Changes in Active Ankle Dorsiflexion Range of Motion After Acute Inversion Ankle Sprain

James W. Youdas, Timothy J. McLean, David A. Krause, and John H. Hollman

Context: Posterior calf stretching is believed to improve active ankle dorsiflexion range of motion (AADFROM) after acute ankle-inversion sprain. Objective: To describe AADFROM at baseline (postinjury) and at 2-wk time periods for 6 wk after acute inversion sprain. Design: Randomized trial. Setting: Sports clinic. Participants: 11 men and 11 women (age range 11–54 y) with acute inversion sprain. Intervention: Standardized home exercise program for acute inversion sprain. Main Outcome Measure: AADFROM with the knee extended. Results: Time main effect on AADFROM was significant ($F_{3,57} = 108$, $P < .001$). At baseline, mean active sagittal-plane motion of the ankle was 6° of plantar flexion, whereas at 2, 4, and 6 wk AADFROM was 7°, 11°, and 11°, respectively. Conclusions: AADFROM increased significantly from baseline to week 2 and from week 2 to week 4. Normal AADFROM was restored within 4 wk after acute inversion sprain.

Keywords: kinematics, ligament, edema, rehabilitation

Sprains of the lateral ligaments of the ankle are the most common injury sustained during sports participation. The mechanism of injury typically involves trauma to the ankle–foot complex whereby the ankle is forcefully plantar flexed and the foot is inverted. Acute stretching or tearing of the ligaments and fibrous capsule of the ankle joint results in bleeding, joint effusion, and loss of joint range of motion. During the acute phase of rehabilitation the rehabilitation professional’s primary goals are to protect the injured tissues and minimize the amount of ankle-joint effusion. This treatment combination involves protection in the form of an ankle brace or gait aids, rest, ice, compression, and elevation (PRICE). Impaired active ankle-joint dorsiflexion range of motion (AADFROM) is considered an indication of severe ankle-joint injury. Reduced AADFROM after
acute ankle sprain has a major impact on walking, as well as other functional activities. For example, $10^\circ$ of passive ankle dorsiflexion range of motion is needed to walk on level surfaces, descend stairs, or kneel, whereas running or sprinting activities require $20^\circ$ to $30^\circ$ of AADFROM. To our knowledge no one has described the magnitude of impairment in AADFROM in subjects who have sustained an acute inversion ankle sprain. AADFROM can be limited by tightness in the muscles that plantar flex the ankle, primarily the gastrocnemius–soleus complex, as well as the talocrural joint’s posterior capsule. Tightness or adaptive shortening of the calf muscle–tendon unit on the side of the ankle sprain could develop soon after the inversion ankle sprain as a result of an antalgic gait pattern. Sports medicine personnel agree that the accepted standard of care for treating acute inversion ankle sprain should include static stretching of the calf muscle–tendon unit with a goal of restoring AADFROM. Nevertheless, the literature lacks clear evidence for the specific duration (dosage) of a static calf muscle-tendon-unit stretching protocol designed to produce lasting gains (hours to days) in AADFROM after acute ankle-inversion sprains. Recently investigators examined the effects of a 6-week program of static stretching of the calf muscle–tendon unit on AADFROM in 100 healthy subjects. Subjects stretched once per day for 30 seconds, 1 minute, or 2 minutes. The investigators reported that a 6-week program of such stretching was not sufficient to increase AADFROM in healthy subjects.

A low-load long-duration stretch is believed to be the safest form of therapeutic stretching, in addition to yielding desirable elastic and long-term plastic changes in connective tissues. According to the biomechanical principle of creep, when a mechanical load is applied to a tissue for an extended time period, the tissue lengthens, resulting in permanent elongation. Previously, Youdas et al did not detect an increase in AADFROM using calf muscle-tendon-unit stretch durations of up to 2 minutes once per day in healthy subjects. We would expect, however, that low-load calf muscle-tendon-unit stretch applied for up to 2 minutes 3 times per day would result in an increase in AADFROM after acute inversion ankle sprains.

The purposes of the current study were to examine subjects with acute inversion ankle sprains to (1) describe the magnitude of impairment in AADFROM and (2) examine the effect of a 6-week program of static stretching in conjunction with PRICE, active ankle range of motion (ROM), isodynamic resistance exercise, and progressive 1-leg balance on flexibility of the calf muscle–tendon unit as measured by AADFROM. We hypothesized that after acute ankle-inversion sprain we would observe a group effect in which values of AADFROM would be differentially affected by the duration of static stretching, with a significantly greater gain in AADFROM for 2-minute stretching sessions than for sessions lasting for 1 minute or 30 seconds. Furthermore, we hypothesized that we would observe a time main effect whereby the values of AADFROM would improve significantly between measurements made at baseline (postinjury) and at 2, 4, and 6 weeks after the initiation of a physical therapy home exercise program that included static stretch to the calf muscle–tendon unit.
Methods

Design and Setting

The dependent measure was AADFROM. A 2-way mixed-model repeated-measures design was employed for testing. The within-group factor was time (4 levels), and the between-groups factor was the intervention, or duration of stretch (3 levels). Testing was performed at the Mayo Clinic’s Sports Medicine Center.

Subjects

Twenty-seven volunteers (14 men, 13 women; age range 12–54 years) were recruited by verbal solicitation from one of the investigators (TJM); each volunteer was being seen for physical therapy at the Sports Medicine Center (Figure 1). We performed an a priori power analysis and considered a 10° change in AADFROM a clinically meaningful change. To guard against a potential dropout rate of 20% we sought to recruit 13 subjects per group (n = 3), yielding a total recruitment target of 39 subjects. We successfully recruited 27 subjects, and 5 of

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![Flow diagram of subject allocation and follow-up]

Figure 1 — A CONSORT flow diagram depicting the passage of subjects with acute inversion ankle sprain through the 4 stages of a trial.
these voluntarily withdrew from the study because they did not adhere to the prescribed stretching frequency for the calf muscle–tendon unit. Numerous potential subjects with acute inversion ankle sprains declined to participate in the study because of the time required to return to the Sports Medicine Center for 3 follow-up measurements of AADFROM during the 6-week time interval. All testing procedures were approved by our institutional review board, and all subjects provided informed consent. Subject characteristics are summarized in Table 1.

To be included in the study, volunteers had to meet the following criteria: (1) an acute inversion ankle sprain that occurred no longer than 96 hours before the initial physical therapy treatment session and involved swelling and/or tenderness on palpation of both the anterior talofibular ligament and calcaneofibular ligament; (2) minimal to no tenderness on palpation of the medial ankle-ligament complex; (3) inability to actively dorsiflex the injured ankle joint beyond neutral (0° of AADFROM) as measured by a goniometer; (4) no bony malformation at the talocrural joint that would limit ankle dorsiflexion or plantar flexion; (5) no previous history of trauma to the calf that required surgery; (6) no subluxation of the tendons of the fibularis longus, fibularis brevis, or tibialis posterior muscles; (7) no injury to the distal tibiofibular syndesmosis as assessed by the external-rotation stress test or squeeze test; (8) no radiologic evidence of ankle fracture or physeal involvement; and (9) no report of an inversion ankle sprain or other lower extremity injury within the previous 12 months. We did not quantify the subjects’ pain or loss of lower extremity function after the inversion ankle sprain.

Instrumentation and Examiner

A universal goniometer with a double-armed full-circle protractor made of transparent plastic (Fred Sammons, Inc, Burr Ridge, IL) was used to measure AADFROM. The examiner (TJM), a physical therapist with 22 years of clinical experience primarily spent working in a sports medicine practice, was responsible for performing all evaluations and for direct care of the subjects. Before subject recruitment we selected 19 patients (7 women and 12 men) referred to the Sports Medicine Center with a variety of lower extremity movement disorders. We selected subjects with lower extremity impairments because they were representative of the subjects with acute inversion ankle sprains we planned to study. The examiner performed 2 measurements of AADFROM of the ankle on the affected lower extremity within minutes of one another using a masked goniometer. The device was read and the value recorded by an assistant, so the examiner remained blinded to each measurement. The consistency of the data was analyzed using an intraclass correlation coefficient (ICC2,1). The ICC estimating intratester reliability was .91, and the standard error of measurement (SEM) was 2°. In addition, to determine whether a patient had improved or declined in AADFROM, we calculated the minimal detectable change (MDC95) using test–retest data. Changes in AADFROM may be attributed to such things as measurement error or random variability within the subject. A rehabilitation professional can be 95% confident that a subject’s change in AADFROM over time represents real change if the measurement value increases or decreases by a value greater than or equal to the MDC95. The MDC was calculated using the following formula:
<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Subjects (n)</td>
<td>7</td>
</tr>
<tr>
<td>Women (n)</td>
<td>4</td>
</tr>
<tr>
<td>Men (n)</td>
<td>3</td>
</tr>
<tr>
<td>Age (y)</td>
<td>17.3 ± 5.1 (13–28)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.7 ± 0.1 (1.5–1.8)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>65.9 ± 15.4 (52–96)</td>
</tr>
<tr>
<td>Body-mass index (kg/m²)</td>
<td>22.7 ± 2.7 (20–24)</td>
</tr>
<tr>
<td>Normal-side AADFROM (°)</td>
<td>9 ± 6</td>
</tr>
<tr>
<td>Side of sprain</td>
<td></td>
</tr>
<tr>
<td>right (n)</td>
<td>3</td>
</tr>
<tr>
<td>left (n)</td>
<td>4</td>
</tr>
<tr>
<td>Activity causing injury (n)</td>
<td>BB 5, CH 1, S 1</td>
</tr>
<tr>
<td>Grade of sprain</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Days (median) between injury and initial treatment</td>
<td>4 (1–7)</td>
</tr>
</tbody>
</table>

AADFROM, active ankle dorsiflexion range of motion; BB, basketball; CH, cheerleading; SKB, skateboarding; S, soccer; SFB, softball; TOS, tripped on stairs; WWHH, walking with high heels; V, volleyball. Values of continuous variables are given as mean ± SD (range). Group 1, 30-s static stretch; group 2, 1-min static stretch; group 3, 2-min static stretch.
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\[ \text{MDC} = \text{z score}_{\text{level of confidence}} \times \text{SD}_{\text{baseline}} \times \sqrt{2[1-r_{\text{test-retest}}]} \]

where the z score (1.96) represented the 95% confidence interval, SD was the standard deviation of the AADFROM values obtained during the first set of measurements, and \( r \) was the form of the ICC. The multiplier of the square root of 2 accounted for the uncertainty created when using difference scores from measurements at 2 points in time. The MDC\(_{95}\) was calculated to be 6°.

**Procedures**

All subjects wore shorts to provide adequate exposure to the ankle-foot-leg complex. Each volunteer lay prone on a standard treatment table. Maximum AADFROM of the affected side was measured with the knee extended. We selected this position because lying prone is a functional position for assessing AADFROM. Both hip and knee joints were extended simultaneously, simulating the stance phase of gait just before heel-off, when there is greatest demand for length of the calf muscle–tendon unit because the gastrocnemius muscle is maximally stretched by a combination of knee extension and ankle dorsiflexion.\(^\text{18}\) The hip of the side to be measured was placed in neutral rotation with the knee in terminal extension and the foot hanging over the table’s edge to permit full AADFROM. The examiner sat in a standard chair at the level of the patient’s leg-ankle-foot complex (Figure 2). Each patient was asked to actively dorsiflex and plantar flex the ankle joint through the available ROM 4 times to precondition the soft tissues of the calf muscle–tendon unit. This maneuver was recommended by Zito et al\(^\text{19}\) because repeated stretch cycles before testing enhance the reproducibility of a measurement, controlling for temporary lengthening mechanisms associated with stretching of connective tissues. The examiner observed the patient’s ankle motion carefully to prevent foot eversion during maximum AADFROM, because this extraneous movement would involve midtarsal joint dorsiflexion in addition to talocrural joint dorsiflexion. We used AADFROM because volitional movement of the dorsiflexors would be expected to inhibit the calf muscle–tendon unit via reciprocal inhibition.\(^\text{20}\)

A fifth bout of AADFROM was performed, and the examiner measured the amount of AADFROM using a technique described by Reese and Bandy.\(^\text{21}\) A right angle formed by the intersection of the leg’s long axis with the foot’s long axis was assumed to be the 0° starting position of ankle sagittal-plane motion. The axis of the universal goniometer was placed along the lateral surface of the hind foot just inferior to the lateral malleolus. Its stationary arm was aligned with the lateral midline of the fibula, and the moveable arm followed the shaft of the fifth metatarsal. The same procedure for recording AADFROM was performed on the unaffected side at the first (baseline) session only.

After the baseline measurements of AADFROM had been completed, subjects were randomly assigned to 1 of 3 groups. Individuals in the treatment groups performed 3 daily repetitions of a static stretch to the calf muscle–tendon unit of the sprained ankle. Individuals in group 1 stretched for 30 seconds, individuals in group 2 stretched for 1 minute, and individuals in group 3 stretched for 2 minutes. We selected these durations of stretch because they were in the middle to upper
ranges reported by previous investigators. \(^{22-25}\) Stretching sessions were carried out at least 5 days per week because this frequency of calf muscle-tendon-unit stretching exceeded that reported by most of the previous investigators who did not find lasting gains in AADFROM in healthy subjects. Subjects returned to the Sports Medicine Center at weeks 2, 4, and 6 for repeat measurements of AADFROM. The examiner also used these sessions to evaluate their response to the treatment regimen and modify the therapeutic interventions. Subjects in the stretching groups were asked to complete a daily stretching diary and return it to the examiner at measurement session number 4 (week 6).

**Components of the Home Exercise Program**

During the first (baseline) session of physical therapy subjects were instructed in a home exercise program (HEP) that included edema-control principles; active ankle ROM; calf muscle-tendon-unit stretching; active resistive exercise to the affected ankle dorsiflexors, plantar flexors, evertors, and invertors; and proprioceptive training. The examiner demonstrated each component of the HEP to the subjects. In addition, subjects received a packet of home instructions in case they needed to review elements of the HEP. PRICE principles were instituted as necessary to minimize ankle-joint pain and normalize gait mechanics. Each subject received a tubular elastic support bandage for edema control (Allegro Medical Supplies, Inc, Tempe, AZ) and a TriLok ankle brace (Cropper Medical Inc, Ash-
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land, OR) to protect the injured lateral ligament complex. During the first treatment session each subject was instructed in active ankle ROM consisting of writing the alphabet in the air with the foot 2 or 3 times per day. Next, each subject was assigned to a stretch group using a previously prepared randomization schedule. Subjects with grade II (n = 14; Table 1) ankle sprains could not bear weight because of ankle-joint pain, so they performed a heel-cord stretch using a towel while seated in a standard chair or in a long-sitting position on the floor. Subjects with grade I ankle sprain (n = 8; Table 1) performed a standing heel-cord stretch. The examiner informed subjects with grade II ankle sprains to discontinue use of axillary crutches when they could bear weight without a limp. At sessions 2, 3, and 4 the examiner individualized the remainder of the program for each subject according to his or her response to the treatment regimen implemented at the baseline session. When a subject could tolerate manually resisted ankle motion, a seated progressive isodynamics program was begun for ankle dorsiflexion, plantar flexion, eversion, and inversion. The isodynamic resistance component began with a yellow Thera-Band (Hygienic Corp, Akron, OH) using 3 sets of 10 to 20 repetitions 1 or 2 times per day and progressed through the remainder of Thera-Band colors (yellow, red, green, black, and gray). When the subject could complete 3 sets of 10 to 20 repetitions of resisted ankle plantar flexion using a gray Thera-Band, he or she began partial-weight-bearing calf raises. Subjects performed 2 or 3 sets daily of 10 to 20 calf raises with as much body mass on the affected side as was comfortable. When able to bear weight on 1 leg, subjects began a progressive single-leg balance routine on the side of the sprained ankle without wearing the TriLok ankle brace. After subjects performed single-leg stance and balance on 1 leg with the knee slightly flexed, the examiner instructed them to stand on 1 leg with the shoulders flexed to 90°, elbows extended, and forearms supinated. When this activity was mastered, subjects were encouraged to perform single-leg balance with eyes shut. When this was no longer a challenge, they repeated the standing-balance sequence with eyes shut while standing on a thick pillow or cushion. The examiner informed subjects that the proprioceptive balance protocol was similar to a ladder on which they must master the initial step before advancing to more challenging positions. Each stage was performed for 2 to 3 minutes for 2 or 3 sessions daily.

**Static Stretching of the Calf Muscle–Tendon Unit**

To stretch the calf muscle–tendon unit, subjects stood barefoot about 2 to 3 ft (0.5–1 m) from a wall (Figure 3). The foot of the sprained ankle was placed perpendicular to the wall. They were instructed to move the affected ankle–foot complex backward while keeping the unaffected foot forward, placing their hands against the wall and maintaining the hip and knee of the affected lower extremity in extension with the foot flat on the floor. This posture simulated the posture of the ankle joint of the posterior leg during the stance phase of gait just before heel-off. We chose not to have the subjects place the subtalar joint in a neutral position because Worrell et al reported no difference in AADFROM between the supinated and pronated stretching positions. Subjects in this study were instructed to move their affected foot back from the wall until they felt a substantial pull in the posterior calf that was just short of being painful. They were to maintain this
sensation throughout the session either by leaning farther into the wall or by moving the affected foot even farther back from the wall. Some subjects were initially unable to perform the standing wall stretch because weight bearing was too painful. In these cases they were instructed to assume a long-sitting position with a towel or belt looped around the forefoot of the sprained ankle–foot complex. They then grasped the 2 ends of the towel or belt and pulled the ankle into dorsiflexion. They progressed to the wall stretch when weight bearing became tolerable.

**Figure 3** — Standing stretch for the calf muscle–tendon unit (MTU). To stretch the calf MTU, subjects stood barefoot about 2 to 3 ft (0.5–1 m) from a solid wall. The foot of the sprained ankle was placed perpendicular to the wall. Subjects were instructed to move the affected ankle–foot complex backward while keeping the unaffected foot forward, placing their hands against the wall and maintaining the hip and knee of the affected lower extremity in extension with the foot kept flat on the floor.
Statistical Analyses

Mean age, height, body mass, body-mass index, and AADFROM for the normal ankle were calculated for each of the 3 groups. At baseline a 1-way ANOVA was used to test for equivalency among the groups over these descriptive measures to determine whether any covariates might influence the analysis. A 2-way mixed-model ANOVA with 1 within-group repeated factor (time with 4 levels) and 1 between-groups factor (stretch duration with 3 levels) was used to test baseline comparability of AADFROM and to compare AADFROM among the groups at 2, 4, and 6 weeks ($\alpha = .05$). The assumption of sphericity for repeated measures was violated, so we applied the Greenhouse–Geisser correction to degrees of freedom. Post hoc tests were conducted with Bonferroni-corrected $t$ tests ($\alpha = .05$).

Results

Descriptive data regarding age, height, body mass, body-mass index, and active AADFROM for the normal side for subjects by group are shown in Table 1. The 3 groups did not significantly differ from each other at baseline in age ($P = .47$), height ($P = .78$), body mass ($P = .60$), body-mass index ($P = .77$), or AADFROM for the normal ankle ($P = .55$). Fourteen (64%) subjects had sustained a grade II inversion ankle sprain, and 8 (36%), a grade I ankle sprain. The number of ankle sprains by grade was equal across the 3 stretch-duration groups (Table 1). Because of ankle pain when bearing weight each subject with a grade II sprain began the calf muscle-tendon-unit stretch in sitting, whereas all subjects with a grade I ankle sprain could tolerate weight-bearing ankle dorsiflexion without pain and performed the stretch in standing. After the week 2 measurement session, all subjects with a grade II ankle sprain ($n = 14$) were instructed by the examiner to begin stretching the calf muscle–tendon unit in standing because of a reduction in the acute signs of inflammation, particularly a subject’s self-report of diminished pain and edema. We did not intentionally exclude subjects with grade III inversion ankle sprains from participating in the study. Subjects with a grade III ankle sprain were either missed in the recruitment process or declined to participate in the study. Subjects with a grade II inversion ankle sprain ($n = 14$; group 1, $n = 4$; group 2, $n = 5$; group 3, $n = 5$) required axillary crutches for pain-free gait at the baseline intervention session. Time between injury and the initial physical therapy session ranged from 1 to 7 days with a median of 2.5 days. Five subjects voluntarily withdrew from the study (Figure 1) because they failed to adhere to the recommended stretching frequency: 3 from group 1, 1 from group 2, and 1 from group 3. Over the 6-week period subjects could potentially stretch 126 times (3 times per day for 42 days). According to subjects’ self-reports from the daily diary, median adherence to the stretching routine was 76% for group 1 (96 times), 83% for group 2 (105 times), and 76% for group 3 (96 times). Subjects did not complete a diary for the nonstretching components of the HEP.

The groups (Table 2) did not differ in AADFROM of the sprained ankle at baseline ($P = .71$). The lambda coefficient, $\lambda$, showed no significant association between sex and group assignment ($P = .58$). At the baseline measurement session (Table 2), on average subjects in each experimental group demonstrated a substantial impairment in AADFROM of the sprained ankle evidenced by an inability
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To reach the neutral starting position (0° of dorsiflexion) for measurement of ankle sagittal-plane motion, subjects in group 1 on average were 4° short of reaching the neutral starting position (4° of ankle plantar flexion), and subjects in both groups 2 and 3 were 7° short of attaining the neutral starting position (7° of ankle plantar flexion).

At the baseline measurement session, AADFROM loss resulting from inversion ankle sprain was computed by subtracting AADFROM obtained from the injured ankle from the AADFROM of the normal ankle. Mean (± SD) loss values were 13° ± 8°, 15° ± 7°, and 13° ± 9° for group 1, group 2, and group 3, respectively. At baseline, 20 of 22 subjects (91%) experienced AADROM loss that equaled or exceeded the MDC95 of 6°. Furthermore, we examined the improvement in AADFROM of the injured ankle between the baseline session and the conclusion of the 6-week treatment regimen. Mean (± SD) improvement values in AADFROM were 16° ± 5°, 19° ± 6°, and 18° ± 9° for group 1, group 2, and group 3, respectively. Moreover, all subjects with inversion ankle sprain experienced improvement in AADFROM that equaled or exceeded the MDC95 value of 6° at the completion of the 6-week HEP.

Table 2 Effect of Stretching on Active Ankle Dorsiflexion Range of Motion (AADFROM)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (n = 7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>baseline</td>
<td>−4</td>
<td>9</td>
<td>−10 to 3</td>
</tr>
<tr>
<td>2 wk</td>
<td>7</td>
<td>7</td>
<td>3–12</td>
</tr>
<tr>
<td>4 wk</td>
<td>11</td>
<td>5</td>
<td>7–16</td>
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<tr>
<td>6 wk</td>
<td>12</td>
<td>6</td>
<td>7–17</td>
</tr>
<tr>
<td>Group 2 (n = 8)</td>
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<td></td>
<td></td>
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<tr>
<td>baseline</td>
<td>−7</td>
<td>9</td>
<td>−13 to −5</td>
</tr>
<tr>
<td>2 wk</td>
<td>8</td>
<td>7</td>
<td>4–12</td>
</tr>
<tr>
<td>4 wk</td>
<td>12</td>
<td>8</td>
<td>7–16</td>
</tr>
<tr>
<td>6 wk</td>
<td>12</td>
<td>8</td>
<td>7–17</td>
</tr>
<tr>
<td>Group 3 (n = 7)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>baseline</td>
<td>−7</td>
<td>8</td>
<td>−14 to −8</td>
</tr>
<tr>
<td>2 wk</td>
<td>5</td>
<td>3</td>
<td>1–10</td>
</tr>
<tr>
<td>4 wk</td>
<td>9</td>
<td>3</td>
<td>4–14</td>
</tr>
<tr>
<td>6 wk</td>
<td>10</td>
<td>4</td>
<td>5–15</td>
</tr>
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</table>

AADFROM was measured in degrees with the subject in a prone position with the knee extended. A minus sign indicates a position of ankle plantar flexion. Group 1, 30-s static stretch; group 2, 1-min static stretch; group 3, 2-min static stretch.
According to the results of the ANOVA, the between-groups factor (duration of calf muscle-tendon-unit stretch) on AADFROM was not significant \((F_{2,19} = .52, \; P = .6)\), nor was the group × time interaction \((F_{6,57} = .37, \; P = .72)\). However, we did detect a significant main effect of time on AADFROM \((F_{3,57} = 108, \; P < .001)\). Therefore, we collapsed the values for AADFROM across the 3 groups for each of the 4 time periods (Figure 4). At baseline the mean value of active sagittal-plane motion of the sprained ankle was 6° of plantar flexion, and at 2, 4, and 6 weeks, the mean values of AADFROM were 7°, 11°, and 11°, respectively. AADFROM increased significantly from baseline to week 2 \((P < .001, \; ES = 1.85)\), from baseline to week 4 \((P < .001, \; ES = 2.40)\), from baseline to week 6 \((P < .001; \; ES = 2.41)\), from week 2 to week 4 \((P = .001, \; ES = 0.65)\), and from week 2 to week 6 \((P < .001, \; ES = 0.73)\). We did not detect a significant difference in AADFROM from week 4 to week 6 \((P < .569, \; ES = 0.11)\).

Figure 4 — Active ankle dorsiflexion range of motion in prone with the knee in extension measured with a universal goniometer. Measurements were obtained at the initiation of a physical therapy home exercise program (baseline) and at 2-week intervals until the completion of the 6-week treatment regimen. A minus sign indicates a position of ankle plantar flexion; a plus sign indicates a position of ankle dorsiflexion. *Statistically significant difference \((P < .05)\).
Discussion

We measured AADFROM with the knee straight over a 6-week time interval in 22 subjects who had sustained an acute inversion ankle sprain. This clinical procedure is similar to that reported in standard textbooks on goniometry.\(^\text{17}\) Regardless of the treatment intervention all subjects demonstrated a statistically significant increase (from a mean value of 6° of plantar flexion to a mean value of 7° of dorsiflexion) in AADFROM at the end of the initial 2-week interval. This change in AADFROM was not only statistically significant but also clinically meaningful, because the change exceeded the MDC\(_{95}\) value of 6°. Therefore a rehabilitation professional can be 95% confident that improved AADFROM was the result of real change and not measurement error or random fluctuation in the subject. Subjects continued to demonstrate significant improvement in AADFROM at the end of the 4-week interval (from 7° to 11° of dorsiflexion). Nevertheless, the 4° difference in AADFROM between the 2-week and 4-week intervals failed to exceed the MDC\(_{95}\) value of 6°, so we did not consider it clinically meaningful. Overall, we did not detect a group effect, because values of AADFROM were not differentially affected by the duration of static stretching. We did, however, detect a time effect. Values of AADFROM in subjects after acute inversion ankle sprain improved significantly between measurements made at baseline and at 2-week, 4-week, and 6-week intervals after the initiation of a physical therapy HEP that included static stretch to the calf muscle–tendon unit. By 4 weeks after the initiation of the HEP subjects had regained the 10° of AADFROM necessary to walk on level surfaces.\(^\text{8}\)

Investigators have argued that in addition to estimates of reliability, responsiveness is an important element when making clinical measures of joint ROM.\(^\text{31}\) Responsiveness has been defined as the ability of an instrument such as a standard goniometer to measure true change in joint ROM over time.\(^\text{29}\) Wilson et al\(^\text{32}\) examined the responsiveness of a goniometer to measure loss of total sagittal-plane ROM of the ankle and foot in 21 college athletes with grade I or grade II ankle sprains. Reduction in total ROM for each subject was calculated by subtracting measurements made on the injured ankle from those obtained from the normal ankle. The authors recorded change in total ROM over a 1-week period that began on day 3 after the ankle sprain and extended through day 10. Mean observed change in loss of ankle ROM was 4.7°, whereas the authors’ estimate of responsiveness, minimal reliable change, was 11.3°. Based on their results, Wilson et al concluded that true deficits in total sagittal-plane ankle and foot ROM could not be differentiated from measurement error in subjects after acute inversion ankle sprain. Recently Martin and McPoil\(^\text{31}\) reviewed the level of responsiveness of ankle ROM measurements described in 11 articles that satisfied their inclusionary criteria. Because the only article that described the responsiveness of a goniometer to detect true change in ankle goniometric measurements was that by Wilson et al, Martin and McPoil concluded that the responsiveness of ankle-ROM measurements to detect change is in doubt and should be examined on additional patient populations. In the current study we used the MDC\(_{95}\) to estimate responsiveness of a universal goniometer when making measurements of AADFROM in subjects with an acute inversion ankle sprain. Our MDC\(_{95}\) value (6°) was less than the minimum reliable change value (11.3°) reported by Wilson et al. In the current study baseline relative loss in AADFROM for the 3 calf muscle-tendon-unit
Changes in Active Ankle Dorsiflexion Range of Motion

Stretch groups ranged from 13° to 15°. After acute inversion ankle sprain 91% (20 out of 22) of subjects exceeded the MDC_95 value of 6°. Furthermore, improvement in AADFROM after a 6-week HEP ranged from 16° to 19°, and all subjects exceeded the MDC_95 value of 6°. We are confident that both loss and improvement values of AADFROM after acute inversion ankle sprain reflected real change because most of these values exceeded the MDC_95.

We were unable to find any studies that explicitly described the impairment of active AADFROM after acute inversion ankle sprain. Cross et al.\(^{33}\) examined 20 college athletes after an acute lateral ankle sprain and immediately after their return to sport. They obtained measurements of both the involved and uninvolved ankles’ active range of motion (AROM) while the subjects sat in a long-sitting position on a treatment table. Using a goniometer the examiner recorded the total sagittal-plane AROM in degrees. At baseline the mean ankle AROM was 70° ± 15° and 53° ± 11° for the uninvolved and involved extremities, respectively. Eleven subjects were assessed on return to sport, and the mean ankle AROM of the uninvolved and involved ankles was 68° ± 10° and 63° ± 8°, respectively. The injured ankles’ mean sagittal AROM had improved by 10°, although we do not know how much of this change was a result of improved AADFROM. On average, the time for the athlete to return to sport was 14.7 ± 8.8 days. Because Cross et al recorded total ankle AROM we cannot directly compare the impairment of AADFROM of their subjects after acute lateral ankle sprain with our data. Because 11 of the athletes examined by Cross et al returned to sport in 2 weeks they presumably had regained the requisite AADFROM to resume athletic competition. Unlike Cross et al, we did not report data on return to sport. On average, our subjects regained at least 10° of AADFROM at 4 weeks after the initiation of a physical therapy HEP.

Limitations

The salient feature of the current study is that subjects who sustained an acute inversion ankle sprain recovered preinjury AADFROM at the completion of week 4 of a 6-week HEP that included a variety of standard interventions. Based on tissue healing properties, signs of acute inflammation had most likely resolved so subjects could have demonstrated improved AADFROM primarily from a reduction in ankle edema and pain inhibition.\(^{34–36}\) Hence, it would seem spurious to attribute the recovery of AADFROM after acute inversion ankle sprain to a regular program of static calf muscle-tendon-unit stretching. The primary limitation of the current study was the absence of a true control group that did not receive a HEP after acute inversion ankle sprain. Lack of a true control group has affected the conclusions we can draw from this study, because each of the 22 subjects performed identical therapies except for duration of calf muscle-tendon-unit stretching. Consequently, we cannot discern whether the improvement in AADFROM resulted from the stretching, another exercise, or merely the natural healing process that occurred after the acute inversion ankle sprain. Another limitation of this study is that we did not measure subjects’ temporal and spatial gait parameters at baseline or the 3 subsequent measurement sessions. Such information could be provided in a subsequent investigation, because a rehabilitation professional would have a more objective assessment of the time necessary for the return of normal gait kinematics after acute inversion ankle sprain.
Another problem associated with this study was the number of dropouts and the difficulty recruiting subjects. To detect a 10° difference in active AADFROM between the groups with 80% power, we a priori estimated a sample size of 8 subjects per treatment group. Despite remuneration for completing the study, a number of qualified subjects declined to participate because of the inconvenience associated with reporting for measurement sessions 2 through 4. Although we examined 22 subjects instead of the target of 24 subjects—8 per treatment group—we still would not have been able to detect a treatment main effect. The mean differences between the 3 treatment groups ranged from 0° to 3° of AADFROM at weeks 4 and 6 (Table 2). To detect a mean difference of 2° of AADFROM at a desired power of .80 using a sample standard deviation of 6° would have required 146 subjects per treatment group.

In the current study, measurement of AADFROM was obtained actively in a non-weight-bearing position. Nevertheless, other investigators\textsuperscript{37} have suggested that AADFROM might have been greater with the subjects standing in a weight-bearing position, thus duplicating the position of the wall stretch. Furthermore, in the weight-bearing position subjects could be asked to simultaneously contract the muscles of the leg’s anterior compartment to inhibit the lengthened calf muscle–tendon unit by reciprocal inhibition. To assess the mobility of AADFROM, Tiberio\textsuperscript{38} recommended that the examiner forcefully dorsiflex the subject’s ankle while the subject actively assisted the manual dorsiflexion force. To assess a patient’s AADFROM, we used AADFROM with the knee extended simply because of the potential for error introduced by the examiner when applying a repeated maximum manual dorsiflexion force to the patient’s forefoot.

**Conclusion**

After an acute inversion ankle sprain, subjects on average were unable to actively dorsiflex the ankle to a neutral position while in a prone non-weight-bearing position with the knee extended. Each subject was prescribed a 6-week HEP and then randomly assigned to a treatment group distinguished by the dosage of daily static stretching to the calf muscle–tendon unit (30 seconds × 3, 1 minute × 3, or 2 minutes × 3). We were unable to demonstrate a significant group effect. Therefore, we are not able to recommend with confidence that after an inversion ankle sprain subjects perform a minimum of 3 daily static heel-cord stretches each of 30 seconds duration. We found a significant time main effect whereby AADFROM increased significantly from baseline to week 2 and from week 2 to week 4, but there was not a significant difference in AADFROM from week 4 to week 6. Future research could build on this study by quantifying changes in ankle edema, pain, and physical function over the duration of the 6-week HEP.

**References**


