of group 3, which had greater PROM values than group 1. At week 6, groups 2 and 4 had greater PROMs than the control group. The PROMs for the 4 experimental groups, however, were not different from each other. Biweekly changes are presented in Figure 2.

Discussion

Our study was designed to obtain a more thorough understanding of stretching protocols for increasing ROM and how the use of therapeutic physical agents can affect these protocols in the clinical setting. According to the data, in a treatment lasting 4 weeks or less, hot packs, active exercise, or ultrasound prior to stretching or stretching alone achieved similar results in increasing ankle dorsiflexion AROM. In terms of cost-effectiveness, stretching alone would increase AROM sufficiently over a 4-week time frame compared with hot packs, exercise, or ultrasound with stretching. If the treatment extends over a period of 6 weeks, then ultrasound is the intervention of choice for increasing the extensibility of the plantar-flexor muscles.

If increases in ankle dorsiflexion PROM and a treatment duration of at least 2 weeks are desired, then ultrasound is the treatment of choice. When treating a patient for 4 weeks, however, stretching alone or hot packs, ultrasound, or active exercise warm-up prior to stretching will increase ankle dorsiflexion PROM equally. If the treatment duration is 6 weeks in length, the clinician would have the option of choosing stretching, hot packs, or ultrasound prior to stretching to produce equivalent gains in ankle dorsiflexion PROM. For example, patients receiving postsurgical physical therapy of 6 weeks duration or longer may benefit from ultrasound prior to stretching. This study, however, did not include patients who had had surgery within the past 2 years.

Group 2 also had a mean difference between pretest and posttest measurements of 6.11 degrees, which was not different from the increases in PROM in the other experimental groups receiving warm-up prior to stretch, indicating that warm-up may not be any more beneficial than normal activity prior to the treatment.

Because the available ROM at the ankle joint is relatively small compared with that of other joints in the human body, a ceiling effect may have masked differences in the effectiveness of the protocols studied. In addition, insufficient power may explain the nonsignificant results. Significant differences across groups might also have been achieved with a greater number of subjects in each experimental group. In our opinion, greater increases in ROM may be more beneficial to the individual because a patient's adherence to a home exercise program after discharge cannot be guaranteed to ensure the maintenance of gains in ROM.

The type of stretch used in the experimental protocol was a runner's stretch. When performing a runner's stretch, the lower extremity being stretched is kept extended at the knee, elongating the plantar flexors. However, the soleus muscle may not elongate fully if the gastrocnemius muscle is tight. To completely elongate the soleus muscle to the absolute end-range of tissue resistance, the runner's stretch can be used, but the lower extremity being stretched should be flexed at the knee. This would cause the gastrocnemius muscle to slacken and be actively insufficient. If the soleus muscle had been isolated and stretched in this manner, greater increases in ROM might have occurred, possibly resulting in other differences among groups.

Areas for Future Research

Future researchers should allow the experimental group performing the stretching-only protocol to adequately rest and cool the leg muscles before performing the stretch. This project could also be adapted to test the extensibility of other 2-joint muscle groups such as the hamstrings or quadriceps femoris muscles. Future research also could focus on whether inflexibility causes musculoskeletal problems.

Conclusion

All experimental groups in this study produced increases in the extensibility of the plantar flexors, resulting in increases in AROM and PROM when compared with the control group. The group receiving ultrasound prior to stretching obtained the greatest increases in ankle dorsiflexion AROM over a 6-week period and in ankle dorsiflexion PROM over a 2-week period. This study will allow clinicians more options in effectively increasing the extensibility of the plantar-flexor muscles. In addition, the results of this study will permit the clinician the choice of a cost-effective treatment alternative in an era of more stringent reimbursement.

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