

Identifying Range-of-Motion Deficits and Talocrural Joint Laxity After an Acute Lateral Ankle Sprain

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Context: Approximately 72% of patients with an ankle sprain report residual symptoms 6 to 18 months later. Although 44% of patients return to activity in less than 24 hours after experiencing a sprain, residual symptoms should be evaluated in the long term to determine if deficits exist. These residual symptoms may be due to the quality of ligament tissue and motion after injury.

Objective: To compare mechanical laxity of the talocrural joint and dorsiflexion range of motion (DFROM) over time (24 to 72 hours, 2 to 4 weeks, and 6 months) after an acute lateral ankle sprain (LAS).

Design: Cross-sectional study.

Setting: Athletic training research laboratory.

Patients or Other Participants: A total of 108 volunteers were recruited. Fifty-five participants had an acute LAS and 53 participants were control individuals without a history of LAS.

Main Outcome Measure(s): Mechanical laxity (talofibular interval and anterior talofibular ligament length) was measured in inversion (INV) and via the anterior drawer test. The weight-bearing lunge test was conducted and DFROM was measured.

The data were analyzed using repeated-measures analysis of variance, independent-samples *t* tests, and 1-way analysis of variance.

Results: Of the 55 LASs, 21 (38%) were grade I, 27 (49%) were grade II, and 7 (13%) were grade III. Increases were noted in DFROM over time, between 24 and 72 hours, at 2 to 4 weeks, and at 6 months ($P < .05$). The DFROM was less in participants with grade III than grade I LASs ($P = .004$) at 24 to 72 hours; INV length was greater at 24 to 72 hours than at 2 to 4 weeks ($P = .023$) and at 6 months ($P = .035$) than at 24 to 72 hours. The anterior drawer length ($P = .001$) and INV talofibular interval ($P = .004$) were greater in the LAS group than in the control group at 6 months.

Conclusions: Differences in range of motion and laxity were evident among grades at various time points and may indicate different clinical responses after an LAS.

Key Words: talofibular interval, inversion, anterior drawer test, weight-bearing lunge test

Key Points

- At 6 months, subjective ankle instability and ankle function scores on the Cumberland Ankle Instability Test and Foot and Ankle Ability Measure-Activities of Daily Living and Sport were worse in the acute lateral ankle sprain (LAS) group than in the control group.
- Inversion and anterior drawer length were greater in the acute LAS group versus the control group at 6 months.
- Long-term deficits in the ankle joint may persist for at least 6 months after an acute LAS, which may lead to negative outcomes, such as chronic ankle instability and residual symptoms.

Ankle sprains account for many acute sport-related injuries sustained by athletes who present to the emergency department, with a cost of more than \$1000 per lateral ankle sprain (LAS).¹ The ankle joint is the most commonly injured body part in an athletic population. Of all ankle injuries in the collegiate setting, sprains most often affect the lateral ankle ligament complex.² The sports with the highest prevalence of ankle sprains were men's and women's basketball, as well as women's track, women's soccer, and women's field hockey.² The time to return to full activity was less than 24 hours after injury for 44% and more than 21 days for only 3.6%.²

In a general clinic-based population, approximately 72% of patients after an ankle sprain reported residual symptoms 6 to 18 months later.³ Of these, 40% described at least 1 moderate to severe symptom, such as ankle weakness,

ankle instability, pain, or swelling. Factors that were associated with moderate to severe symptoms were reinjury of the ankle, activity restriction of more than 1 week, and limited weight bearing for longer than 28 days.³ Previous researchers⁴ have shown that approximately 30% of patients with an initial ankle sprain developed *chronic ankle instability* (CAI), a condition in which patients sustain recurrent ankle sprains and may have prolonged symptoms and exhibit mechanical or functional instability (or both).^{5,6}

Reduced dorsiflexion range of motion (DFROM) after an ankle sprain has been identified as a strong predictor of a subsequent ankle sprain.⁷ Earlier investigators⁸ determined that this deficit may result from anterior displacement of the talus or loss of posterior talar glide. As deficits in range of

Acute ankle sprain group: n = 55

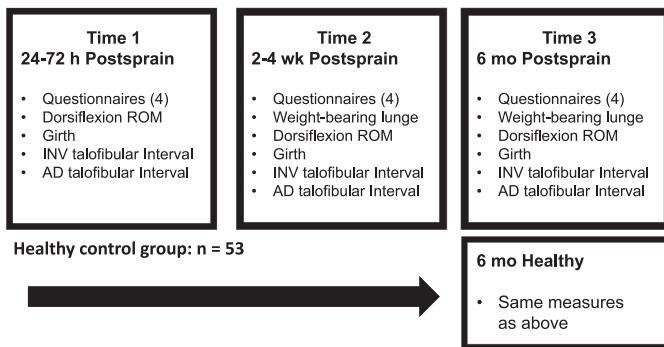


Figure 1. Experimental design. Abbreviations: AD, anterior drawer; INV, inversion; ROM, range of motion.

motion occur after an ankle sprain, deficits in talocrural, ankle joint, and laxity also occur.⁹

Laxity, or the amount of mechanical instability within the joint, has been identified as an indicator of subsequent injury to the ankle ligaments.¹⁰ After an initial evaluation, the clinician grades the injury (I, II, or III), depending upon the severity of the injury and the symptoms present. Grading is typically based on the results of manual stress tests, such as the anterior drawer (AD) and talar tilt.¹¹ Manual stress tests were less reliable than instrumented arthrometry for measuring laxity in the joint¹²; thus, the clinical decision regarding injury severity was less accurate. This can be problematic because understanding the severity of an ankle sprain plays a significant role in the clinician's reasoning with respect to specific rehabilitation protocols and time to return to play. The AD and inversion (INV) talar tilt methods have been performed via multiple methods: stress radiography, stress ultrasonography, stress magnetic resonance imaging, and instrumented arthrometry.

Croy et al¹³ measured ankle laxity using stress ultrasonography and a stress device (Telos Medical USA). The *talofibular interval* (TI) was the distance between the talus and the fibula according to the measuring tool on the ultrasound unit. After an acute LAS, the TI was greater on the injured than the uninjured side.¹⁴ Hubbard and Cordova¹⁰ examined the natural recovery of talocrural mechanical laxity over an 8-week period after an ankle sprain. Participants with acute ankle sprains were tested at 3 days and 8 weeks after injury. Laxity was measured using an instrumented arthrometer. Anterior displacement and INV rotation were greater at day 3 and week 8 in the injured group than in the healthy group. The authors concluded that mechanical laxity after an ankle sprain may persist beyond 8 weeks. However, clinicians' identification of ankle sprain severity has not been investigated.

Therefore, the purpose of our study was to compare mechanical laxity of the talocrural joint and DFROM in a college-aged population over time after an LAS. We hypothesized that the TI and anterior talofibular ligament (ATFL) length demonstrated on the AD and INV would increase in the LAS group after a grade II or III injury compared with the control (CON) group. We hypothesized that the ATFL length within 24 to 72 hours of injury would

Table 1. Participant Demographics for Lateral Ankle Sprain and Control Groups^a

Demographic	Group		
	Lateral Ankle Sprain (n = 55)	Control (n = 53)	Total (N = 108)
Females/males	27/28	31/22	58/50
Age, y	20.4 ± 1.9	20.3 ± 1.7	20.3 ± 1.8
Height, cm	175.9 ± 12	169.3 ± 10.1	172.7 ± 11.5
Mass, kg	77.4 ± 15.1	68.8 ± 13.3	73.3 ± 14.9

^a Values are mean ± SD except where indicated otherwise.

be greater in patients with grade II and grade III ankle sprains than 2 to 4 weeks later.

METHODS

In our cross-sectional design, the independent variables were time (24–72 hours, 2–4 weeks, and 6 months), injury severity (grade I, II, or III), and group (LAS and CON). The dependent variables were DFROM (°), weight-bearing lunge test (WBLT) results (°, centimeters; Figure 1), INV TI (mm), INV length (mm), AD TI (mm), and AD length (mm). Covariates were sex, height, and mass. Testing took place at 3 time points after LAS: 24 to 72 hours, 2 to 4 weeks, and 6 months. The CON group was tested once, around the 6-month time point for the LAS group. During each testing session, the same sequence was completed by the same athletic trainer (AT), who had 4 years of experience using each measure: (1) DFROM, (2) WBLT, and (3) stress ultrasonography.

Participants

We recruited 108 volunteers (58 females, 50 males) for this study. All participants were recreational or competitive university student-athletes (Table 1) who engaged in physical activity for at least 30 minutes, 3 times a week. Each person provided informed consent, and the investigation was approved by the university's institutional review board. Recruitment and testing occurred over an 18-month period (fall 2017 to spring 2019). Participants were further divided into the LAS (n = 55) and CON (n = 53) groups (Figure 1). For the LAS group, all data were collected on unilateral acute LASs within 24 to 72 hours of injury using the International Ankle Consortium definition of ankle sprain.¹⁵ Ankle sprains were included whether or not the participant had incurred a previous LAS on that side. Nine LAS participants were not included in the 6-month testing session because they were either unavailable or not near the testing location at that time. Among the LAS group, each person's injury severity was classified (grade I, II, or III).¹⁶ For assignment to the LAS group, we selected those with a previous LAS on the same side. Those who had their first LAS on that side were also included in the study. A history of previous LAS on that side served as a covariate to attempt to account for this difference. A single experienced rater who is an AT completed the injury classification. We did not conduct a separate reliability analysis because the determination was also based on the laxity measurement. The reliability of each measure was taken from previous work and is outlined in the "Instrumentation" section. Communication regarding follow-up data collection took place via email and the participant's school AT. The

Table 2. Injury Classification for Lateral Ankle Sprain

Grade	Decreased Range of Motion, °	Edema, cm	Stress
I	<5	>0.5	Normal
II	5–10	0.5–2	Normal
IIIA	>10	>2	Normal
IIIB	>10	>2	Laxity >3 mm

involved limb and height and weight within 10% for the LAS individuals were matched in the CON group. In accord with the International Ankle Consortium guidelines¹⁵ for CON participants, the CON group had no history of LAS sprain on either side with Cumberland Ankle Instability Tool (CAIT) and Identification of Functional Ankle Instability (IdFAI) scores of 30 and 0, respectively. Excluded from the study were any participants with CAI (CAIT score < 24 or IdFAI score > 11) or who were currently seeking treatment for a separate lower extremity injury (not including an LAS) or had undergone any lower extremity surgery within the last year.¹⁵ In the LAS group, 44 of the 55 participants (80%) were National Collegiate Athletic Association Division I or II competitive athletes who received initial treatment within 24 to 72 hours and progressive rehabilitation (protection, rest, ice, compression, and elevation; range of motion; strength; balance; and joint mobilizations) from an AT. Although the rehabilitation process may affect outcomes after LAS, we did not evaluate the rehabilitation protocols. The remaining 20% of participants (n = 11) with LAS were recreational noncompetitive athletes who received an initial evaluation by a physician within 24 to 72 hours but did not pursue rehabilitation with an AT. However, these athletes reported verbally by the 2- to 4-week testing session that they had returned to physical activity (eg, military training, running, and ultimate Frisbee) after the LAS.

Instrumentation

Mechanical laxity of the talocrural joint was measured using the LigMaster device (LigMaster, Inc) to stress the ankle in the AD and INV positions, while taking an ultrasound image (musculoskeletal ultrasound [MSUS]) using the LOGIQ E system (General Electric Co) at a 12-MHz frequency and 2.5-cm depth. The transducer head was positioned in the sinus tarsi, obliquely with respect to the distal fibula, from the origin to the insertion of the ATFL.¹⁷ Ultrasonic gel (Aquasonic 100; Parker Laboratories, Inc) was used as a conductive medium. For the DFROM and WBLT, an inclinometer, protractor, and tape measure were used.

Demographic and Anthropometric Data

Before the testing session, participants completed a questionnaire that addressed general information, such as age, sex, height, weight, and lower extremity injury history. They also completed 3 surveys related to foot and ankle function and instability so that we could determine if any participants had CAI, which would exclude them from this study. The 3 surveys were the CAIT, IdFAI, and Foot and Ankle Ability Measure (FAAM) Activities of Daily Living (ADL) and Sports Subscales.⁶

Injury Classification

To determine each individual's injury severity and grade (I, II, or III), we measured ankle girth (ie, edema) using a tape measure in a figure-eight method, DFROM using a goniometer, and laxity using stress ultrasound. The methods of Malliaropoulos et al¹⁶ for classifying LAS grade are described in Table 2. Because a grade I ankle sprain is associated with negative AD and talar tilt tests, we analyzed severity separately.

Dorsiflexion Range of Motion

Participants were asked to sit up on the plinth supporting themselves on outstretched arms with their legs straight and ankles hanging off the table. Using a goniometer and the methods of Malliaropoulos et al,¹⁶ we placed the axis at the distal edge of the lateral malleolus, with the stationary arm in line with the midline of the fibula and the movement arm parallel to the fifth metatarsal. Recruits were instructed to maintain neutral position (0° on the goniometer). They were then told to use their toes to pull the foot back toward them as far as they could. Three measurements were taken, and the largest measure was used for comparison. The uninvolved ankle was measured first, followed by the involved ankle.

Weight-Bearing Lunge Test

We administered the WBLT using the methods described by Bennell et al.¹⁸ Range of motion (°) and the distance away from the wall (centimeters) were collected. Three trials were performed, and the maximal range of motion was used for analysis. If the participant easily reached the wall with the toes at 10 cm, the trial was repeated at a greater distance, 1 cm at a time until maximal distance and range were achieved. The opposite was done if the participant was unable to touch the wall without the heel rising at 10 cm. The foot moved closer to the wall 1 cm at time until maximal distance and range were achieved. The inclinometer was placed on the participant's anterior distal tibia.

Inversion Talofibular Interval

For the last portion of the testing session, we placed the participant's leg in the LigMaster device using the guidelines for INV. The counter bearing was positioned near the lateral knee without creating pressure on the joint line. A cushion underneath the distal hamstrings was provided for added comfort. The pressure actuator was placed so that the edges of the rubber padding delivered pressure at the level of the most medial point on the medial malleolus (Figure 2A).¹⁹ Three static images were taken consecutively before the stress was imposed. A force of 15 dN was applied unless the participants reported pain before that value was reached; in that case, the force application was stopped between 12 and 15 dN. The MSUS images were obtained over the ATFL, with 3 images taken consecutively at the maximal stress position (Figure 2B).²⁰ Using the device's measurement function, we assessed the distance between the peaks of the lateral malleolus and talus, or TI, which constitutes the anatomic origin and insertion of the ATFL (Figure 3A).^{14,21} Measurements of the uninjured ankle were compared with

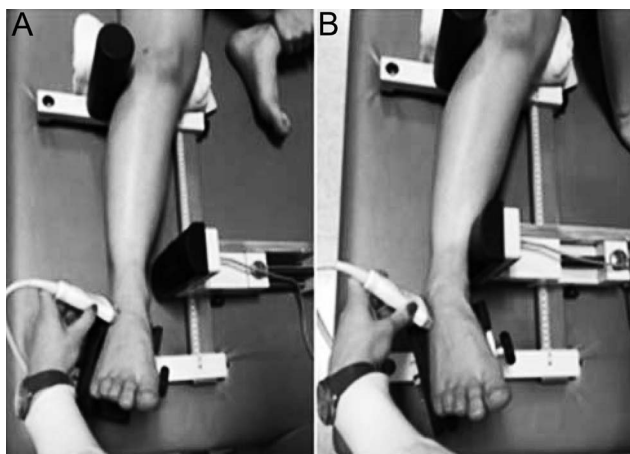


Figure 2. Inversion talofibular interval. A, Static position. B, Stressed position.

the injured side. An average of the 3 images was used for analysis, and the difference between the injured and uninjured ankles was determined.¹⁴ The *INV TI* was defined as the difference between the stress and static measures. The *INV length* was defined as the distance between the peak of the talus and the fibula at the maximal stress position.

Anterior Drawer Talofibular Interval

The last measurement we took was in the AD position using the LigMaster device using methods similar to those of Croy et al.¹⁴ Participants were asked to lie on the side opposite the test ankle. The pressure actuator was placed so that the edges of the rubber padding delivered pressure at the level of 5.0 cm proximal to the medial malleolus (Figure 4). Three static images were taken consecutively before stress was imposed. A force of 15 dN was applied, unless the participant reported pain before that value was reached, in which case the force was removed between 12 and 15 dN.¹⁸ The MSUS images were obtained over the ATFL, with 3 images taken consecutively at the maximal stress position. We used the device's measurement function to determine the distance between the peaks of the lateral malleolus and talus, or TI, which constitutes the anatomic origin and insertion of the ATFL (Figure 3A).^{14,21} Measurements of the uninjured ankle were compared with

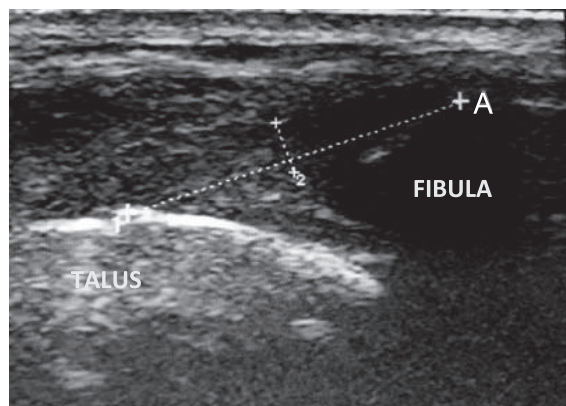


Figure 3. Musculoskeletal ultrasound. A, Talofibular interval.



Figure 4. Anterior drawer talofibular interval, static position.

the injured side. An average of the 3 images was used for analysis, and the difference between the injured and uninjured ankles was determined.¹³ The *AD TI* was defined as the difference between the stress and static measures. The *AD length* was defined as the distance between the peak of the talus and the fibula at the maximal stress position.

Statistical Analysis

Based on an a priori power analysis (G*Power, version 3.1.9; Heinrich-Heine-Universität Düsseldorf), 50 participants each were needed in the LAS and CON group to obtain power of 0.80, effect size of 1.4, and $P \leq .05$. The following statistical analyses were used: (1) repeated-measures analysis of variance (ANOVA) to evaluate DFROM, WBLT, and AD and INV TI and length in the LAS group over the 3 time periods (24 to 72 hours, 2 to 4 weeks, and 6 months); (2) independent-samples *t* tests to compare the variables between groups (LAS and CON) at the 6-month time point; and (3) one-way ANOVA to compare the variables according to the 3 severity grades (grade I, II, III) in the LAS group during the 3 time periods. We calculated Cohen *d* effect sizes to determine the standardized difference in the means of significant findings. A *small effect size* was represented by 0.2, *medium* by 0.5, and *large* as 0.8.²² All data were analyzed using SPSS (version 25; IBM Corp). An a priori α level of .05 was used to denote statistical significance.

RESULTS

Each variable (injury classification and function, DFROM, WBLT, INV TI and length, and AD TI and length) was assessed in the LAS group over time, by group at 6 months, by LAS severity over time, and between ankles in the LAS group. Five new participants were added to the LAS group between the 24- to 72-hour and 2- to 4-week testing sessions (total of 55 participants) when they were identified after the 72-hour window, and they returned for the 6-month analysis. From the 2- to 4-week (50 participants) and 6-month (46 participants) testing sessions, 9 participants dropped out because they were unavailable,

Table 3. Injury Classification and Ankle Laxity After Lateral Ankle Sprain

Variable	Time, Mean \pm SD		
	24–72 h	2–4 wk	6 mo
Girth, cm	51.7 \pm 3.8 ^a	50.7 \pm 4.2 ^a	49.2 \pm 3.9 ^a
Dorsiflexion, °	5.8 \pm 3.2 ^a	8.3 \pm 3.7 ^a	9.9 \pm 3.7 ^a
Weight-bearing lunge test			
cm	NA	6.6 \pm 3.8 ^a	9.0 \pm 3.5 ^a
°	NA	37.2 \pm 10.5 ^a	42.7 \pm 8.1 ^a
Inversion, mm			
Talofibular interval	1.9 \pm 2.9 ^b	−0.21 \pm 2.5 ^b	0.57 \pm 2.3
Length	22.1 \pm 3.1 ^b	21.1 \pm 3.6 ^b	22.3 \pm 3.1 ^b
Anterior drawer, mm			
Talofibular interval	1.7 \pm 1.7	1.5 \pm 2.3	1.0 \pm 2.1
Length	22.4 \pm 3.8	21.9 \pm 2.9	22.7 \pm 3.6
Cumberland Ankle Instability Tool score	19.2 \pm 8.3	19.4 \pm 6.4 ^b	23.3 \pm 6.5 ^b
Identification of Functional Ankle Instability score	17.5 \pm 7.9 ^b	20.9 \pm 6.7 ^b	16.6 \pm 6.4 ^b
Foot and Ankle Ability Measure, %			
Activities of Daily Living	54.9 \pm 26.2 ^a	67.2 \pm 22.2 ^a	79.3 \pm 10.8 ^a
Sports	53.5 \pm 10.4 ^a	71.4 \pm 10.6 ^a	86.2 \pm 4.7 ^a

Abbreviation: NA, not assessed.

^a Indicates difference between time points ($P < .001$).

^b Indicates difference between time points ($P < .05$).

not near the testing location, or sustained another injury before the 6-month session.

Of those who sustained an acute LAS, 21 of 55 (38%) injuries were grade I, 27 of 55 (49%) were grade II, and 7 of 55 (13%) were grade III. Regarding the injured ankle, participants had sustained an average of 2.16 ± 2 previous LASs.

Changes Over Time

In the LAS group, girth decreased between 24 and 72 hours, 2 and 4 weeks, and 6 months (Table 3). Over time, DFROM increased from 24 to 72 hours to 2 to 4 weeks and 6 months. The WBLT also increased between 2 to 4 weeks and 6 months. The INV length demonstrated a very small difference (1 mm) between 24 to 72 hours and 2 to 4 weeks. However, INV TI was greater at 24 to 72 hours than at 2 to 4 weeks. No differences were detected in the LAS group over time in AD TI ($P = .280$) or AD length ($P = .228$).

The CAIT score was lower at 2 to 4 weeks than at 6 months ($P = .035$). The IdFAI score was highest at 2 to 4 weeks compared with 24 to 72 hours and 6 months. The FAAM-ADL and FAAM-Sports scores increased over time from the 24- to 72-hour to 2- to 4-week to 6-month time frames ($P < .001$; Table 3).

Six Months

At 6 months, we found no differences in girth between groups ($P = .288$; Table 4). Dorsiflexion ROM and WBLT performance did not differ between groups. The AD length, INV TI, and INV length were greater in the LAS group than in the CON group. The AD TI did not differ between groups.

All functional questionnaire scores of the LAS group differed from those of the CON group; the former exhibited lower CAIT, higher IdFAI, lower FAAM-ADL, and lower FAAM-Sports scores.

Severity of LAS

Using a 1-way ANOVA to examine differences between severity of ankle sprain (grade I, II, or III), we found that the FAAM-Sports score at 24 to 72 hours was lower in participants with grade III than grade I injuries ($P = .030$; Table 5). No differences were noted among grades at 24 to 72 hours for girth ($P = .788$) or CAIT ($P = .486$) or IdFAI ($P = .360$) or FAAM-ADL ($P = .101$) score. At 2 to 4 weeks, participants with grade III LASs displayed lower FAAM-Sports scores than those with grade I ($P = .026$) or II ($P = .034$) injuries. During this time, the CAIT was lower in recruits with grade III LASs than those with grade I ($P = .006$) or II ($P = .043$) injuries. The IdFAI and FAAM-ADL scores were not different between grades at 2 to 4 weeks ($P = .539$ and $P = .080$, respectively). At 6 months, the FAAM-Sports score was lower in individuals with grade III than grade I LASs ($P = .041$). Girth and the CAIT, IdFAI, and FAAM-ADL scores did not differ at 6 months.

At 24 to 72 hours, DFROM was less in those with grade III than grade I LASs. No difference was seen among grades at 2 to 4 weeks or 6 months ($P = .980$). At 24 to 72 hours, the WBLT was not conducted. At 2 to 4 weeks, the WBLT result (°) approached differences by severity ($P = .053$), yet the centimeter measure was not different ($P = .080$). Conversely, at 6 months, the WBLT result (centimeters) approached differences by severity ($P = .061$), but the result in degrees was not different ($P = .174$).

At 24 to 72 hours, INV length was larger in participants with grade III than grade I ($P = .023$) or II ($P = .035$; Table 5) LASs. However, no differences were noted between those with grade II and III injuries ($P = .651$). The AD TI was larger in individuals with grade II than grade I or III LASs at 24 to 72 hours ($P = .009$). The INV length and TI did not differ by severity at 2 to 4 weeks or 6 months. The AD length and TI did not differ by severity at 2 to 4 weeks or 6 months.

Table 4. Injury Classification and Ankle Laxity by Group at 6 Months

Variable	Group, Mean \pm SD		Cohen d Value
	Lateral Ankle Sprain (n = 46)	Control (n = 53)	
Girth, cm	49.3 \pm 3.9	48.5 \pm 3.0	0.23
Dorsiflexion, °	9.9 \pm 3.6	10.6 \pm 3.9	0.18
Weight-bearing lunge test			
cm	8.8 \pm 3.6	9.8 \pm 3.6	0.27
mm	42.4 \pm 8.3	44.9 \pm 10.1	0.27
Inversion, mm			
Talofibular interval	0.72 \pm 2.5 ^a	-0.88 \pm 2.4 ^a	0.65^c
Length	22.3 \pm 3.1 ^b	19.4 \pm 2.9 ^b	0.96^c
Anterior drawer, mm			
Talofibular interval	1.01 \pm 2.1	0.53 \pm 1.7	0.25
Length	22.7 \pm 3.6 ^a	20.6 \pm 2.8 ^a	0.65^c
Previous ankle sprains, No.	2.2 \pm 2.2 ^b	0.0 \pm 0.0 ^b	1.4^c
Cumberland Ankle Instability Tool score	23.3 \pm 6.5 ^b	28.8 \pm 1.2 ^b	1.2^c
Identification of Functional Ankle Instability score	16.6 \pm 6.4 ^b	2.5 \pm 2.5 ^b	2.9^c
Foot and Ankle Ability Measure, %			
Activities of Daily Living	79.3 \pm 10.8 ^b	83.5 \pm 1.4 ^b	1.1^c
Sports	86.2 \pm 4.7 ^b	99.3 \pm 0.66 ^b	1.3^c

^a Indicates difference among grades ($P < .05$).

^b Indicates difference among grades ($P < .01$).

^c Boldface indicates medium to large effect size.

DISCUSSION

The long-term effects of an acute LAS on ankle joint laxity and function have not been previously identified in a college-aged population compared with a healthy, uninjured cohort. Our purpose was to assess mechanical laxity of the talocrural joint over time after an LAS. The primary finding was that, at 6 months after injury, the LAS group displayed differences in laxity.

Injury Classification

Among the 55 participants who sustained an acute LAS, 38% (n = 21) were grade I, 49% (n = 27) were grade II, and 13% (n = 7) were grade III injuries. Our distribution pattern was similar to that reported by Malliaropoulos et al,¹⁶ who identified 208 track and field athletes and found 44% (n = 92) were grade I, 30% (n = 63) were grade II, and 26% (n = 53) were grade III.¹⁶ Our results were not surprising as we used the same criteria as Malliaropoulos et al¹⁶ to classify LAS severity.

As we noted, girth decreased over time in the LAS group, which was expected due to tissue healing. At 6 months, CAIT scores were 5.5 points lower in the LAS group than in the CON group. Wright et al²³ identified the minimal detectable change as 3.08 and the minimally clinical important difference as ≥ 3 points. The FAAM-ADL and FAAM-Sports scores increased in the LAS group between 24 to 72 hours and 2 to 4 weeks and demonstrated a smaller increase between 2 to 4 weeks and 6 months. Croy et al¹⁴ described increases in both FAAM-ADL and FAAM-Sports scores from baseline to week 3 (21.9 \pm 16.2, $P < .0001$ and 23.8 \pm 16.9, $P < .0001$, respectively) and from week 3 to week 6 (2.5 \pm 4.4, $P = .009$ and 10.5 \pm 13.2, $P = .001$, respectively). Doherty et al²⁴ observed that a lower level of self-reported function and poor dynamic postural control 6 months after a first-time LAS ultimately predicted the

development of CAI. Although girth decreased and self-reported function improved over time, substantial deficits were still present at 6 months and depended on the severity of the LAS.

Range of Motion

After an LAS, reduced DFROM compared with the healthy ankle has been recognized as a strong predictor of lower extremity injury.²⁵ Those with reduced DFROM (34°) were approximately 5 times more likely to sustain an LAS than those with an average DFROM (45°).²⁶ During gait, restricted DFROM may increase the risk of LAS by limiting the ankle's ability to reach a closed-packed position during midstance.²⁷ For normal walking, at least 10° of dorsiflexion is required; however, for running, 20° to 30° of dorsiflexion is required.²⁸

Few previous researchers have investigated the differences in DFROM and WBLT results by severity of LAS.²⁹ Our classification of the injury during the first 24 to 72 hours depended on the measured DFROM and the difference between the injured and uninjured ankles and was, thus, the basis for the difference among grades. In a grade II or III LAS, the structure of the ATFL has been disrupted; during the remodeling phase, scar tissue builds up around the repairing ligament.^{30,31} This scar tissue is less mobile than that in an intact ligament. Earlier authors⁸ concluded that this may shift the talus to a more anterior position, causing a decrease in ankle DFROM. We postulate that this explains the decrease in WBLT among those with a grade II or III LAS. As DFROM improves over time after LAS, it may be important to consider the difference between the injured and uninjured limbs. We contend that the WBLT is important to use and monitor in those who sustain a grade II or III LAS to ensure no persistent differences. As DFROM improved over time

Table 5. Injury Classification and Ankle Laxity in LAS by Grade

	24–72 Hours, Mean \pm SD			2–4 Weeks, Mean \pm SD			6 Months, Mean \pm SD		
	I (n = 21)	II (n = 24)	III (n = 5)	I (n = 22)	II (n = 27)	III (n = 6)	I (n = 16)	II (n = 24)	III (n = 6)
Girth, cm	52.0 \pm 3.7	52.6 \pm 4.4	51.6 \pm 1.5	51.7 \pm 4.2	51.8 \pm 4.3	47.9 \pm 2.5	49.3 \pm 3.9	49.8 \pm 4.0	47.0 \pm 2.4
DFROM, °	7.2 \pm 3.1 ^a	5.5 \pm 2.9	2.2 \pm 1.9 ^a	8.3 \pm 3.8	8.2 \pm 3.9	6.8 \pm 1.6	9.8 \pm 3.7	9.9 \pm 3.7	10.2 \pm 3.7
WBLT, cm	X ^b	X ^b	X ^b	7.8 \pm 3.2	6.2 \pm 4.0	3.6 \pm 2.9	10.2 \pm 2.9	7.6 \pm 3.8	9.7 \pm 3.4
WBLT, °	X ^b	X ^b	X ^b	40.5 \pm 8.2	35.6 \pm 8.7	28.2 \pm 20.2	44.5 \pm 8.2	40.2 \pm 8.1	45.5 \pm 8.3
AD TI, mm	.88 \pm 1.7 ^c	2.4 \pm 1.6 ^c	1.4 \pm 1.3	1.2 \pm 2.4	1.7 \pm 2.6	2.1 \pm 1.4	.42 \pm 2.4	1.27 \pm 2.16	1.5 \pm .66
INV TI, mm	1.1 \pm 2.5	2.4 \pm 3.3	3.5 \pm 2.0	-.75 \pm 2.5	.09 \pm 2.3	.38 \pm 2.6	.93 \pm 2.5	.58 \pm 2.7	.71 \pm 2.5
AD length, mm	21.6 \pm 3.3	23.0 \pm 4.2	22.6 \pm 3.8	21.4 \pm 2.8	22.4 \pm 3.2	21.7 \pm 2.8	22.0 \pm 4.0	23.2 \pm 3.5	22.5 \pm 2.2
INV length, mm	20.7 \pm 2.2 ^a	22.9 \pm 3.2 ^a	24.6 \pm 3.2 ^a	19.6 \pm 2.6	21.8 \pm 4.2	22.4 \pm 2.9	21.8 \pm 2.2	22.7 \pm 3.7	21.9 \pm 2.3
IdFAI	16.8 \pm 7.4	17.2 \pm 7.9	23.0 \pm 10.7	19.5 \pm 7.2	21.5 \pm 6.3	22.6 \pm 7.2	14.0 \pm 5.6	17.4 \pm 6.8	20.0 \pm 5.0
CAIT	20.9 \pm 6.8	17.9 \pm 9.0	18.3 \pm 11.0	22.0 \pm 4.1 ^c	19.5 \pm 6.8 ^c	12.6 \pm 5.4 ^c	27.3 \pm 2.3	21.9 \pm 7.2	19.6 \pm 7.1
FAAM-ADL, %	62.6 \pm 26.5	52.1 \pm 24.7	29.3 \pm 18.6	78.1 \pm 4.6	60.3 \pm 29.3	64.3 \pm 10.2	78.1 \pm 17.1	81.6 \pm 2.9	74.6 \pm 8.8
FAAM-Sport, %	59.0 \pm 10.5 ^c	48.2 \pm 9.9	6.2 \pm 3.5 ^c	82.5 \pm 4.8 ^c	53.7 \pm 11.9 ^c	42.1 \pm 6.5 ^c	89.6 \pm 5.0 ^c	88.1 \pm 3.3	71.2 \pm 5.9 ^c

Abbreviations: AD, anterior drawer; ADL, Activities of Daily Living; CAIT, Cumberland Ankle Instability Tool score; DFROM, dorsiflexion range of motion; FAAM, Foot and Ankle Measure score; IdFAI, Identification of Functional Ankle Instability score; INV, inversion; LAS, lateral ankle sprain; TI, talofibular interval; WBLT, weight-bearing lunge test.

^a Significant differences between grades of $P < .01$.

^b Variable was not assessed.

^c Significant differences between grades of $P < .05$.

after the LAS, deficits were noted by severity of LAS and DFROM did not tend to return to normal at the same rate.

Talocrural Joint Laxity

The recent focus of research³² has been on mechanical instability of the ankle joint, or laxity, after LAS, especially when determining a participant's risk for repetitive injuries or CAI. Croy et al¹⁴ conducted bilateral stress ultrasound imaging at baseline (<7 days) and on the affected ankle at 3 weeks and 6 weeks after injury in 3 conditions: neutral, AD, and INV. The AD length increased TI in the involved ankle (22.65 ± 3.75 mm, $P = .017$) compared with the uninvolved ankle (19.45 ± 2.35 mm) at baseline. To our knowledge, these authors were the first to discuss TI changes in neutral position. However, we defined TI (in millimeters) as the difference between the stressed and static positions on the MSUS image. Our results showed that those who had sustained an acute LAS still displayed differences in ankle laxity versus a healthy CON group at 6 months after injury.

The differences in INV length by severity showed that the grade assigned at 24 to 72 hours was correct according to the demonstrated laxity. Croy et al¹⁴ noted that INV stress resulted in greater interval changes in the injured (23.41 ± 2.81 mm) than the uninvolved ankle (21.13 ± 2.08 mm). They reported a main effect for time in INV (21.93 ± 3.75 mm, $P = .019$), but not AD (21.18 ± 2.34 mm, $P = .055$), which is in line with our findings. The TI decreased between baseline and week 3 for INV only ($F_{1,26} = 5.6$, $P = .026$). Similarly, we determined that TI decreased between 24 to 72 hours and 2 to 4 weeks after injury. Still, Croy et al¹⁴ did not include a control or healthy group but instead compared the values with those of the uninvolved ankle. Also, the ending time points were different: up to 6 weeks after injury versus our 6-month time point to determine the long-term effects of ankle laxity via stress ultrasonography.

Hubbard and Cordova¹⁰ examined the natural course of mechanical laxity of the talocrural joint over 8 weeks after an LAS. Participants with acute LASs were tested 3 days after injury and at follow-up 8 weeks later. Laxity was measured by anterior and posterior displacement (millimeters) and INV and eversion rotation (°) using an instrumented arthrometer. We included participants with grade I–III injuries, whereas Hubbard and Cordova³³ studied participants with grade I or II LASs. The authors reported more anterior displacement at day 3 ($P = .001$) and at week 8 ($P = .010$) in the injured group than in the healthy group. Also, INV rotation was greater at day 3 ($F = 2.70$, $P = .002$) and week 8 ($F = 5.4$, $P = .033$) in the injured group than in the healthy group. They concluded that reduction of mechanical laxity after an LAS may take longer than 8 weeks. Similarly, we showed that at 6 months after LAS, participants displayed persistent differences in ankle laxity (INV and AD) compared with a healthy CON group. We believe that by 6 months after LAS, the ligament (specifically the ATFL) is healing and developing collagen fibers appropriately; yet the ligament is unable to withstand the same mechanical forces as a healthy, uninjured ligament, leading to additional microinjuries to the structure. Initially after an LAS, talocrural joint laxity depends on the severity of the injury

and improves little over time, becoming greater than in healthy control at 6 months.

Clinical Implications

Miklovic et al³⁴ suggested that an acute LAS leads to CAI by a pathway of dysfunction. This pathway develops because of impairments that have been previously associated with CAI, including decreased range of motion, strength, and postural control and altered movement patterns during functional activities. An impairment-based rehabilitation model created by Donovan and Hertel³⁵ was an effective rehabilitation strategy for those with CAI. In summary, the impairment-based model involves assessing each possible impairment, identifying deficits, and then addressing the impairment through rehabilitation.³⁵ Because similar impairments are seen in all groups, the impairment-based model may be effective for treating patients with an acute LAS.³⁴

Recently, the International Ankle Consortium³⁶ developed recommendations based on expert consensus for the clinical assessment of patients with acute LAS injuries. The Rehabilitation-Oriented Assessment includes an evaluation of the patient's ankle in multiple areas: joint pain, joint swelling, range of motion, arthrokinematics, strength, static and dynamic postural balance, gait, level of physical activity, and self-reported joint function. Along with establishing the mechanism of injury and assessing the ankle joint bones and ligaments through stress tests, clinicians need to consider all aspects of the injury.³⁶ We showed that deficits can be identified early, at 24 to 72 hours, and persist at 6 months after injury. We urge clinicians to evaluate these clinical outcomes throughout the healing process, which can take up to 6 months after LAS. Future researchers should focus on the patterns after 6 months to see if these deficits continue or worsen.

As clinicians, we must incorporate these models into our education and continuing education of new and current clinicians and promote their use on every patient with an acute LAS. Each LAS may display different impairments that need to be addressed and reevaluated after return to full function. In an athletic population, investigators³³ found that these patients may return to full participation too early in the healing process, without specific and detailed outcome measure follow-ups, which may lead to incomplete recovery. We learned that participants' self-reported function did not improve by 6 months after the LAS. From the onset of the LAS, at each clinical evaluation, clinicians should establish the patient's deficits using specific outcome measures (questionnaires, range of motion, and laxity) compared with the healthy, uninjured ankle and continue to assess them up to 6 months postinjury, even after the person returns to full participation. We emphasize that at 6 months after LAS, differences were still present. We believe that the use of musculoskeletal ultrasound to obtain subjective information can be important to clinicians early in the management of patients with an LAS.

Limitations

Although we offer clinicians and researchers additional insight into the long-term effects of an acute LAS, our

study was not without limitations. To obtain a large enough sample, we were unable to collect baseline test results before the LAS because the potential participant pool was very large. For the CON group, we did not pursue additional testing sessions to coincide with the 24- to 72-hour and 2- to 4-week time points in the LAS group; thus, the comparison between groups occurred only at the 6-month time period. We attempted to avoid a possible history bias by testing both groups at the approximate 6-month time point of the LAS group. Future researchers may consider studying only patients with first-time LASs if the cohort is large enough or may wish to split the group into those with previous LASs and those without. Also, given the scope of our work, we did not take into account individual rehabilitation protocols, even though most participants were collegiate athletes treated by an AT. Future authors should also determine the role of rehabilitation in the ankle's response to LAS.

During the INV and AD stress tests, performed with the LigMaster device at 24 to 72 hours after the injury, a small number of participants had pain, causing the examiner to decrease the force from 15 dN to 10 to 12 dN. In the device manual, LigMaster, Inc, recommended that decreasing to 10 to 12 dN would still achieve the same results; however, the stress on the injured fibers might be less. Most individuals who experienced pain had sustained a grade II or III ankle sprain. Before the test, the examiner asked the participant to acknowledge "pain that is uncomfortable and unbearable that we need to stop the test for." Also, the design of the LigMaster device presented the examiner with difficulties when used on a participant who had a longer or shorter lower limb length (knee to ankle) or foot size (length and width). The placement of the foot in the machine (ie, fit and angle) varied slightly due to each participant's size. Future researchers should consider using lower limb length as a covariate and determine if it is related to stress values. Even though all measurements were completed by 1 rater, another limitation is that we did not establish the reliability of each measure used. Due to the many statistical analyses conducted, we performed covariate analyses to limit type II error; however, we may not have been able to eliminate the error entirely.

Future Directions

To our knowledge, this investigation is the only one of its kind to assess the long-term effects of an acute LAS on participants compared with a healthy CON group. As clinicians, we must assess patients with LASs in the areas mentioned (range of motion, ankle laxity, dynamic balance, and musculoskeletal ultrasound) to determine if differences exist over time, especially if the athlete has returned to play and still displays deficits. We showed that laxity differences were present at 6 months after LAS. Future researchers should use our methods over longer terms (1 year, 2 years, and beyond), comparing the LAS group with a healthy CON group, and addressing the potential for developing CAI.

CONCLUSIONS

Laxity differences persisted in patients 6 months after an LAS compared with a healthy CON group. Increases in INV, AD, and talar tilt were also noted between the

groups at that time. At 24 to 72 hours, patients with grade II and III LASs had greater INV and AD ATFL length. Our results indicated that long-term deficits were present in the ankle joint at least 6 months after an LAS, which may lead to negative outcomes, such as the development of CAI and residual symptoms. One theory may be that ligament healing slows if return to activity is introduced while the inflammatory process is still occurring.

REFERENCES

- Browne GJ, Barnett PLJ. Common sports-related musculoskeletal injuries presenting to the emergency department. *J Paediatr Child Health*. 2016;52(2):231–236. doi:10.1111/jpc.13101
- Roos KG, Kerr ZY, Mauntel TC, Djoko A, Dompier TP, Wickstrom EA. The epidemiology of lateral ligament complex ankle sprains in National Collegiate Athletic Association sports. *Am J Sports Med*. 2017;45(1):201–209. doi:10.1177/0363546516660980
- Braun BL. Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. *Arch Fam Med*. 1999;8(2):143–148. doi:10.1001/archfami.8.2.143
- van Rijn RM, van Os AG, Bernsen RM, Luijsterburg PA, Koes BW, Bierma-Zeinstra SM. What is the clinical course of acute ankle sprains? A systematic literature review. *Am J Med*. 2008;121(4):324–331.e6. doi:10.1016/j.amjmed.2007.11.018
- Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: evolution of the model. *J Athl Train*. 2011;46(2):133–141. doi:10.4085/1062-6050-46.2.133
- Gribble PA, Delahunt E, Bleakley CM, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *J Athl Train*. 2014;49(1):121–127. doi:10.4085/1062-6050-49.1.14
- De Noronha M, França LC, Haupenthal A, Nunes GS. Intrinsic predictive factors for ankle sprain in active university students: a prospective study. *Scand J Med Sci Sport*. 2013;23(5):541–547. doi:10.1111/j.1600-0838.2011.01434.x
- Wikstrom EA, Hubbard TJ. Talar positional fault in persons with chronic ankle instability. *Arch Phys Med Rehabil*. 2010;91(8):1267–1271. doi:10.1016/j.apmr.2010.04.022
- Hubbard TJ, Hicks-Little CA. Ankle ligament healing after an acute ankle sprain: an evidence-based approach. *J Athl Train*. 2008;43(5):523–529. doi:10.4085/1062-6050-43.5.523
- Hubbard TJ, Cordova M. Mechanical instability after an acute lateral ankle sprain. *Arch Phys Med Rehabil*. 2009;90(7):1142–1146. doi:10.1016/j.apmr.2009.01.020
- Kaminski TW, Hertel J, Amendola N, et al. National Athletic Trainers' Association position statement: conservative management and prevention of ankle sprains in athletes. *J Athl Train*. 2013;48(4):528–545. doi:10.4085/1062-6050-48.4.02
- Fujii T, Luo ZP, Kitaoka HB, An KN. The manual stress test may not be sufficient to differentiate ankle ligament injuries. *Clin Biomech (Bristol, Avon)*. 2000;15(8):619–623. doi:10.1016/s0268-0033(00)00020-6
- Croy T, Koppenhaver S, Saliba S, Hertel J. Anterior talocrural joint laxity: diagnostic accuracy of the anterior drawer test of the ankle. *J Orthop Sports Phys Ther*. 2013;43(12):911–919. doi:10.2519/jospt.2013.4679
- Croy T, Saliba S, Saliba E, Anderson WM, Hertel J. Talofibular interval changes after acute ankle sprain: a stress ultrasonography study of ankle laxity. *J Sport Rehabil*. 2013;22(4):257–263. doi:10.1123/jsr.22.4.257
- Gribble PA, Bleakley CM, Caulfield BM, et al. 2016 consensus statement of the International Ankle Consortium: prevalence, impact and long-term consequences of lateral ankle sprains. *Br J Sport Med*. 2016;50(24):1493–1495. doi:10.1136/bjsports-2016-096188
- Malliaropoulos N, Papacostas E, Papalada A, Maffulli N. Acute lateral ankle sprains in track and field athletes: an expanded classification. *Foot Ankle Clin*. 2006;11(3):497–507. doi:10.1016/j.fcl.2006.05.004
- Liu K, Gustavsen G, Royer T, Wikstrom EA, Glutting J, Kaminski TW. Increased ligament thickness in previously sprained ankles as measured by musculoskeletal ultrasound. *J Athl Train*. 2015;50(2):193–198. doi:10.4085/1062-6050-49.3.77
- Bennell KL, Talbot RC, Wajswelner H, Techovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physiother*. 1998;44(3):175–180. doi:10.1016/s0004-9514(14)60377-9
- LigMaster user's manual. Sport Tech Inc. http://ligmaster.com/docs/LM_UserManual_2012.pdf. Published 2003.
- Docherty CL, Rybak-Webb K. Reliability of the anterior drawer and talar tilt tests using the LigMaster joint arthrometer. *J Sport Rehabil*. 2009;18(3):389–397. doi:10.1123/jsr.18.3.389
- Croy T, Saliba SA, Saliba E, Anderson MW, Hertel J. Differences in lateral ankle laxity measured via stress ultrasonography in individuals with chronic ankle instability, ankle sprain copers, and healthy individuals. *J Orthop Sports Phys Ther*. 2012;42(7):593–600. doi:10.2519/jospt.2012.3923
- Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: L Erlbaum Associates; 1988.
- Wright CJ, Linens SW, Cain MS. Establishing the minimal clinical important difference and minimal detectable change for the Cumberland Ankle Instability Tool. *Arch Phys Med Rehabil*. 2017;98(9):1806–1811. doi:10.1016/j.apmr.2017.01.003
- Doherty C, Bleakley C, Hertel J, Caulfield B, Ryan J, Delahunt E. Recovery from a first-time lateral ankle sprain and the predictors of chronic ankle instability. *Am J Sports Med*. 2016;44(4):995–1003. doi:10.1177/0363546516628870
- de Noronha M, Refshauge KM, Herbert RD, Kilbreath SL, Hertel J. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? *Br J Sports Med*. 2006;40(10):824–828. doi:10.1136/bjsm.2006.029645
- Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in Army recruits. *Aust J Physiother*. 1998;44(3):165–172. doi:10.1016/s0004-9514(14)60376-7
- Drewes LK, McKeon PO, Kerrigan DC, Hertel J. Dorsiflexion deficit during jogging with chronic ankle instability. *J Sci Med Sport*. 2009;12(6):685–687. doi:10.1016/j.jsams.2008.07.003
- Lindsjo U, Danckwardt-Lilliestrom G, Sahlstedt B. Measurement of the motion range in a loaded ankle. *Clin Orthop Relat Res*. 1985;199:68–71.
- Terada M, Pietrosimone BG, Gribble PA. Therapeutic interventions for increasing ankle dorsiflexion after ankle sprain: a systematic review. *J Athl Train*. 2013;48(5):696–709. doi:10.4085/1062-6050-48.4.11
- Thornton GM, Bailey SJ. Healing ligaments have shorter lifetime and greater strain rate during fatigue than creep at functional stresses. *J Biomech Eng*. 2013;135(9):91004. doi:10.1115/1.4024754
- Hildebrand KA, Frank CB. Scar formation and ligament healing. *Can J Surg*. 1998;41(6):425–429.
- Hubbard TJ. Ligament laxity following inversion injury with and without chronic ankle instability. *Foot Ankle Int*. 2008;29(3):305–311. doi:10.3113/FAI.2008.0305
- van Middelkoop M, van Rijn RM, Verhaar JA, Koes BW, Bierma-Zeinstra SM. Re-sprains during the first 3 months after initial ankle sprain are related to incomplete recovery: an observational study. *J Physiother*. 2012;58(3):181–188. doi:10.1016/S1836-9553(12)70109-1
- Miklovic TM, Donovan L, Protzuk OA, Kang MS, Feger MA. Acute lateral ankle sprain to chronic ankle instability: a pathway of

- dysfunction. *Phys Sportsmed*. 2018;46(1):116–122. doi:10.1080/00913847.2018.1409604
35. Donovan L, Hertel J. A new paradigm for rehabilitation of patients with chronic ankle instability. *Phys Sportsmed*. 2012;40(4):41–51. doi:10.3810/psm.2012.11.1987
36. Delahunt E, Bleakley CM, Bossard DS, et al. Infographic. International Ankle Consortium Rehabilitation-Oriented Assessment. *Br J Sports Med*. 2019;53(19):1248–1249. doi:10.1136/bjsports-2018-099935

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