Effect of Neuromuscular Electrical Stimulation on Ankle Swelling in the Early Period After Ankle Sprain

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Background and Purpose

Neuromuscular electrical stimulation (NMES) is frequently used to decrease swelling in the early period after ankle sprain. The purpose of this study was to evaluate its effectiveness in this treatment.

Subjects

Thirty-four subjects (11 female, 23 male; mean age=30.2 years) who were recovering from ankle sprain participated.

Methods

Outcome measures were ankle-foot volume, ankle girth, and self-assessed ankle function. Three testing/training sessions occurred within 5 days of injury. Subjects were randomly assigned to 1 of 3 groups: a group that received NMES treatment, a group that received submotor ES treatment (designed to act as a control group), and a group that received sham treatment.

Results

There were no statistically significant differences among the groups for ankle-foot volume and self-assessed ankle function. The statistically significant differences for ankle girth may have been compromised due to the significantly different values among groups at baseline. Ankle girth measurements were shown to be statistically significant from session 1 to session 3 for the NMES group but not for the other 2 groups.

Discussion and Conclusion

The results indicate that NMES, as designed and used in this study, is not effective in decreasing ankle-foot volume or increasing self-assessed ankle function in the early period after ankle sprain.

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Sprains occur most commonly in the ankle, with more than 25,000 ankle sprains occurring each day in the United States.[1] Soft tissue injuries commonly elicit the physiological inflammatory responses of redness, swelling, heat, and pain, and acute ankle sprain injuries are no exception.[2,3] Edema formation is a significant hindrance to the healing process[4] and can cause pain and reduced mobility.[5] Nilsson and Haugen[3] stated that swelling and pain are responsible for the functional disability that follows ankle sprains.

Similar to the knee joint, where effusion appears to cause inhibition of the quadriceps femoris muscle group, decreased H-reflex excitability of muscles around the ankle joint has been reported in the presence of ankle effusion.[6] However, for the sake of completeness, not all muscles tested in that study showed this "decreased" excitability. Norwig[7] stated that the recovery rate for ankle function after a sprain injury may be related to the control of edema at the injury site, but no data were provided to support this statement. Nonetheless, it is generally accepted among clinicians that the appropriate method of care following ankle sprain is functional management of the injury (ie, restoring the patient back to his or her preinjury functional status). Voight stated, "the swelling that is secondary to the inflammation is the greatest enemy of healing. Therefore, the goal of early treatment should be to delay or minimise swelling."[8(p278)]

Various treatment protocols are used to control swelling in the postacute phase of ankle sprains.[9] The rest, ice, compression, and elevation (RICE) regimen is probably the standard treatment protocol used, but physical therapists also use additional adjuncts in order to minimize swelling. Electrical stimulation (ES), with or without muscle contraction, is one such example.[10] It is thought that neuromuscular electrical stimulation (NMES) causes muscle contractions, which can compress venous and lymphatic vessels.[11] This mechanical effect may assist in the resolution of posttraumatic and chronic edema.[11] Repetitive contractions may induce an increase in venous return[12] and lymphatic flow,[13] which may reduce edema. Thus, motor ES may affect the lymph drainage or the interstitial hydrostatic pressure components of fluid exchange, which can affect edema formation and resolution.

Only a few studies have investigated the direct effect of motor ES on edema reduction in humans by assessing edema change as an outcome measure.[14–17] One of the earliest investigations advocating the use of motor ES in reducing joint swelling was by Crisler,[14] who used an "Ultrafaradic Impulse Generator" device to "stimulate nerves and muscles by means of controlled electric shocks" in the treatment of patients with acute strains and sprains. In 6 of the 18 subjects, treated edema was "grossly in evidence," and a reduction in swelling following a single treatment of ES of 5 minutes duration or less was reported. However, no description was given as to how the amount of swelling reduction was measured.

Gould and associates[15] reported a statistically significant difference in knee edema 4 weeks after open meniscectomy between patients who received voluntary isometric exercise training and patients who received NMES treatment. The authors reported that, following treatment, 70% of the subjects in the ES group had no swelling and that 30% of those subjects had minimal swelling, as measured by circumference at the tibiofemoral joint space. All of the subjects in the voluntary exercise group showed "visible or moderate swelling" 4 weeks after the surgery.

Numerous studies have investigated how motor ES, by eliciting the muscle pump, may affect blood and lymph flow—the 2 main effects thought to reduce edema. Studies showing positive effects of motor ES in increasing blood flow have been done on both human[18–20] and animal[21,22] models. The muscle pump can be elicited voluntarily or electrically and can lead to a reduction of edema by moving the fluid from the interstitial compartment to the blood vascular system. Faghri et al[23] also suggested that electrically stimulated contractions activate the skeletal muscle pump, thereby promoting limb blood flow, and may be effective in reducing venous pooling and edema. Lymph flow has been shown to increase during muscular exercise.[24] The extrinsic forces caused by the contracting muscles may increase the lymph propulsion. In light of this, one of our previous investigations demonstrated that the increase in foot and ankle volume that occurs with prolonged standing can be limited with the application of NMES to the lower leg muscles.[25]

The main aim of this study was to test the effects of motor-level biphasic ES applied to the gastrocnemius and tibialis anterior muscles on ankle swelling in patients within 5 days of an ankle sprain injury. The main hypothesis was that 3 sessions of NMES applied to the lower leg muscles would significantly reduce ankle swelling compared with no NMES.

Method

Subjects

Thirty-four subjects within the age range of 18 to 60 years with acute ankle sprain injury (occurring within 5 days of the first scheduled test) were recruited within 12 months from the Minor Injuries Unit, Guy's

Hospital, London. Subjects who had a clinical diagnosis of a sprained ankle recorded in their medical notes were invited to participate in the study. The severity of the ankle injury was not documented in the medical notes in the form of any grading or classification system. Subjects with diabetes, peripheral vascular disease or any neurovascular deficits or metal implants in the lower leg, injury to the contralateral ankle that required surgical attention in the previous year, or open wounds and subjects who were taking diuretics or wore pacemakers were excluded from the study. All subjects gave written informed consent prior to testing.

Experimental Protocol

Subjects were assigned to 1 of 3 treatment groups using concealed randomization: (1) a group with NMES applied to the lower leg muscles, (2) a group with submotor ES applied to the lower leg muscles, or (3) a group with electrodes set up on the lower leg muscles with no ES applied (sham ES group). Originally, the study had only groups 1 and 2 in order to assess the effects of muscle contractions caused by NMES on reducing swelling. Therefore, the intention was to test a group that received ES that caused muscle contractions (NMES) and compare the results with a group of subjects who received ES that did not cause visible muscle contractions (submotor ES). This latter group, therefore, would act as a placebo group with the submotor ES applied in a fashion that would not trigger electrophoresis, the theoretical basis for treating swelling with submotor ES.[26] However, because it was not known whether the submotor ES could affect ankle volume, group 3 was added where no ES was applied but subjects were prepared and measured in the same way as the other 2 groups (sham treatment).

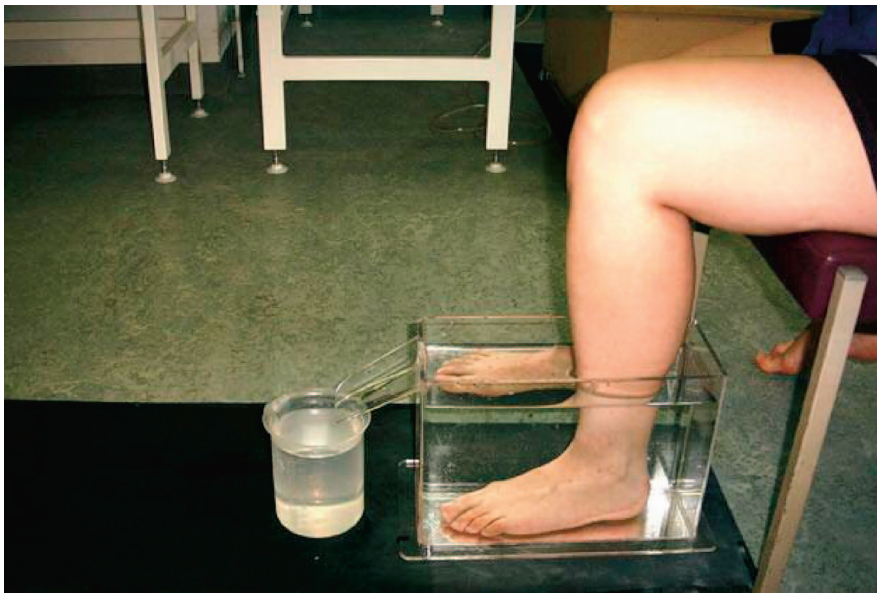

Figure 1.
Subject positioning during volumetric testing.

Before arriving at the testing laboratory, subjects were randomly assigned, in groups of 3, to 1 of the 3 groups, using a die protocol. Upon arrival at the testing laboratory, the medical history and history of the present complaint were documented for all subjects. From this information, patient eligibility for participation in the study was determined. Subjects then completed an adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders. We modified the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders from a similar questionnaire used for knee disorders.[27] Its validity and reliability in patients with ankle injuries have not been tested.

Height and body mass were measured, and then, with the subjects positioned supine, ankle girth was assessed with the figure-of-eight tape measurement technique.[28,29] Blinded bilateral girth measurements were taken before treatment at all 3 test sessions to allow for a comparison in girth between both sides, to assess whether swelling was present in the injured leg before treatment commenced, and to allow clinicians who do not have access to volumetry to evaluate the results relative to their patients.

Before the electrodes were applied to each subject's leg, 2 volumetric measurements were taken for both ankles. To be able to test all subjects on consecutive days, 2 different assessors were involved in assessing ankle-foot volume. Although not all subjects were assessed by the same researcher, the same researcher assessed volume for each subject in each of the 3 test sessions. Reliability testing of the volumetric measurements was performed for the 2 testers on 20 uninjured ankles that were tested on 2 separate days. The 2 volume assessors were blinded to the group allocation of the subjects. Ankle-foot volume was assessed with each subject in the sitting position (Fig. 1).

The volumeter was filled with tepid water (temperature ranged from 20° to 35°C), and the excess water that flowed out of the overflow spout was collected in a jug. Once the

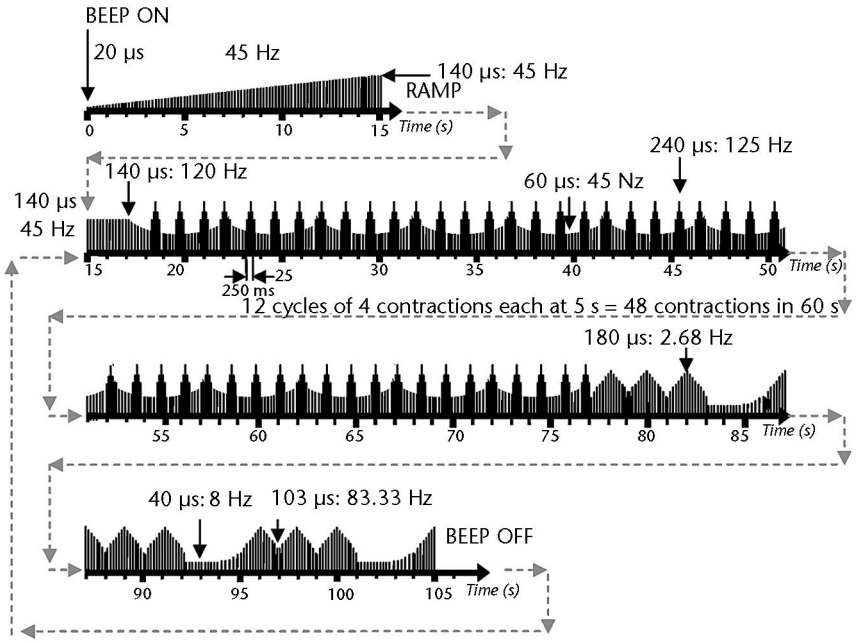

Figure 2.
Diagram of the electrical stimulation pattern used.

excess water had flowed to less than one drip a second, the water was discarded from the collecting jug, the spout was dried, and a dry, empty jug was placed underneath the overflow spout. The subject sat with one leg on either side of the volumeter and then was asked to gently place the leg that was being tested into the volumeter until the plantar aspect of the foot was flat on the bottom of the volumeter and the lower leg was as far back into the volumeter as possible, without actually touching the back of the volumeter. The ankle was in a neutral position, and the knee joint was at approximately 90 degrees of flexion.

As the leg was placed into the volumeter, the displaced water was collected in the jug below the overflow spout. The subject was asked to remain still until the excess water had flowed to a rate of less than one drop of water a second. Once all the displaced water had been collected, the jug was carefully removed and weighed. This measurement was converted from grams to milliliters using the conversion 1 g=1 mL.[30] The subject then was allowed to remove the leg from the volumeter. The same jug was used in each trial to collect the displaced water and was dried before and after each trial. The leg also was dried before each trial. This procedure was repeated, and the arithmetic mean was calculated to represent the ankle-foot volume.

Upon completion of the volumetric measurements, the leg was dried and 4 electrodes were secured to each subject's skin over the tibialis anterior muscle and the gastrocnemius muscle heads of the injured leg for simultaneous ES over these muscles. The subject was positioned supine, and the injured leg was elevated above heart level and supported over a stool. The leg was secured to the stool with a strap placed at the level of the ankle. In an attempt to minimize ankle joint movement, the subject was asked to place the foot up against a stable cabinet. The subject also was secured to the plinth with a strap around the level of the pelvis.

Four 10-cm-diameter Carbonflex disk electrodes* were applied to the lower leg muscles of the injured leg of all subjects. They were made of conductive carbonized rubber and secured with a standard crepe bandage to the subject's lower leg with a water-soaked sponge separating the skin and the electrodes. Two electrodes were placed over the muscle belly of the gastrocnemius muscle, and 2 electrodes were placed over the tibialis anterior muscle of the injured limb. The sensations that would likely be felt were explained to the subjects who were allocated to receive either NMES or submotor ES.

For ES, the HEALTHFIT dual-channel P4-Microstim stimulator† was used. The 2 electrodes on each muscle were connected to a separate channel of the stimulator. The ES was characterized by a low-voltage, rectangular waveform having modulated patterns of frequency and pulse duration (Fig. 2). The 30-minute ES pattern used for the subjects in the NMES and submotor ES groups had a total of 360 cycles, with each cycle lasting 5 seconds. Each cycle consisted of 400 pulses having different combinations of pulse-to-pulse intervals and duration values. The calculated average frequency of ES was 80 Hz, but the actual ES was delivered in packets (bursts) causing short-lasting muscle contractions every 1.25 seconds (0.8 Hz) for the subjects in the NMES group. During each burst, the pulse duration varied from 60 to 240 microseconds, and the pulse-to-pulse interval was 8 milliseconds (125 Hz).

* Bloomex International Inc, 295 Molnar Dr, Elmwood Park, NJ 07407.
† Valmed SA, Sion, Switzerland.

Over this burst pattern, there was superimposed another pattern of ES. This pattern had a repeat cycle of 5 seconds and a frequency of pulses varying from 45 to 120 Hz, with simultaneous variation of pulse duration from 60 to 140 microseconds. The last phase of the cycle started about 77 seconds after the unit was switched on. The frequency ranged from 2.68 to 83.33 Hz, with a pulse duration ranging from 40 to 180 microseconds. This unit was battery operated and was tested on the researcher before each application to ensure that the batteries were in working order.

For subjects in the NMES group, the intensity of ES was increased to the subjects' maximum level of tolerance and was adjusted as necessary throughout the 30-minute test period. For subjects in the submotor ES group, the unit was switched on and the intensity was increased until a flicker of muscle contraction was seen in the stimulated muscles. At this stage, the intensity was reduced very slightly until the flicker of contraction disappeared. Subjects should still have had some cutaneous sensation of the electrical current occurring under and around the electrode pads. At the end of 30 minutes of ES, the maximum stimulation level reached for each muscle was recorded. Subjects in the sham ES group were positioned in the same manner as subjects in the other 2 groups with the electrodes attached, but no ES was applied. The unit was switched on until the subjects heard the initial alarm, and then the examiner switched off the unit. The subjects had been advised that they should not feel any sensation during the next 30 minutes. After 30 minutes of being in this position the subjects' bilateral foot and ankle volume was remeasured.

Two volumetric measurements of the injured ankle were taken first followed by 2 measurements of the uninjured ankle. The subjects then were rescheduled to attend the second and third sessions as soon as possible, usually on consecutive days. When subjects attended for their subsequent tests, they were asked several questions regarding whether they had taken any more analgesics or anti-inflammatories and whether any other treatments (eg, physical therapy, ice) had been applied to the ankle since the previous session. When subjects attended for their last session, they also were asked to complete the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders after the posttest ankle volume measurements were taken. The distances from the left-hand anchors in the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders were measured by the volume assessors who were blinded to the treatment groups of the patients. Three further questions were asked to monitor their ankle injury on the subsequent test days: how they felt their ankle condition had changed since the previous session (ie, improved, worsened, no different), how great they felt any change was (using a visual analog scale), and whether they had done any different activities since the last session. The data collected for these 3 questions were not used in this study.

Data Analysis

The data collected were subject age, height, body mass, bilateral ankle volume before and after intervention for all 3 test sessions, figure-of-eight girth measurements, and adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores.

Prior to comparing outcomes in the groups, an analysis was performed to evaluate whether the groups were similar with respect to factors that might affect outcome other than the study treatment given. The comparability of the subjects in the 3 groups at baseline was assessed by analyzing the age, height, and body mass data (all normally distributed) using a one-way analysis of variance (ANOVA) test. To ensure that the subjects were not significantly more swollen or perceived themselves to be more limited in one group compared with another, the injured ankle volume, swelling volume (injured-uninjured ankle volume), injured ankle girth measurements, ankle girth differences (injured-uninjured ankle girth), and adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores as recorded on the first test session before intervention were analyzed for all subjects in the 3 groups. Tests of normality indicated that the ankle volumes, ankle girth measurements, and adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores were normally distributed, so comparability among the 3 groups at baseline was assessed with an ANOVA test.

In addition to comparing the groups for their baseline status, they also were evaluated for other treatments (eg, analgesic or anti-inflammatory medication, other physical therapy treatment, ice) that occurred during the period between the first and last tests. The percentage of subjects who were taking analgesic medication and the percentage of subjects who sought other treatment during the study were calculated and are shown in Table 1.

Test-retest reliability was analyzed for the 2 volume assessors on a total of 20 uninjured ankle volumes. Least significant difference (LSD) test and intraclass correlation coefficient (ICC[3,*k*]) values were calculated. The LSD value represents the level below which the observed value will be attributable to measurement error.

Table 1.
Comparisons of Possible Confounding Factors Among the 3 Groups[a]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)
Mean period between injury and test 1 (d)	3.3	3.5	3.5
Mean period between test 1 and test 3 (d)	3.4	2.9	2.5
No. of subjects with prior history of ankle injury	5 (45%)	4 (36%)	7 (58%)
No. of subjects taking analgesics or NSAID medication during study	8 (72%)	8 (72%)	7 (58%)
No. of subjects receiving additional treatment during study (ie, ice, formal physical therapy[b])	3 (27%)	8 (72%)	6 (50%)

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation, NSAID=nonsteroidal anti-inflammatory drug.
[b] Formal physical therapy treatment that was reported included soft tissue mobilization techniques and ultrasound. No compression therapy modalities were reported.

The outcome measures used in this study were the pretreatment and posttreatment changes for: (1) mean injured ankle volume, (2) mean swelling volume, (3) mean injured ankle girth, and (4) mean ankle girth difference measured at each test session and adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores obtained during the first and third test sessions.

Kolmogorov-Smirnov tests of normality indicated that the volume, girth, and questionnaire data were normally distributed. However, due to the small sample size and the shape of the histograms (asymmetrical and skewed), the nonparametric Kruskall-Wallis test for *k* independent samples was used to test for statistically significant differences among the 3 groups for all of these variables.

To analyze differences among the 3 test sessions (over time) for each of the 3 groups, the nonparametric Friedman test for *k* related samples for the volume and girth data was used. Because the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders was completed only during the first and third sessions, the nonparametric Wilcoxon test was used to assess for differences between the first- and third-session (over time) questionnaire scores for each group.

Data analyses were performed using SPSS for Windows 10.1[‡] and Excel[§] packages. Unless otherwise stated, a criterion level of $P<.05$ was used for all analyses.

Results

The subject characteristics of the 3 groups at baseline are shown in Table 2. Height and injured and uninjured ankle girth measurements were statistically different at baseline. The Tukey Honestly Significant Difference *post hoc* analysis showed the difference to be between the sham ES and submotor ES groups. The characteristics of each group for the other possible confounding variables are displayed in Table 1.

Descriptive data for the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders are shown in Table 3. Kruskall-Wallis analyses showed no statistically significant differences among groups for the change in adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores between the first and third test sessions ($P>.05$). A Wilcoxon signed ranks test showed a statistically significant difference between the first and third session scores for the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders within the 3 groups ($P<.05$).

The descriptive data for mean injured ankle volume are shown in Table 4 and displayed in Figure 3. Kruskall-Wallis analysis of the mean injured ankle volume changes in each test session showed no significant differences among the 3 groups. Analyses for comparisons of mean injured ankle volume change between test sessions (over time) performed with the Friedman test showed no significant differences from one test session to the next for all 3 groups (NMES group: $\chi^2=1.273$, $P=.529$; submotor ES group: $\chi^2=1.636$, $P=.441$; sham ES group: $\chi^2=3.167$, $P=.205$). No statistically significant differences were found in any of the 3 groups when the pretest injured ankle volume at session 1 and the posttest injured ankle volume at session 3 were compared ($P>.017$, Bonferroni adjusted level).

Table 5 summarizes the means (±SD) of the swelling volumes for each group at each test session. Kruskall-Wallis analysis of the mean

[‡] SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.
[§] Microsoft Corp, One Microsoft Way, Redmond, WA 98052-6399.

Table 2.
Subject Characteristics at Baseline (Mean±SD) With Test for Statistically Significant Differences Among Groups[a]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)	Significance Level
Age (y)	34 (11)	29 (6)	28 (8)	F=1.296, *P*=.288
Height (cm)	175 (9)	180 (9)	169 (11)	F=3.468, *P*=.044[b]
Body mass (kg)	84 (25)	83 (19)	72 (12)	F=1.532, *P*=.232
Adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders score[c]	65 (13)	70 (10)	63 (12)	F=1.120, *P*=.339
Injured ankle volume (mL)	1,522 (262)	1,597 (339)	1,324 (215)	F=3.045, *P*=.062
Uninjured ankle volume (mL)	1,445 (207)	1,465 (268)	1,296 (156)	F=2.173, *P*=.131
Swelling volume (injured ankle–uninjured ankle) (mL)	77 (109)	132 (125)	28 (106)	F=2.401, *P*=.107
Injured ankle girth (cm)	58.0 (4.7)	59.5 (5.7)	54.0 (4.5)	F=3.768, *P*=.034[b]
Uninjured ankle girth (cm)	56.1 (4.2)	57.5 (4.9)	53.4 (4.6)	F=3.346, *P*=.048[b]
Girth difference (injured ankle–uninjured ankle) (cm)	1.9 (2.1)	2.0 (2.0)	1.1 (1.2)	F=0.878, *P*=.426

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation.
[b] Significant difference *P*<.05.
[c] Range of possible scores for the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders score is 0 to 100, with 0 representing a score for a fully functioning ankle.

changes in swelling volume in each test session showed no significant differences among the 3 groups. A Friedman test analysis of the change in swelling volume changes showed no statistical significance from one test session to the next (over time) for each group (NMES group: χ^2=2.364, *P*=.307; submotor ES group: χ^2=1.636, *P*=.441; sham ES group: χ^2=0.167, *P*=.920).

The results for the injured ankle girth measurements are shown in Table 6. Kruskal-Wallis analysis showed a statistically significant difference among the 3 groups for the injured ankle girth measurements taken at test sessions 1 and 2. Over the 3 test sessions, a Friedman test analysis showed a significant difference for the NMES injured ankle girth measurements (χ^2=14.558, *P*=.001). No statistically significant differences were found for the injured ankle girth data over time in the submotor ES group or the sham ES group.

The mean girth differences are shown in Table 7. Kruskal-Wallis analysis showed no statistically significant differences among the 3 groups for the girth differences measured at the 3 test sessions. The girth differences were significantly different between sessions for the NMES group (*P*=.040). There were no statistically significant differences over time for the girth differences in the submotor ES group or the sham ES group (*P*>.05).

The ratings of the 2 volume assessors had very high reliability, with an ICC (3,*k*) of .999 each and an LSD test value ranging from 12 to 15 mL. This finding indicates that any volume changes of less than 15 mL can be

Table 3.
Mean (±SD) Scores for the Adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders[a] (95% Confidence Intervals Are Shown in Italics)[b]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)
Score for session 1	65 (13) *(56 to 74)*	70 (10) *(63 to 77)*	63 (12) *(55 to 71)*
Score for session 3	42 (20) *(29 to 55)*	45 (17) *(34 to 56)*	46 (16) *(36 to 56)*
Change in scores from session 1 to session 3	23 (14)[c] *(14 to 32)*	25 (21)[c] *(11 to 39)*	17 (15)[c] *(7 to 27)*

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation. Range of possible scores for the adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders is 0 to 100, with 0 representing a score for a fully functioning ankle.
[b] Confidence intervals are approximate due to the asymmetrical shape of the histograms.
[c] Significant difference *P* <.05.

Table 4.
Mean (±SD) Volume (in Milliliters) of Injured and Uninjured Ankles in the 3 Groups With Kruskall-Wallis Test for Statistically Significant Differences Among Groups[a] (95% Confidence Intervals for the Injured Ankle Are Shown in Italics)[b]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)	Significance Level
Pretest volume, session 1				
Injured ankle	1,522 (262)	1,597 (339)	1,324 (215)	
Uninjured ankle	1,445 (207)	1,465 (268)	1,296 (156)	
Posttest volume, session 3				
Injured ankle	1,515 (230)	1,573 (314)	1,352 (213)	
Uninjured ankle	1,459 (232)	1493 (282)	1,306 (163)	
Change in volume from first to last test (pretest 1–posttest 3)				
Injured ankle	8 (65)	24 (57)	−28 (38)	
Uninjured ankle	−14 (41)	28 (47)	−11 (27)	
Pretest–posttest volume in session 1				
Injured ankle	−20 (28) *(−40 to −2)*	−8 (40) *(−35 to 17)*	−32 (28) *(−51 to −13)*	χ^2=3.239, *P*=.198
Uninjured ankle	5 (33)	−16 (31)	−2 (27)	
Pretest–posttest volume in session 2				
Injured ankle	−27 (12) *(−35 to −19)*	−10 (31) *(−31 to 11)*	−19 (15) *(−29 to −9)*	χ^2=3.039, *P*=.219
Uninjured ankle	14 (29)	−3 (18)	3 (12)	
Pretest–posttest volume in session 3				
Injured ankle	−27 (21) *(−41 to −13)*	−6 (29) *(−25 to 13)*	−21 (31) *(−41 to −1)*	χ^2=3.630, *P*=.163
Uninjured ankle	−1 (18)	−9 (28)	−6 (23)	

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation. For difference scores, negative values indicate an increase in volume, and positive values indicate a decrease in volume.
[b] Confidence intervals are approximate due to the asymmetrical shape of the histograms.

attributed to measurement error rather than a real change resulting from the intervention. An ICC(3,k) of .99 has been reported for the figure-of-eight tape measurement technique with an LSD value within the range of 0.53 and 0.73 cm.[31] The LSD test value of the assessors was 0.57 cm, which agrees with the findings of other researchers.

Discussion

Although a significant difference in adapted Hughston Clinic Subjective Rating Scale for Ankle Disorders scores was found in the final session compared with the first session in all 3 groups, no significant difference was found among the 3 groups. This finding suggests that the NMES group did not provide any advantage over the control groups in returning the subjects to their self-assessed preinjury functional status.

Statistical differences were found for injured ankle girth among the 3 groups at sessions 1 and 2 and for the injured ankle girth and girth differences in the NMES group over the 3 sessions; however, these findings may not be meaningful because there was a statistically significant difference in ankle girth measurements taken at baseline among the 3 groups (Tab. 2). As there also was an unexpected, but significant, difference with the uninjured ankle girth measurements, it is possible that subjects in the sham ES group had smaller limbs than subjects in the other 2 groups. However, this difference was not found for the baseline ankle volume measurements. This could be because the volumeter is more accurate than the tape measure at recording volume or more likely because the small sample size produced this spurious result. The unexpected difference in subjects' height among the 3 groups at baseline further supports the argument that the small sample size is a limitation of the study.

Arguably the most likely conclusion from these results is general in nature: that submotor and motor ES, as used in this study, are not effective in decreasing ankle-foot swelling in the early period after an ankle sprain. In particular, given that the study was designed to evaluate the effectiveness of NMES, the evidence here is strongest in regard to its ineffectiveness, and this was surprising given the previously demonstrated ability of the stimulator used in this investigation to decrease ankle-foot volume changes caused by prolonged standing.[25]

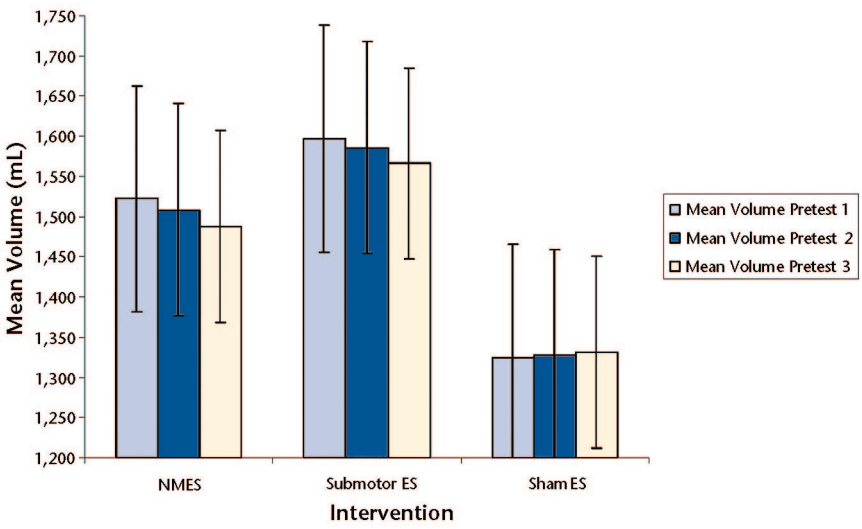

Figure 3.
Injured ankle volume (mean±SD, in milliliters) at the beginning of each session. NMES=neuromuscular electrical stimulation, ES=electrical stimulation.

Other interpretations, however, should be considered before making a strong conclusion, and one possible interpretation of these findings is that NMES is effective, but was not found to be effective in this study because of the small sample size, especially given the large standard deviations found. Consequently, a power analysis of the injured ankle volume change was undertaken to determine the chance of a type II error occurring, and the power (2-sided, $P<.05$) was 0.325 for the difference between the NMES and sham ES groups and 0.672 for the difference between the submotor ES and sham ES groups. The low power of this study, therefore, should be taken into consideration when interpreting the statistically nonsignificant findings. A small effect size (<0.18) also was found when the change scores for volume, girth and Hughston Clinic Subjective Rating Scale for Ankle Disorders score were analyzed.

Table 5.
Mean (±SD) Swelling Volumes (Injured Ankle-Uninjured Ankle Volume) at Each Test Session (in Milliliters) With Kruskall-Wallis Test for Statistically Significant Differences Among Groups[a] (95% Confidence Intervals Are Shown in Italics)[b]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)	Significance Level
Swelling volume, pretest 1	77 (109)	132 (125)	28 (106)	
Swelling volume, posttest 1	103 (91)	125 (97)	59 (85)	
Change in swelling volume, session 1	−26 (34) *(−49 to −3)*	7 (54) *(−29 to 43)*	−30 (44) *(−58 to −2)*	$\chi^2=4.219$, $P=.121$
Swelling volume, pretest 2	60 (109)	113 (82)	42 (95)	
Swelling volume, posttest 2	101 (94)	121 (86)	64 (90)	
Change in swelling volume, session 2	−41 (35) *(−64 to −16)*	−8 (35) *(−32 to 16)*	−22 (16) *(−32 to −12)*	$\chi^2=4.930$, $P=.085$
Swelling volume, pretest 3	30 (103)	83 (74)	31 (116)	
Swelling volume, posttest 3	56 (83)	80 (72)	46 (93)	
Change in swelling volume, session 3	−26 (37) *(−51 to −1)*	3 (39) *(−23 to 29)*	−15 (47) *(−45 to 15)*	$\chi^2=2.848$, $P=.241$

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation. For changes in swelling volumes, negative values indicate an increase in volume, and positive values indicate a decrease in volume.
[b] Confidence intervals are approximate due to the asymmetrical shape of the histograms.

Table 6.
Mean (±SD) Injured and Uninjured Ankle Girth Measurements (in Centimeters) With Kruskall-Wallis Test for Statistically Significant Differences Among Groups[a] (95% Confidence Intervals for the Injured Ankle Are Shown in Italics)[b]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)	Significance Level
Ankle girth, session 1				
Injured ankle	58.0 (4.7) *(54.8 to 61.2)*	59.5 (5.7) *(55.7 to 63.3)*	54.0 (4.5) *(51.1 to 56.9)*	χ^2=7.033, P=.030[c]
Uninjured ankle	56.1 (4.2)	57.5 (4.9)	53.4 (4.6)	
Ankle girth, session 2				
Injured ankle	57.7 (4.3) *(54.8 to 60.6)*	58.8 (5.8) *(54.9 to 62.7)*	54.0 (4.7) *(51.0 to 57.0)*	χ^2=6.191, P=.045[c]
Uninjured ankle	55.7 (4.1)	57.5 (4.8)	53.4 (4.4)	
Ankle girth, session 3				
Injured ankle	56.7 (4.6) *(53.6 to 59.8)*	58.2 (6.2) *(53.0 to 62.4)*	54.3 (4.4) *(51.5 to 57.1)*	χ^2=3.042, P=.218
Uninjured ankle	55.5 (4.3)	57.1 (5.6)	53.3 (4.3)	
Difference in ankle girth from test 1 to test 3				
Injured ankle	1.2 (0.6)	1.3 (1.4)	−0.3 (1.2)	
Uninjured ankle	0.5 (0.6)	0.4 (1.1)	0.1 (0.9)	

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation.
[b] Confidence intervals are approximate due to the asymmetrical shape of the histograms.
[c] Significant difference $P < .05$.

Table 7.
Mean (±SD) Ankle Girth Differences (Injured Ankle Girth-Uninjured Ankle Girth) (in Centimeters) With Kruskall-Wallis Test for Statistically Significant Differences Among Groups[a] (95% Confidence Intervals Are Shown in Italics)[b]

	NMES Group (n=11)	Submotor ES Group (n=11)	Sham ES Group (n=12)	Significance Level
Girth difference at test 1	1.9 (2.1) *(0.5 to 3.3)*	2.0 (2.0) *(0.7 to 3.3)*	1.1 (1.2) *(0.3 to 1.9)*	χ^2=1.290, P=.525
Girth difference at test 2	2.1 (2.0) *(0.8 to 3.4)*	1.7 (1.1) *(1.0 to 2.4)*	1.0 (1.8) *(−0.1 to 2.1)*	χ^2=1.361, P=.506
Girth difference at test 3	1.2 (1.7) *(0.1 to 2.3)*	1.1 (1.1) *(0.4 to 1.8)*	1.5 (1.4) *(0.6 to 2.4)*	χ^2=0.496, P=.780
Change in girth differences from test 1 to test 3	0.7 (1.0)	0.9 (1.6)	−0.4 (1.1)	

[a] NMES=neuromuscular electrical stimulation, ES=electrical stimulation.
[b] Confidence intervals are approximate due to the asymmetrical shape of the histograms.

It is also possible that NMES is effective but not in the manner used in this study or not on this sample. This allows the opportunity to consider how the NMES treatment strategy might have been altered in order to increase its effectiveness. The study design, ES parameters, and treatment duration used in this study differed from those of other studies in which the researchers advocated the use of NMES in reducing edema,[14–17] which may have influenced the apparent ineffectiveness of NMES in reducing edema. The studies by Crisler[14] and Lake[17] were descriptions of clinical results of NMES treatment that they had applied in practice, rather than a randomized trial. Furthermore, Crisler reported the use of an Ultrafaradic M-4 Impulse Generator on 400 cases of various sprains and strains without identifying the positioning of the electrodes in the different regions.

Gould et al[15] applied the NMES more intensely than that used in the current study. They applied the ES for 16 hours a day for 2 weeks following open meniscectomy and reported "several hundred contractions per day." This is very different from the 30-minute treatment session for 3 days that was used in this study. The other study that advocated the use of NMES in reducing edema was by Griffin et al,[16] who applied a single 30-minute session of ES that had a pulse frequency of 8 pps (pulse duration was not specified) to produce minimal visible contractions. Therefore, the intensity of treatment was lower than that used in our study, and only one treatment session was given. All of these variations in treatment durations, ES parameters, and design methodology contribute to the conflicting results for the efficacy of NMES in edema reduction. Future work should evaluate whether different treatment intensities, durations (number and duration of sessions), frequencies (sessions over time), current parameters, target muscle groups and electrode positioning, type of contraction (static versus dynamic), and periods of intervention relative to the injury (ie, more or less acute stage) affect treatment effectiveness.

It is possible that NMES, as used in this study on this sample, is effective in reducing swelling, but its effectiveness remains undetected. The effectiveness of NMES can be deduced if the sample in this study was not representative of individuals recovering from ankle sprain or the test tools used in this study were no good. We suspect that the former explanation is not valid. In regard to the latter explanation, a variety of measures covering outcomes that we think clinicians and patients consider important were used to mitigate this problem. We know of no other measure of the main outcome, foot-ankle volume, that is more accurate than the volumetric method used in this study. The accuracy of the volumetric method also may have been reflected in the differences found among groups at baseline for the ankle girth measurements but not for the volume measurements. Finally, the possibility exists that the inclusion of the foot in this analysis may have hidden changes in ankle volume. If that were the case, then the volume changes in the ankle, which have been shown to affect the surrounding neuromuscular system[32] and are suspected to be more critical than foot volume changes, may have responded differently in the 3 groups.

In an earlier study,[25] the motor ES method used in the present study was found to be effective in limiting the increase in ankle-foot volume that occurs in prolonged standing. This finding raises the question as to why a positive finding occurred in only one of these studies. To address this question, one should first consider the differences between the 2 studies. The studies mainly differed in the type of sample evaluated (uninjured versus injured subjects), the position of the subjects during the ES (standing versus supine lying with legs elevated), and the number of sessions in which the treatment was evaluated (1 versus 3). Of these 3 methodological differences, we suspect that the type of sample studied is the most likely cause for the ineffectiveness of NMES found in our study. The subjects evaluated in our study had swelling resulting from a musculoskeletal injury (ie, a sprained ligament). Such an injury would tend to cause swelling of an inflammatory nature where an increase in capillary permeability would produce an accumulation of interstitial fluid causing swelling.

It is more likely that the swelling produced by prolonged motionless standing in the earlier study would have been venous in nature and caused by an increase in the venous pressure. Because NMES reduces excess fluid primarily by simulation of the musculo-venous pump, which would lower the increased venous pressure,[33] it may be possible that this mechanism would be more effective in reducing swelling produced by raised venous pressure rather than increased capillary permeability. The pressure of restraining the limb to the stool in our study also may have affected the lymphatic and venous return in the leg. This, in turn, could have affected the amount of limb swelling reduction and contributed to the nonsignificant differences of edema reduction with NMES.

Swelling that has been produced by increased capillary permeability, as in the case of musculoskeletal injury, also may respond better to submotor ES rather than NMES, as supported by the animal studies conducted by Mendel and Fish.[34] They performed a series of studies using high-voltage cathodal ES (120 pps, 10% below visible contractions) on frog and rat

models and found that up to four 30-minute treatment sessions with either 30- or 60-minute rest periods between treatments curbed edema formation for up to 24 hours after injury. Their findings support the theory put forth by Reed[35] that submotor ES may have reduced microvessel permeability, which could affect the amount of fluid accumulating in the interstitial spaces.

Another possible theory suggested as to how cathodal ES may help to decrease swelling is by a electrophoretic phenomenon where negatively charged current repels negatively charged serum proteins, which, in turn, causes a fluid shift and reduces edema.[26] However, Karnes et al[36] also used anodal current in their experiments and found that, although it did not curb edema formation, it was not exacerbated either, thus suggesting that the electrophoretic effect is not likely to be the main means of how submotor ES controls edema. The submotor ES parameters used by Mendel and colleagues[34,36] were not applied in our study. However, it is not known exactly how submotor ES works to reduce edema, and therefore it may have affected some of the changes that occurred in the submotor ES group.

An interesting trend observable in this study was the consistent increase in injured ankle-foot volume during the "treatment" sessions in all 3 groups as exemplified in Table 4. When swelling volume was analyzed (Tab. 5), the change in swelling was greater at the end of "treatment" for the NMES and sham ES groups for all 3 sessions and for the submotor ES group for the second session. This finding indicates an increase in injured-side swelling or a decrease in uninjured-side volume. The latter is reasonable because it is expected that placing the leg in the nondependent position for prolonged periods would decrease the ankle-foot volume, although we did not find statistically significant differences between sitting and supine lying in uninjured individuals in a previous study[37] and there was not a consistent decrease in uninjured ankle volume in this study (Tab. 4). The increase in volume of the injured side is much more difficult to explain. One explanation is that the motor ES was acting as an irritant to the tissues causing an increase in swelling, but this was countered by the increase in swelling in the sham ES group.

Conclusion

Using the present study design, no differences were found between the NMES and submotor or sham ES groups in ankle-foot volumes in the early period after ankle sprain. This little researched area requires additional, larger studies that consider alterations in the treatment protocol given the variety of NMES approaches that can be taken when this treatment is given.

Dr Man and Dr Morrissey provided concept/idea/research design, writing, data analysis, project management, and institutional liaisons. Dr Man provided data collection, fund procurement, and facilities/equipment. Dr Cywinski provided the stimulators for the study and reviewed the manuscript.

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References

1 National Institute of Arthritis and Musculoskeletal and Skin Diseases. Available at: http://www.niams.nih.gov/hi/topics/strain_sprain/strain_sprain.htm. Accessed December 20, 2005.

2 Rourke K. The evaluation and treatment of acute ankle sprains *J Emerg Nurs*. 1994; 20:528–535.

3 Nilsson S, Haugen GB. Volumetry in the evaluation of swelling in the ankle and foot. *J Oslo City Hosp*. 1981;31:11–15.

4 Cote DJ, Prentice WE Jr, Hooker DN, Shields EW. Comparison of three treatment procedures for minimizing ankle sprain swelling. *Phys Ther*. 1988;68: 1072–1076.

5 Wilkerson GB, Horn-Kingery HM. Treatment of the inversion ankle sprain: comparison of different modes of compression and cryotherapy. *J Orthop Sports Phys Ther*. 1993;17:240–246.

6 Hall RC, Nyland J, Nitz AJ, et al. Relationship between ankle invertor H-reflexes and acute swelling induced by inversion ankle sprain. *J Orthop Sports Phys Ther*. 1999;29:339–344.

7 Norwig JA. Edema control and the acutely inverted ankle sprain. *Athletic Therapy Today*. January 1997:40–41.

8 Voight ML. Reduction of post traumatic ankle edema with high voltage pulsed galvanic stimulation. *Athletic Training*. Winter 1984:278–311.

9 Rucinski TJ, Hooker DN, Shields WE Jr, Cote-Murray DJ. The effects of intermittent compression on oedema in postacute ankle sprains. *J Orthop Sports Phys Ther*. 1991;14:65–69.

10 Taylor K, Fish DR, Mendel FC, Burton HW. Effect of a single 30-minute treatment of high-voltage pulsed current on edema formation in frog hind limbs. *Phys Ther*. 1992;72:63–68.

11 Robinson AJ, Snyder-Mackler L. *Clinical Electrophysiology: Electrotherapy and Electrophysiologic Testing*. 2nd ed. Baltimore, Md: Williams & Wilkins; 1995.

12 Bettany JA, Fish DR, Mendel FC. High-voltage pulsed direct current: effect on edema formation after hyperflexion injury. *Arch Phys Med Rehabil*. 1990;71: 677–681.

13 Ladd MP, Kottke FJ, Blanchard RS. Studies of the effect of massage on the flow of lymph from the foreleg of the dog. *Arch Phys Med*. October 1952:604–612,.

14 Crisler GR. Sprains and strains treated with the Ultrafaradic M-4 Impulse Generator. *J Flor Med Assoc*. 1953;40:32–34.

15 Gould N, Donnermeyer D, Gammon GG, et al. Transcutaneous muscle stimulation to retard disuse atrophy after open meniscectomy. *Clin Orthop*. 1983;178:190–197.

16 Griffin JW, Newsome LS, Stralka SW, Wright PE. Reduction of chronic post-traumatic hand edema: a comparison of high-voltage pulsed current, intermittent pneumatic compression, and placebo treatments. *Phys Ther*. 1990;70:279–286.

17 Lake DA. Increases in range of motion of the edematous hand with use of the Electromesh glove. *Physical Therapy Forum*. April 1989:6–7.

18 Tracy JE, Currier DP, Threlkeld AJ. Comparison of selected pulse frequencies from two different electrical stimulators on blood flow in healthy subjects. *Phys Ther*. 1988;68:1526–1532.

19 Miller BF, Gruben KG, Morgan BJ. Circulatory responses to voluntary and electrically induced muscle contractions in humans. *Phys Ther*. 2000;80:53–60.

20 Currier DP, Petrilli CR, Threlkeld AJ. Effect of graded electrical stimulation on blood flow to healthy muscle. *Phys Ther*. 1986; 66:937–943.

21 Mohr T, Akers TK, Wessman HC. Effect of high-voltage stimulation on blood flow in the rat hind limb. *Phys Ther*. 1987;67: 526–533.

22 Clemente FR, Matulionis DH, Barron KW, Currier DP. Effect of motor neuromuscular electrical stimulation on microvascular perfusion of stimulated rat skeletal muscle. *Phys Ther*. 1991;71:397–404.

23 Faghri PD, Van Meerdervort HF, Glaser RM, Figoni SF. Electrical stimulation-induced contraction to reduce blood stasis during arthroplasty. *IEEE Trans Rehabil Eng*. 1997;5:62–69.

24 Olszewski W, Engeset A, Jaeger PM, et al. Flow and composition of leg lymph in normal men during venous stasis, muscular activity and local hyperthermia. *Acta Physiol Scand*. 1977;99:149–155.

25 Man IOW, Lepar GS, Morrissey MC, Cywinski JK. Effect of neuromuscular electrical stimulation on foot and ankle volume during standing. *Med Sci Sports Exerc*. 2003;35:630–635.

26 Cosgrove KA, Alon G, Bell SF, et al. The electrical effect of two commonly used clinical stimulators on traumatic edema in rats. *Phys Ther*. 1992;72:228–233.

27 Flandry F, Hunt JP, Terry GC, Hughston JC. Analysis of subjective knee complaints using visual analog scales. *Am J Sports Med*. 1991;19:112–118.

28 Esterson PS. Measurement of ankle joint swelling using a figure of 8. *J Orthop Sports Phys Ther*. 1979;1:51–52.

29 Van Herp G, Al Shatti T. Ankle size measurements with the foot in a free hanging position: reliability of the figure-of-eight tape method. *S Afr J Phys*. 1998;54:14–16.

30 Weast RC, Selby SM. *Handbook of Chemistry and Physics: A Ready-Reference Book of Chemical and Physical Data*. 47th ed. Cleveland, Ohio: Chemical Rubber Co; 1966:F-4–F-5.

31 Tatro-Adams D, McGann SF, Carbone W. Reliability of the figure-of-eight method of ankle measurement. *J Orthop Sports Phys Ther*. 1995;22:161–163.

32 Palmieri RM, Ingersoll CD, Hoffman MA, et al. Arthrogenic muscle response to a simulated ankle joint effusion. *Br J Sports Med*. 2004;38:26–30.

33 Stick C, Jaeger H, Witzleb E. Measurements of volume changes and venous pressure in the human lower leg during walking and running. *J Appl Physiol*. 1992;72:2063–2068.

34 Mendel FC, Fish DR. New perspectives in edema control via electrical stimulation. *Journal of Athletic Training*. 1993;28: 63–74.

35 Reed BV. Effect of high-voltage pulsed electrical stimulation on microvascular permeability to plasma proteins. *Phys Ther*. 1988;68:491–495.

36 Karnes JL, Mendel FC, Fish DR, Burton HW. High-voltage pulsed current: its influence on diameters of histamine-dilated arterioles in hamster cheek pouches. *Arch Phys Med Rehabil*. 1995; 76:381–386.

37 Man IOW, Glover K, Nixon P, et al. Effect of body position on foot and ankle volume in healthy subjects. *Clin Physiol Funct Imaging*. 2004;24:323–326.