*Journal of Athletic Training* 2025;60(10):730–736
doi: 10.4085/1062-6050-0260.24

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# Preoperative and Postoperative Cutaneous Reflexes and Perceived Instability During Gait in an Individual With Chronic Ankle Instability

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***Context:*** In recent studies, researchers exploring chronic ankle instability (CAI) have found alterations in cutaneous reflexes of musculature surrounding the ankle that may contribute to perceived instability and recurrent lateral ankle sprain in this population. Chronic ankle instability is considered a multifaceted condition, making it difficult to determine the underlying cause of these altered reflexes.

***Objective:*** To explore lower limb cutaneous reflexes during gait and patient-reported outcome measures in a patient with pathologic laxity of lateral ankle ligaments before and after allograft reconstruction.

***Design:*** Case report.

***Setting:*** Research laboratory.

***Patients or Other Participants:*** A physically active woman (age = 25 years, height = 64 in [162.56 cm], mass = 130 lb [58.5 kg]) who had 7 previous lateral ankle sprains and met CAI diagnostic criteria based on CAI questionnaire scores. The patient underwent a Broström reconstruction of the calcaneofibular ligament via allograft and partial synovectomy.

***Main Outcome Measure(s):*** Chronic ankle instability questionnaire scores, middle latency lower limb cutaneous reflexes, and perceived instability (range, 0–10) after sural nerve stimulation during gait.

***Results:*** After surgery, the patient's Cumberland Ankle Instability Tool and Foot and Ankle Ability Measure questionnaire scores aligned with those of an individual without CAI. Peroneus longus reflexes were diminished or inhibitory during the stance phases of gait. Pronounced variability of peroneus longus reflexes may have contributed to this lack of facilitation. Biceps femoris facilitation at midstance was absent during both testing sessions, and biceps femoris and rectus femoris facilitation was generally reduced postoperatively. The patient's mean perceived instability after sural stimulation markedly decreased from the preoperative ($6.5 \pm 0.48$) to the postoperative ($1.9 \pm 0.24$) session.

***Conclusions:*** Mechanical instability likely contributed to the reflex variations in this patient preoperatively, and the enhanced static stability provided by the surgical procedure may have reduced the need for dynamic stability via lower limb cutaneous reflexes observed in the postoperative session. Identifying the specific limitations of an individual with CAI will allow for more effective monitoring and treatment and provide improved long-term health-related quality-of-life outcomes.

***Key Words:*** lateral ankle sprain, sensorimotor deficits, Bröstrom reconstruction, ligamentous stability

**Key Points**

- Mechanical instability likely contributed to the cutaneous reflex alterations observed during gait, namely, a lack of protective peroneus longus and biceps femoris facilitation.
- The surgical intervention improved mechanical stability, which likely improved perceptions of instability and reduced the need for dynamic stabilization via reflexive activity at the ankle and knee.
- Considering the multifaceted nature of chronic ankle instability, specific symptoms should be identified on an individual basis to improve functional and patient-reported outcome measures.

Over 2 million lateral ankle sprains (LASs) occur in the United States annually, accounting for approximately 15% of all athletic injuries.[1,2] Half of LASs seen in US emergency departments are not associated with athletics, indicating these injuries substantially affect the general population as well.[1] Up to 70% of individuals experiencing acute LASs are estimated to develop *chronic ankle instability* (CAI), a condition characterized by perceptions of ankle weakness or giving way, diminished sensorimotor function, and recurrent LAS.[1,3] Those with CAI often report lower health-related quality of life and lower levels of physical activity and are at a higher risk of developing early onset osteoarthritis, all of which contribute to this condition's substantial burden on public health.[4,5] Although CAI was initially thought to stem from mechanical deficiencies such as pathologic laxity, researchers from the last few decades have informed the development of a new, more complex model of CAI, consisting of pathomechanical, sensory-perceptual, and motor-behavioral impairments.[3,6]

Researchers have reported alterations in cutaneous reflexes of musculature surrounding the ankle that may contribute to perceived instability, postural instability, and reinjury rates seen in those with CAI.[7–11] Given that CAI is considered a multifaceted condition, patients present with several interrelated deficits, making it difficult to determine the underlying cause of these altered reflexes.[3,12] We conducted this case study to explore lower limb cutaneous reflexes during gait and patient-reported outcome measures in a patient with known pathologic laxity of lateral ankle ligaments. In addition, although in the current literature substantial evidence is provided for the pathomechanical and functional benefits of Bröstrom reconstruction, little is known regarding the direct sensorimotor changes that may take place after surgical intervention.[13–16] Therefore, we also sought to identify alterations in cutaneous reflex characteristics and perceived instability from cutaneous stimulation after allograft reconstruction to assess the effect of mechanical instability on neuromuscular recovery after LAS. This is the only case study to date in which these outcomes have been explored in an individual with CAI before and after surgical intervention.

## CASE PRESENTATION

### Patient

A physically active woman (age = 25 years, height = 64 in [162.56 cm], mass = 130 lb [58.5 kg]) presented with mechanical ankle instability diagnosed by her orthopaedic physician. She had a grade 3 tear of the calcaneofibular ligament (CFL) and os trigonum. A Broström reconstruction of the CFL via allograft including a partial synovectomy and debriding of the affected region was scheduled. The patient informed the researchers of her upcoming procedure. She provided written informed consent, and the study was approved by the Institutional Review Board of the Human Research Protection Program of Indiana University—Bloomington.

### Interventions

Two days before surgical intervention, the patient reported to the laboratory for testing and completed the Identification of Functional Ankle Instability (IdFAI); the Cumberland Ankle Instability Tool (CAIT); and the Foot and Ankle Ability Measure (FAAM), which was modified to target instability.[17–19] Muscle activity of the tibialis anterior (TA), medial (MG) and lateral (LG) gastrocnemius, peroneus longus (PL), biceps femoris (BF), and rectus femoris (RF) was measured via wired bipolar surface electrodes that communicated with a Delsys Bagnoli electromyography (EMG) system (model DS-B04; Delsys Incorporated). Sural nerve stimulations were administered via a stimulating bar electrode (model MLADDF30; Ambu Inc) affixed over the sural nerve just posterior to the lateral malleolus on the affected limb. Stimulation intensity for testing was determined as 2× radiating threshold, ensuring the stimulation was non-noxious and did not produce a withdrawal reflex.

The patient walked for approximately 20 minutes at 4 km/h on a treadmill (Gait Trainer model 950-402; Biodex). A constant current stimulator (model DS7A; Digitimer North America) connected to a custom-built latency device was used to administer 5-train pulse stimulations during the 8 phases of gait. Heel-toe sensors were inserted into both shoes to collect heel-strike data used for timing of each stimulation, which was manually entered into the custom-built device. The 8 phases of the gait cycle were divided equally across the patient's stride, from the initial heel strike of the affected limb to subsequent heel strike of the same limb. These phases represented heel strike (phase 1), stance (phases 2–4), toe-off (phase 5), and swing (phases 6–8). Stimulation trials were randomized to ensure 10 stimulations occurred at each phase. After each stimulation trial, the patient reported her perceptions of instability on a scale from 0 (*no instability* or *you feel normal*) to 10 (*severe instability* or *you feel you may stumble*). All EMG, stimulation, and heel-strike data were recorded using an MP160 acquisition system with Acq*Knowledge* 5.0 software (Biopac Systems, Inc). The patient returned approximately 5 months (148 days) later to undergo the same study protocol, having completed a physician-prescribed rehabilitation program and received physician clearance for full return to activity.

### Data Processing

All data processing was completed using Acq*Knowledge* 5.0 software. Raw EMG data were filtered at a low-frequency cutoff of 50 Hz and high-frequency cutoff of 500 Hz. The root-mean-square was derived for the smoothed signals for each muscle. Stimulated trials were reviewed for step-timing consistency, and a minimum of 9 trials were averaged for each phase of gait. Approximately 100 unstimulated trials were also ensemble averaged for comparison with stimulated trials. To compare values between testing sessions, all waveforms were normalized as a percentage of each muscle's maximum EMG amplitude during unstimulated trials (% MVC). Unstimulated waveforms were subtracted from stimulated waveforms to acquire the final reflex trace. For each muscle at each phase, middle latency reflex (MLR) values were identified as the mean amplitude of the reflex waveform 80 to 120 milliseconds after the first pulse in the stimulation train. Positive and negative MLRs are indicative of facilitatory and inhibitory reflexes, respectively. Unstimulated amplitudes during this time window for each of the 6 muscles at all 8 phases were extracted for analysis of background muscle activity. Normalized stimulated trials were extracted for analysis of reflex variability.

### Comparative Outcomes

**Reflex Patterns.** Late-stance facilitatory reflexes were observed in the TA during the preoperative session and were markedly reduced or absent during the postoperative session, specifically at phase 4 (20.60% to −0.93% MVC) and phase 5 (53.30% to 22.10% MVC). Tibialis anterior inhibition was observed at mid- and end-swing preoperatively and was subsequently enhanced postoperatively, from −11.80% to −21.00% MVC at phase 7 and from −22.10% to −34.60% MVC at phase 8. In the MG and LG, pronounced inhibition was observed throughout stance in the preoperative session and was enhanced postoperatively at phase 2 (MG: −19.70% to −23.90% MVC; LG: −4.79% to −7.22% MVC). However, gastrocnemius inhibitory reflexes were reduced from the preoperative session at phase 3 (MG: −48.90% to −26.90% MVC; LG: −53.10% to −45.30% MVC) and phase 4 (MG: −5.06% to −0.44% MVC; LG: −17.10% to −6.21% MVC). Notable gastrocnemius facilitation was also observed preoperatively at the swing-to-stance transition (phase 8) and was reduced postoperatively (MG: 10.60% to 7.23% MVC; LG: 7.23% to 5.64% MVC).

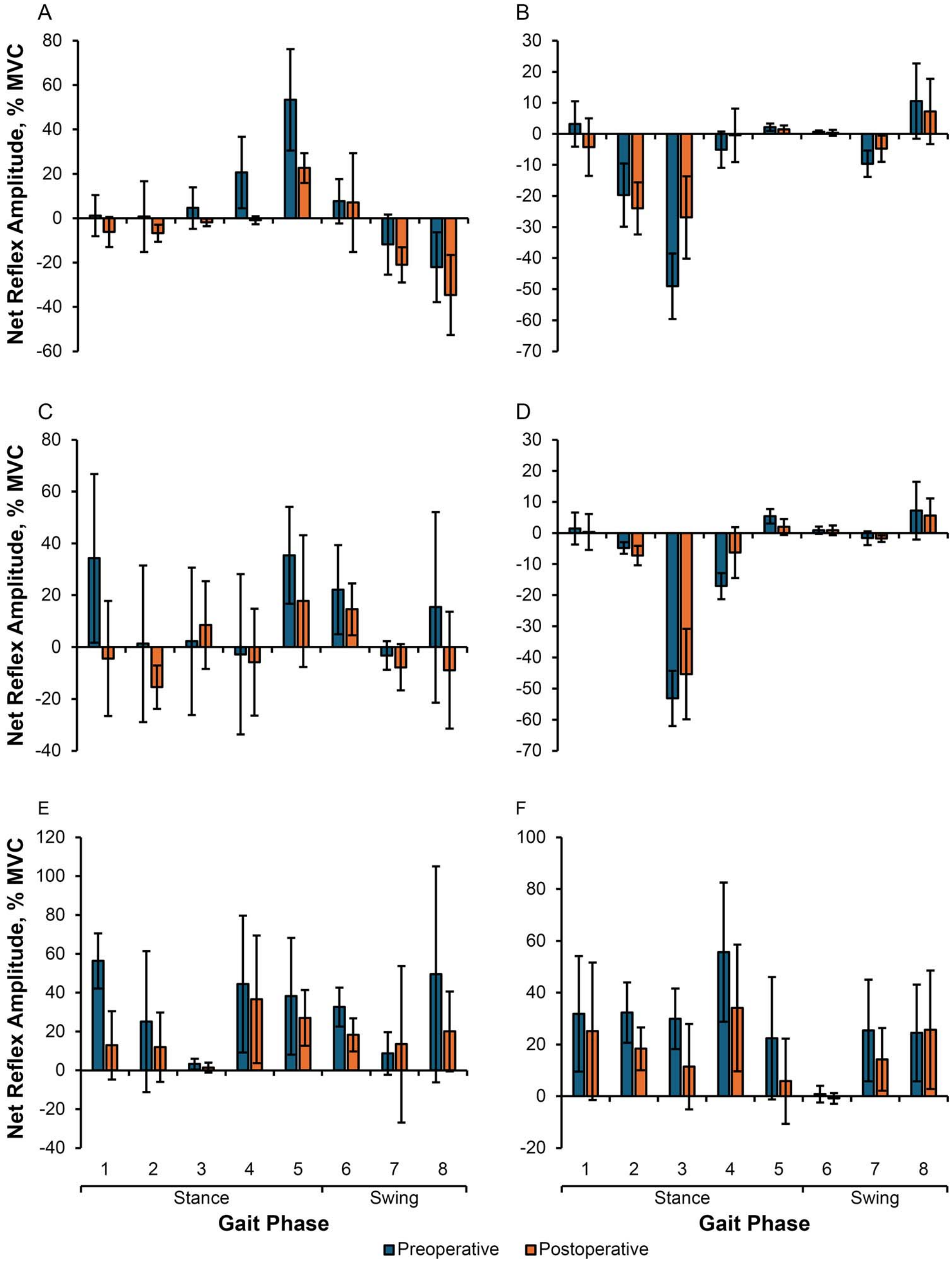


**Figure 1. Mean ± SD preoperative and postoperative cutaneous reflex amplitude of all muscles measured from heel strike (phase 1) to terminal swing (phase 8) of the test limb. A, Tibialis anterior. B, Medial gastrocnemius. C, Peroneus longus. D, Lateral gastrocnemius. E, Biceps femoris. F, Rectus femoris. E and F, Illustration of stride from phase 1 to 8.**

Preoperative facilitation of the PL was reduced during the stance-to-swing transition postoperatively, specifically at phase 5 (35.40% to 17.80% MVC) and phase 6 (22.10% to 14.50% MVC). Peroneus longus reflexes, which were facilitatory during the swing-to-stance transition at the preoperative session, were inhibitory postoperatively, namely at phase 1 (34.30% to −4.39% MVC) and phase 8 (15.40% to −8.90% MVC). Considerable BF and RF facilitation was noted for most of the gait cycle during the preoperative session except for the BF at phase 3 (3.22% MVC) and the RF at phase 6 (0.85% MVC). Facilitatory reflexes were markedly reduced for both muscles postoperatively, other than for the BF at phase 7 (8.72% to 13.50% MVC) and RF at phase 8 (24.40% to 25.70% MVC), where facilitation was somewhat enhanced. Figure 1 shows the reflex patterns across the gait cycle for all muscles measured.

**Reflex Variability.** In the TA, reflex variability was generally steady across the 8 phases of gait, peaking preoperatively at phase 5 (±22.90% MVC) and postoperatively at phase 6 (±22.30% MVC). The TA reflex variability was reduced by a mean of ±5.47% MVC from the preoperative to the postoperative session. In the MG and LG, reflex variability was almost identical before versus after surgical intervention, increasing ±0.59% MVC and ±0.90% MVC, respectively. However, variability in phase 3 was considerably greater during the postoperative session (MG: ±13.30% MVC; LG: ±14.50% MVC) than the preoperative session (MG: ±10.50% MVC; LG: ±8.85% MVC).

Peroneus longus reflex variability was especially high preoperatively, peaking at phase 8 (±36.60%) but was markedly reduced (mean, ±8.10% MVC) during the postoperative

**Table 1. Cutaneous Reflex Variability and Ranges Across the Gait Cycle During Preoperative and Postoperative Sessions**

| Muscle | Preoperative Variability, % MVC | Postoperative Variability, % MVC |
|---|---|---|
| Tibialis anterior | ±14.10 (±9.28 to ±22.90) | ±8.63 (±1.60 to ±22.30) |
| Peroneus longus | ±25.00 (±5.49 to ±36.80) | ±16.90 (±8.38 to ±25.40) |
| Medial gastrocnemius | ±6.48 (±0.43 to ±12.10) | ±7.07 (±0.98 to ±13.30) |
| Lateral gastrocnemius | ±4.39 (±1.21 to ±9.29) | ±5.29 (±1.02 to ±14.50) |
| Biceps femoris | ±24.40 (±2.79 to ±55.70) | ±19.30 (±2.55 to ±40.30) |
| Rectus femoris | ±17.20 (±3.22 to ±26.90) | ±16.20 (±2.03 to ±26.60) |

Abbreviation: % MVC, percentage of each muscle's maximum electromyography amplitude during unstimulated trials.

session, peaking at phase 5 (±25.40% MVC). This reduction was especially notable during phase 2 where variability was decreased from ±30.20% MVC preoperatively to ±8.38% MVC postoperatively. In the BF, variability was also notably reduced from the preoperative to postoperative session by a mean of ±5.10% MVC. However, reflex variability at phase 7 was considerably elevated postoperatively, increasing from ±11.00% to ±40.30% MVC. Rectus femoris reflex variability was generally similar across both sessions, decreasing by a mean of only ±1.00% MVC from preoperatively to postoperatively. Table 1 provides mean reflex variability and ranges across the gait cycle, and Figure 2 provides the mean reflex variability at each phase of gait for all muscles measured.

**Patient-Reported Outcome Measures.** Based on International Ankle Consortium recommendations, the patient met CAI diagnostic criteria based on responses to preoperative questionnaires (Table 2).[20] During the initial session, the patient reported 7 previous sprains in the left ankle and met CAI thresholds for the IdFAI, CAIT, and FAAM-Activities of Daily Living (ADL) and Sport subscales. Her chief concerns included pain and instability during sport and recurrent perceptions of instability during ADL, especially when walking downstairs or on uneven surfaces. When returning after surgical intervention and rehabilitation, the patient no longer met CAI diagnostic criteria based on her responses on the CAIT or FAAM questionnaires. Her IdFAI score was reduced by 14 points but remained above the threshold for CAI diagnosis due to her extensive LAS history before surgical intervention.

During the walking task before the surgical intervention, the patient reported a score of 4 of 10 for perceived instability during unstimulated gait (before stimulated trials) and a mean score of 6.5 ± 0.48 of 10 for perceived instability after sural nerve stimulation. After surgery and recovery, the patient's perceived instability during the walking task decreased to 0 of 10 at baseline and 1.9 ± 0.24 of 10 when stimulated.

## DISCUSSION

### Reflex Characteristics

Dividing the gait cycle into 8 even time points when calculating reflex amplitudes was necessary to accurately align and compare muscle activity between stimulated and unstimulated trials. However, to discuss pertinent findings for clinical interpretation, we present subsequent discussion points regarding the location of reflex measurements across the gait cycle in the following ways: (1) referencing the phase number(s) in which the reflex variable was calculated and (2) using clinically relevant descriptions to illustrate kinematics of the leg and foot at the time of the stimulation. For stance, phases 1 to 2 represent the *heel rocker* (the heel contacts the ground and the foot is lowered by rotating around the heel), phases 2 to 4 represent the *ankle rocker* (the foot is flat on ground and the axis of rotation occurs at the talocrural joint), and phases 4 to 5 represent the *forefoot rocker* (rotation occurs at the metatarsophalangeal joints to lift the heel and midfoot off the ground in preparation for the swing).[21]

A visual inspection of the reflex amplitudes across the gait cycle showed that the patient's cutaneous reflex patterns both preoperatively and postoperatively in the TA, MG, and LG were generally well aligned with those of participants without CAI in previous literature.[7,22,23] The patient exhibited phase-dependent reflex reversal of the TA across both testing sessions, specifically facilitation during the forefoot rocker (phase 5) and inhibition during the limb-placement stage of swing (phases 7 and 8). Although TA reflex patterns were generally the same across sessions, facilitatory activity postoperatively was somewhat reduced at the forefoot rocker, indicating a less effective response to dorsiflex the foot away from a potential obstacle. However, the patient demonstrated greater inhibitory activity in late swing than preoperative measures, which would provide for more rapid foot placement as the patient transitioned into double-legged stance to maintain better postural stability. Gastrocnemius inhibition during stance, a protective unloading mechanism commonly seen in individuals without CAI, was exhibited across the ankle rocker, with inhibition most pronounced at phase 3 and to a lesser degree at phases 2 and 4.[7,22] The postoperative reduction in gastrocnemius inhibition during the ankle rocker suggests a diminished preparedness to potentially shift weight to the contralateral limb if perturbation continues and compromises balance. Perhaps the increased reflex variability observed postoperatively in both the MG and LG contributed to this reduced inhibition throughout the ankle-rocker rotation at midstance.

Reflex patterns of the BF and RF were somewhat variable from those of individuals without CAI.[22,24,25] In both sessions at mid-ankle rocker (phase 3), the patient lacked BF facilitation that typically occurs in tandem with RF facilitation to provide stabilization at the knee after an unexpected perturbation.[24–27] Cofacilitation of the BF and RF was exhibited throughout the other phases of stance (1, 2, and 4) during the preoperative session; however, this facilitation was reduced postoperatively, which would diminish bracing at the knee during weightbearing. As the limb advances into swing, facilitation of the BF is expected to surpass that of the RF to allow for knee flexion as a mechanism of obstacle avoidance.[22,24–26] This reflex was more prominently exhibited during the postoperative testing

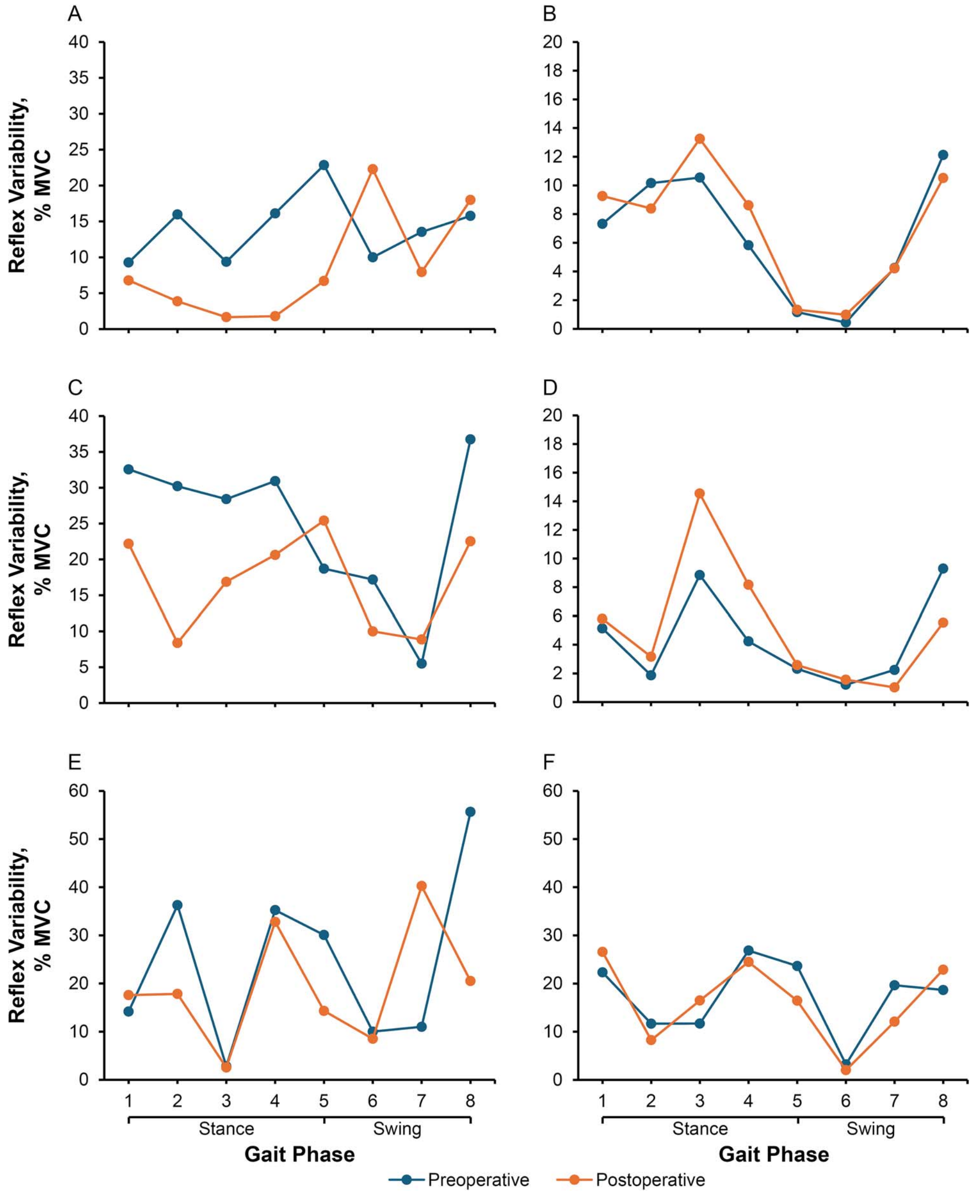


**Figure 2. Mean preoperative and postoperative cutaneous reflex variability across 10 trials of sural nerve stimulation from heel strike (phase 1) to terminal swing (phase 8) of the test limb. A, Tibialis anterior. B, Medial gastrocnemius. C, Peroneus longus. D, Lateral gastrocnemius. E, Biceps femoris. F, Rectus femoris.**

session where RF activity decreased by 16.6% during the forefoot rocker (phase 5). In addition to BF facilitation, reflex variability was reduced at phase 5, implying a more consistent response was exhibited postoperatively. A lack of RF reflex at limb advancement (phase 6) was exhibited during both testing sessions that, combined with prominent BF facilitation, likely acted to further withdraw the limb from a potential obstacle into the swing phase.[22,24,25]

Unique cutaneous reflex patterns were observed in the PL, where both individuals with and those without CAI present with consistent facilitation throughout the gait cycle. Peroneus longus facilitation during weightbearing

**Table 2. Patient-Reported Outcome Measures Before and After Surgical Intervention**

| Questionnaire | CAI Threshold Value[a] | Before Surgical Intervention | After Surgical Intervention |
|---|---|---|---|
| Identification of Functional Ankle Instability score | $\geq$11 | 31 | 17 |
| Cumberland Ankle Instability Tool score | $\leq$24 | 10 | 26 |
| FAAM-ADL, % | <90 | 50 | 97 |
| FAAM-Sport, % | <80 | 46 | 90 |
| Current level of instability (FAAM, %) | NA | Severely abnormal (15) | Normal (90) |
| Perceived instability (after sural stimulation), mean $\pm$ SD | NA | 6.5 $\pm$ 0.5 | 1.9 $\pm$ 0.2 |

Abbreviations: CAI, chronic ankle instability; FAAM, Foot and Ankle Ability Measure; ADL, activities of daily living; NA, not applicable.
[a] CAI threshold values based on International Ankle Consortium recommendations.[20]

increases dynamic stability of the lateral ankle after an unexpected perturbation.[7,8] The patient, however, exhibited facilitation only during the heel rocker (phase 1), the forefoot rocker (phase 5), and limb advancement (phase 6) of the preoperative session. Postoperatively, PL facilitation at these phases was reduced or even reversed to inhibitory activity. During the preoperative session, the patient exhibited highly variable PL reflexes (1.31% $\pm$ 32.56%) late into the heel rocker (phase 2), which then presented as inhibitory postoperatively ($-15.4\% \pm 8.38\%$; Figure 1). Peroneus longus reflexes throughout most of the gait cycle were highly variable, which likely contributed to the corresponding lack of net reflexes. After surgical intervention, PL facilitation was noted during the ankle rocker (phase 3), indicating an improved protective mechanism at the ankle after a lateral perturbation. Variability was also reduced postoperatively at this phase, which may have played a role in this net PL facilitation.

### Perceived Instability

Although the cutaneous reflex patterns observed in this patient during gait were somewhat aligned with those of individuals without CAI (namely, in the TA and gastrocnemius), others varied from patterns previously seen in those with and without CAI. Considering the protective role cutaneous reflexes play during gait, deviation from normal motor responses to perturbation may result in inadequate defense from stumbling or injury which may manifest as a heightened perception of instability. In a recent study, Friedman and Madsen provided evidence of this potential relationship, finding greater reflex variability of the PL is correlated with higher levels of perceived instability after sural nerve stimulation.[11] Mechanical instability resulting from torn lateral ankle ligaments may have contributed to the reflex variations in this patient during the preoperative session. Postoperatively, the general reduction in reflex activity across most muscles and phases suggests that the improved static stability gained from the patient's allograft reconstruction reduced the patient's reliance on reflexive dynamic stabilization. For example, during preoperative testing, the muscles crossing the hip and knee (RF and BF) exhibited increased facilitation, and thus coactivation, when the sural nerve was stimulated during the stance phase. These cutaneous reflexes were likely present because static stability at the ankle was reduced, and the lower limb compensated by stabilizing joints higher up the kinetic chain to maintain a steady gait cycle on the treadmill. When surgical reconstruction was completed and the patient's mechanical ankle stability was improved, the cofacilitation of muscles crossing the hip and knee was reduced, suggesting proximal joints were not assisting as substantially with lower limb dynamic stability.

Whereas those with CAI are typically categorized based on symptoms of pain, instability, and recurrent sprain history, the patients with CAI in earlier studies may not have had substantial mechanical impairments. The addition of prominent mechanical limitations are unique features to this patient and provide further insight into the relationship between sensorimotor and pathomechanical deficits. Considering the inherent interconnectedness of pathologic laxity and sensorimotor deficits such as altered reflexes and perceived instability, attributing the changes in this patient to operative or rehabilitative intervention is difficult.[3,28,29] However, the outcomes explored in this study provide important insights into neuromuscular and sensory-perceptual plasticity after a surgical intervention aimed at improving pathomechanical function.

The postoperative reduction in perceived instability observed in this patient may also be a result of the rehabilitation protocol that the patient reported was more specific to her limitations and performance-related goals than the conservative rehabilitation without surgery she underwent for previous ankle sprains. As a certified athletic trainer, the patient took agency over her rehabilitation after progression to full weightbearing, designing and modifying therapeutic exercises to align with her changing goals and physical tolerance. The patient reported that this autonomy, in addition to her knowledge of the improved mechanical stability in the affected ankle after surgery, enhanced her confidence and ultimately expedited her return to recreational exercise. In addition to patient-specific rehabilitation, the patient also reported early implementation of proprioceptive interventions, namely postoperative scar, soleus, and plantar massage, that may have contributed to the reflexive or perceptual changes observed.[30–32]

## CLINICAL BOTTOM LINE

Considering the heterogeneity of CAI, patients with this condition should be treated based on their specific symptoms rather than a one-size-fits-all rehabilitation protocol.[33] Identifying the specific limitations experienced by an individual with CAI will allow for more effective treatment and provide improved long-term, health-related quality-of-life outcomes. Establishing baselines for proprioceptive and perceptual measures will also help identify specific sensorimotor deficits that exist before rehabilitation so clinicians may accurately monitor training-induced adaptive changes.[34–36] The unique reflexive alterations observed in this case may be another clinical marker for treating chronic symptoms among individuals with pathologic laxity in the ankle. Future research should be done to measure cutaneous reflexes before and after reconstruction or throughout rehabilitation without surgery to determine how modulation patterns are affected by these interventions. Given that cutaneous reflexes may be linked to perceptions of instability and other sensorimotor outcomes, understanding the origin of reflexive changes after LAS may allow for more appropriate, patient-specific treatment and subsequent reduction of future injury.

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## SUPPLEMENTAL MATERIAL

**Supplemental Figure.** A and B. Walking task setup. All measurement devices were secured to the patient while walking at 4 km/h.

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