Comparison of Subjective and Biomechanical Outcomes Between Proprioceptive Training and Modified Broström-Gould Surgery for Chronic Ankle Instability

A Randomized Controlled Trial

Zongchen Hou,*† PhD, Shuang Ren,*† PhD, Yuelin Hu,* MD, Chen Jiao,* MD, Qinwei Guo,* MD, Nan Li,‡ PhD, Xin Miao,* PhD, Si Zhang,* BSc, and Dong Jiang,*§ MD
Investigation performed at Peking University Third Hospital, Beijing, China

Background: Both proprioceptive training and modified Broström-Gould surgery can improve ankle stability in patients with chronic ankle instability (CAI), but further biomechanical evaluation is necessary to determine the optimal treatment.

Purpose: To compare the clinical outcomes and biomechanical changes after proprioceptive training versus modified Broström-Gould surgery in patients with CAI.

Study Design: Randomized controlled trial; Level of evidence, 2.

Methods: A total of 56 patients with CAI were assigned randomly to either a nonoperative group (n = 28) who underwent 3 months of proprioceptive training or an operative group (n = 28) who underwent modified Broström-Gould surgery. Foot and Ankle Ability Measure (FAAM) scores, foot pressure during walking, center of pressure (COP) velocity, and time for the COP to reach the balance boundary (time to boundary [TTB]) during single-leg standing were collected before the intervention (baseline) and at 3, 6, and 12 months after the intervention. Two-way repeated-measures analysis of variance was used to compare group differences and changes over time.

Results: The nonoperative group had significant improvements from baseline in FAAM-Sports score and significantly decreased TTB in both the anterior-posterior and medial-lateral directions at all timepoints, while the operative group showed significant improvements only in FAAM-Sports scores and TTB and COP velocity in the anterior-posterior direction at 6 and 12 months post-intervention. During walking, the nonoperative group had significantly increased peak force under the medial foot at 3 months, which dropped back to baseline levels at 12 months, while the operative group had significantly increased peak force under the medial midfoot and hindfoot that persisted until 12 months ($P < .05$).

Conclusion: In this study, both proprioceptive training and modified Broström-Gould surgery led to improved subjective functional scores, foot pressure distribution during walking, and postural stability during standing for patients with CAI but with different biomechanical patterns. Proprioceptive training led to an earlier recovery of sports function and better medial-lateral stability recovery, while surgery provided more persistent results.

Registration: ChiCTR1900023999 (Chinese Clinical Trial Registry).

Keywords: arthroscopy; chronic ankle instability; foot pressure; modified Broström surgery; proprioceptive training

Lateral ankle sprain is one of the most common sports injuries.[7] After the first sprain, approximately one-third of patients experience chronic ankle instability (CAI), which

The Orthopaedic Journal of Sports Medicine, 12(9), 23259671241274138
DOI: 10.1177/23259671241274138

is characterized by recurrent giving way of the ankle, postural control deficits, and altered biomechanics during functional tasks.[13] The optimal treatment approach for CAI, whether nonoperative training or surgery, has been the subject of ongoing debate. Proprioceptive training is a widely recommended therapeutic intervention to restore ankle function,[18] but 21.4% of patients still report episodes of resprains as well as postural stability deficits after intervention.[15,33] Modified Broström-Gould surgery repairs anterolateral structure of the ankle joint,[3] but postsurgery trauma and complications may impede return to sports after the procedure.[4] Collectively, these results suggest that neither nonoperative training nor surgery can fully restore the normal ankle function for patients with CAI. Thus, it is crucial to evaluate functional outcomes following proprioception training and modified Broström-Gould surgery to strike a balance between their respective benefits and drawbacks.

To evaluate the functional outcomes following interventions, conducting biomechanical analyses that incorporate foot pressure and postural stability measurements can provide critical insights into the mechanical and neuromuscular impairments that may persist after interventions, particularly during activities such as walking and single-leg standing.[11,27] A lateralized pressure distribution during movement and a shorter time for the center of pressure (COP) to reach the boundary of the base of support (ie, time to boundary [TTB]) during standing have been observed in the patients with CAI and indicated an increased risk of ankle sprain.[11,27] After nonoperative treatment such as gait training or sensory-targeted ankle rehabilitation,[6,22] a medial shift in the COP and increased TTB have been observed in patients with CAI. Regarding operative treatment, only 1 study found an asymmetry in foot plantar pressure distribution at 3 years after anatomic reconstruction surgery.[28] Nevertheless, there is currently insufficient evidence available to comprehensively compare the sequential biomechanical alterations between proprioceptive training and modified Broström-Gould surgery in patients with CAI.

The purpose of the current study was to compare the subjective clinical and biomechanical (foot pressure distribution and postural stability) outcomes between proprioception training and modified Broström-Gould surgery for patients with CAI. We hypothesized that both treatment modalities would lead to enhanced functionality in persons with CAI, albeit with distinct profiles concerning subjective outcomes and biomechanical patterns.

METHODS

Participants

This randomized controlled study was approved by the ethics committee of our hospital and the study protocol was registered prospectively in the Chinese Clinical Trial Registry (ChiCTR1900023999). Between September 1, 2018, and April 30, 2019, patients were included according to following criteria[8]: (1) age between 18 and 40 years; (2) at least 1 ankle sprain experience (the first ankle sprain occurred >12 months ago and no ankle sprain occurred within 3 months before study enrollment) that caused inflammatory symptoms and disrupted activity; (3) a score of <24 on the Cumberland Ankle Instability Tool; and (4) isolated grade 3 full anterior talofibular ligament (ATFL)[16,30] and/or calcaneofibular ligament (CFL) lesion, confirmed on magnetic resonance imaging as well as with positive anterior drawer test (increased translation of 3 mm compared with the uninjured side or an absolute value of 10 mm of displacement) and talar tilt test (10° of absolute talar tilt or 5° difference compared with the contralateral side).[5,32] Exclusion criteria were intra-articular lesions (severe arthritis, osteochondral lesion, etc) or insufficient remnants of ATFL for tendon reconstruction examined by magnetic resonance imaging, history of neurological or orthopaedic impairment, history of previous surgery, and/or other acute injury to the musculoskeletal structures (bone, joint fracture, and/or nerve injury) in either lower limb.

An independent statistician prepared the computer-generated randomization schedule, which was stratified by sex. Allocation numbers were concealed in sealed envelopes and were opened only after written informed consent was obtained and the baseline assessment was complete. In total, 56 patients with CAI were enrolled and were divided into 2 groups: those who underwent proprioceptive training (nonoperative group; n = 28) and those who underwent modified Broström-Gould surgery (operative group; n = 28).

Interventions for the Nonoperative Group

The progressive proprioceptive training program was held twice a week (60 minutes each session) for 12 weeks,[9,10] for a total of 24 training sessions supervised by a single researcher (Z.H.). The detailed training protocol included single-leg stance, wobble board, resistance band, and hop-related exercises, as shown in Figure 1. Foot pressure

[§]Address correspondence to Dong Jiang, MD, Department of Sports Medicine of Peking University Third Hospital, Institute of Sports Medicine of Peking University, Beijing Key Laboratory of Sports Injuries, No. 49 North Garden Road, Haidian, Beijing 100191, China (email: bysyjiangdong@126.com).

*Department of Sports Medicine of Peking University Third Hospital, Institute of Sports Medicine of Peking University, Beijing Key Laboratory of Sports Injuries, Beijing, China.

[‡]Research Center of Clinical Epidemiology, Peking University Third Hospital, Beijing, China.

[†]Zongchen Hou and Shuang Ren contributed equally to this study.

Final revision submitted January 20, 2024; accepted February 26, 2024.

One or more of the authors has declared the following potential conflict of interest or source of funding: Funding was received from the National Key Research and Development Program of China (2019YFB1706905, 2018YFF0301100) and the National Natural Science Foundation of China (82072428). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the Peking University Third Hospital Medical Science Research Ethics Committee (IRB00006761-M2019164).

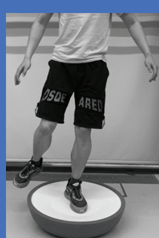
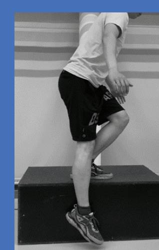
Exercise	Description and Progression	Exercise	Description and Progression
Single-legged stance 	Stood on the floor with eyes open or eyes closed for 30 seconds. 2 sets in each condition. When participant could complete a 30-second trial without a loss of balance, the exercise was progressed as follows: • Changed arms from out to across chest • Increased duration to 60 seconds • Changed to stand on foam pad	**Single-legged ball catch** 	Performed 10 tosses with single leg standing on the floor. Progressed when participant could perform 10 tosses without a loss of balance. • Increased repetitions from 10 to 15 • Tossed ball outside participant's base of support • Increased the ball weight from 10 to 15 pounds • Performed during stance on a foam pad
Wobble board movements 	Slowly moved the board in the plantarflexion/dorsiflexion and inversion/eversion directions on injured side for 10 repetitions in each direction. When participant could complete 10 repetitions (loss of balance allowed), the exercise was progressed as follows: • Increased to 15 repetitions in each direction • Moving without letting the board contact the ground • Rotation direction was added	**Toe touch-down** 	Maintained single-legged stance on a step while lowering the uninjured ankle until the foot contacted the floor. Performed up to 3 sets of 10 repetitions. Progressed when participant could complete all trials without a loss of balance and with good lower extremity alignment (no eversion collapse) • Increased number of repetitions from 5 to 10 • Increased height of step from 4 to 12 inches in 2-inch increments
Single-legged hop 	Hopped in the anterior-posterior and medial-lateral directions for 5 repetitions. Progressed when participant could perform the task with minimal ankle and hip motion and no loss of balance on landing. • Allowed to use arms to keep hands on the hips • Increased number of repetitions from 5 to 10 • Increased distance from 18 to 24 inches	**Hop ups and downs** 	Hopped off a step and landed on the floor in a single-legged stance. Performed up to 3 sets of 10 repetitions. Progressed when participant could complete all hops without a loss of balance or fatigue. • Increased number of repetitions from 5 to 10 • Increased height of step from 4 to 12 inches in 2-inch increments • Hopped up onto step • Holding a 10-pound ball when hopping

Figure 1. Balance training protocol.

distribution and postural stability tests were performed after 12 weeks of training, and recommendations regarding return to sports were provided to all patients in this group.

Interventions for the Operative Group

All surgeries were performed by the same surgeon (D.J.), who has 25 years of experience in modified Broström-Gould surgery. Under spinal lumbar anesthesia, the patient first underwent arthroscopic evaluation under standard anteromedial and anterolateral portals. The patient then underwent arthroscopic modified Broström-Gould surgery using two 1.8-mm Mitek Mini-GII suture anchors (Johnson & Johnson) to fix the ATFL and inferior extensor retinaculum.[29]

After the operation, patients used a short-leg cast in slightly eversion position for 2 weeks then transitioned to a walking boot. The following home-based rehabilitation program was provided to all patients by a single researcher (Z.H.): passive plantarflexion and dorsiflexion stretch and isometric exercises were performed at weeks 2 to 4, and inversion and eversion related exercises were performed at weeks 4 to 6. When the range of motion returned to normal, patients gradually progressed to full weightbearing. From week 6, concentric and eccentric muscle strengthening of the hip, knee, and ankle joints and balance exercises were implemented to improve neuromuscular control. After 12-week foot pressure distribution and postural stability testing, all patients were instructed to return to sports within their pain and locomotive tolerance.[14]

Data Collection

Subjective and biomechanical outcomes (foot pressure during walking and postural stability during single-leg standing) were collected at 0 months (baseline), 3 months, 6 months, and 12 months after intervention. Patients who completed at least 2 follow-up assessments were included for analysis.

Subjective Outcomes. Patient-reported outcomes consisted of the Foot and Ankle Ability Measure (FAAM; 29 items),[21] which is divided into the Activities of Daily Living (ADL; 21 items) and Sports (8 items) subscales. Item score totals (0-116) are converted into percentages, with higher scores representing better function.

Foot Pressure During Walking. Participants were asked to perform 3 trials of barefoot walking on a 2-m footscan system (RSscan International) at a sampling rate of 126 Hz.[24] The peak forces under the subregions of the medial heel (HM), lateral heel (HL), first to fifth metatarsal heads (M1-M5), and toes (T1) were calculated and normalized by bodyweight.[24] The time to peak force for each subregion was calculated as the ratio of the time from heel strike to peak force under the subregion and the total stance time.[24]

Postural Stability During Single-Leg Standing. Patients performed 3 trials of eyes-closed single-leg standing on a force plate (AMTI) at a sampling rate of 1000 Hz on both sides for 10 seconds.[11] COP velocity and TTB during single-leg standing were collected and analyzed separately in the medial-lateral (ML) and anterior-posterior (AP) directions using previously described methods.[11] Boundaries of the base of support for unipedal stance were modeled as a rectangle allowing for separation of the AP and ML components of COP. Each TTB measure was calculated using the instantaneous position and velocity of each corresponding COP point. A series of TTB measures in the time domain showed a series of peaks and valleys. Each valley represented the least amount of time the COP would take to reach the boundary if it continued to move in the same direction without a change in velocity. A smaller TTB measure indicates greater postural instability. The TTB measures serving as dependent variables included the minimum and the mean and standard deviation of minima in the AP and ML directions.

Data Analysis

Shapiro-Wilk tests were used to assess the normality of data. The baseline beween groups was compared by independent t test or Chi-Squared test according to the category of data. A minimum group difference of 10 points in the FAAM score was considered a clinically significant difference.[21] Two-way repeated-measures analysis of variance was used to evaluate differences between groups. If significant interactions were detected, a 2-tailed paired t test with Bonferroni correction was used to assess differences in the dependent measures between both groups at each timepoint (preintervention and 3, 6, and 12 months postintervention). The alpha level was set a priori at .05. All analyses were performed with SPSS Version 26.0 (IBM Corp).

Given the standard deviation of the FAAM-Sports score in the dataset, a sample size of 22 for each group was found to yield a power of 80% (actual power, 0.882) when the level of significance was set at .05.

RESULTS

From the 56 patients with CAI who were initially enrolled, 49 completed the 1-year follow-up and were included in the final analysis: 24 of 28 patients (follow-up rate, 85.7%) in the nonoperative group and 25 of 28 patients (follow-up rate, 89.3%) in the operative group (Figure 2). The patient characteristics of the final study groups are presented in Table 1. There were no significant differences at baseline between the groups.

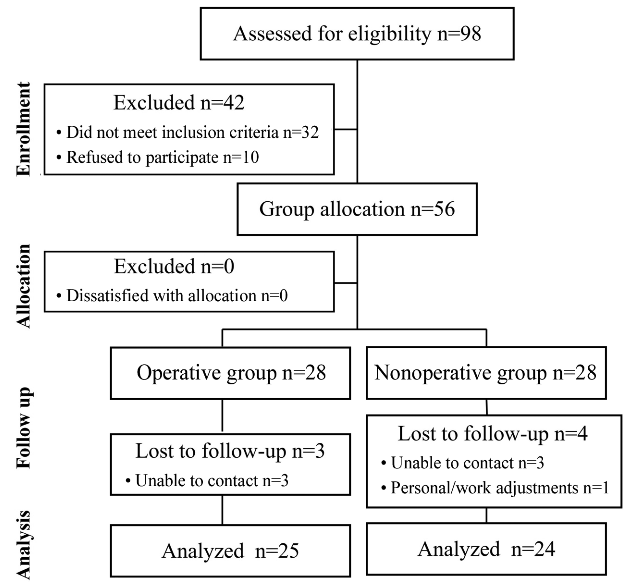


Figure 2. Description of group allocation and study flow.

Subjective Outcomes

A significant group × time interaction effect was found regarding the FAAM-Sports score, in that, compared with baseline, the nonoperative group saw significant increases in scores at 3 months postintervention while the operative group saw significant increases at 6 months postintervention (P = .032) (Table 2). These group differences in FAAM-Sports scores continued until 12 months postintervention (P = .025). Both groups showed similar improvements in FAAM-ADL scores compared with baseline, with no group differences (Table 2 and Figure 3).

Biomechanical Outcomes

Significant group × time interaction effects were observed in peak force at M2, M4, M5, HM, and T1 as well as time to peak force at M2, and HM (Table 3). Significant changes from baseline for these variables were seen in the nonoperative group at 3 months postintervention, indicating a shortened midstance period and increased pressure in the entire medial part of the foot ($P < .05$), while the values in the operative group still remained near baseline levels. However, at 12 months postintervention, only peak force at T1 and time to peak force at HM remained significantly different from baseline in the nonoperative group, whereas in the operative group,

TABLE 1
Baseline Characteristics According to Study Group[a]

	Nonoperative (n = 28)	Operative (n = 28)	t/χ^2	P
Age, y	26.4 ± 5.2	27.5 ± 6.4	0.329	.439
Sex, male/female	14/14	13/15	0.944	.876
BMI, kg/m^2	21.62 ± 2.21	20.88 ± 1.57	0.129	.542
No. of sprains	8.2 ± 4.1	9.0 ± 5.2	0.268	.578
Months since last sprain	21.1 ± 21.6	19.8 ± 23.5	0.793	.222
Beighton score	2 (0-3)	3 (0-4)	0.747	.344
CAIT score	15 (11-20)	14 (9-18)	0.981	.983
FAAM-ADL score	67.6 ± 10.3	68.6 ± 9.9	1.012	.092
FAAM-Sports score	55.9 ± 11.4	54.5 ± 12.5	0.634	.176

[a]Data are shown as mean ± SD, n, or median (range). ADL, activities of daily living; BMI, body mass index; CAIT, Cumberland Ankle Instability Tool; FAAM, Foot and Ankle Ability Measure.

TABLE 2
Comparison of FAAM Scores Between Groups and at Different Timepoints[a]

		Postintervention			
	Preintervention	3 months	6 months	12 months	$P_{\text{Group} \times \text{Time}}$
FAAM-ADL					.212
Nonoperative	66.9 (52.8-78.9)	82.6 (74.4-95.8)*	87.3 (82.3-94.5)*	88.6 (82.4-94.8)*	
Operative	68.9 (53.5-75.6)	79.9 (73.7-93.2)*	85.5 (81.4-89.9)*	87.4 (83.6-91.1)*	
FAAM-Sports					**.032**
Nonoperative	58.9 (50.1-68.2)	79.4 (69.8-87.8)*,**	85.8 (75.8-95.9)*,**	84.7 (80.9-88.4)*,**	
Operative	59.1 (50.0-67.9)	63.3 (54.7-67.7)**	75.3 (69.2-81.4)*,**	92.3 (88.5-96.1)*,**	

[a]Data are shown as mean (95% CI). Boldface P value indicates statistically significant group × time interaction effect for that variable ($P < .05$). ADL, activities of daily living; CI, confidence interval; FAAM, Foot and Ankle Ability Measure.
*Statistically significant difference compared with preintervention value ($P < .05$).
**Statistically significant difference between groups for that timepoint ($P < .05$).

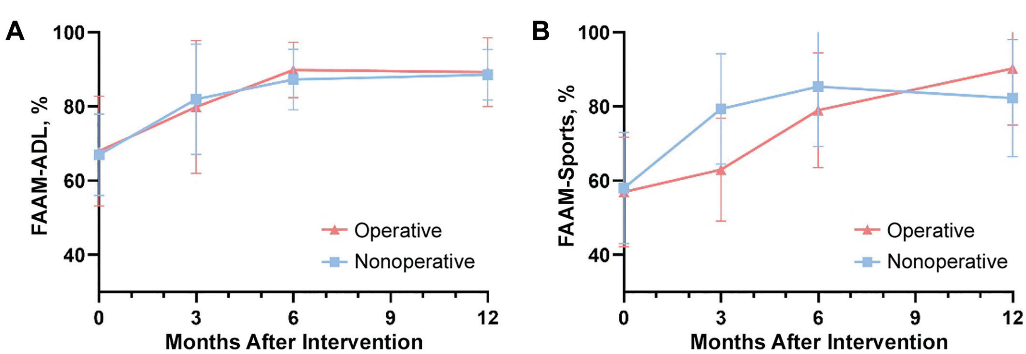


Figure 3. Mean baseline and postintervention (A) FAAM-ADL and (B) FAAM-Sports scores in the operative and nonoperative groups. Error bars indicate 95% CIs. ADL, activities of daily living; CI, confidence interval; FAAM, Foot and Ankle Ability Measure.

significant increases from baseline were seen in peak force at M1, M2, and HM and time to peak force at HM and HL.

Alterations in foot pressure of 2 patients, one from the nonoperative group and the other from the operative group, are shown in Figure 4. No differences between the groups were found at baseline (Figure 4, A and E). The foot pressure distribution had a medial shift in both groups, but this occurred at different timepoints and had different distribution patterns. The foot pressure of the nonoperative group focused on the whole medial side of the foot at 3 months (Figure 4B) but only the toe area at 12 months (Figure 4D). The foot pressure in the operative

TABLE 3
Comparison of Foot Pressure Between Groups and Different Timepoints[a]

	Preintervention	Postintervention: 3 months	Postintervention: 6 months	Postintervention: 12 months	$P_{\text{Group} \times \text{Time}}$
Peak Force, N/kg					
M1					
Nonoperative	1.14 (0.52-1.78)	1.23 (0.64-1.65)	1.34 (0.61-1.74)**	1.38 (0.98-1.78)**	**.021**
Operative	1.05 (0.45-1.62)	1.11 (0.53-1.68)	1.95 (1.21-2.69)*,**	1.97 (1.55-2.39)*,**	
M2					
Nonoperative	2.64 (1.90-3.39)	3.15 (2.47-3.84)*,**	2.79 (1.48-4.11) **	2.71 (1.49-3.94)	**<.001**
Operative	2.71 (1.86-3.45)	2.74 (1.91-3.51)**	3.39 (2.43-4.17)*,**	3.68 (2.47-4.61)*,**	
M3					
Nonoperative	3.15 (2.20-4.11)	3.29 (1.98-4.77)	3.31 (2.03-4.36)**	3.49 (1.99-5.00)**	.560
Operative	3.13 (2.01-4.25)	3.16 (1.89-4.43)	3.27 (1.93-4.43)	3.47 (2.26-4.47)	
M4					
Nonoperative	1.45 (0.85-2.06)	1.09 (0.32-1.67)*,**	1.06 (0.67-1.53)*,**	1.48 (0.92-1.95)	**.014**
Operative	1.34 (0.64-2.05)	1.31 (0.51-2.10)**	1.34 (0.65-2.08)**	1.43 (0.82-2.03)	
M5					
Nonoperative	1.14 (0.69-1.58)	0.74 (0.38-1.11)*,**	1.23 (0.61-1.87)	1.03 (0.67-1.40)	**.045**
Operative	1.24 (0.94-1.53)	1.45 (1.02-1.89)**	1.30 (0.56-2.05)	1.11 (0.68-1.54)	
HL					
Nonoperative	4.65 (3.87-5.43)	5.37 (4.28-6.47)	4.23 (3.12-5.15)	5.58 (4.70-6.46)	.448
Operative	4.99 (4.08-5.92)	5.19 (3.89-6.48)	4.69 (3.49-5.89)	5.00 (3.96-6.03)	
HM					
Nonoperative	3.52 (2.74-4.31)	5.07 (4.20-5.94)*,**	3.68 (2.67-4.69)	3.77 (2.75-4.88)**	**.015**
Operative	3.39 (2.45-4.32)	3.60 (2.57-4.64)**	3.47 (2.27-4.67)	4.83 (3.25-6.40)*,**	
T1					
Nonoperative	1.68 (0.77-2.57)	2.77 (1.56-4.22)*,**	2.48 (1.16-3.79)*,**	2.56 (1.10-4.01)*,**	**.017**
Operative	1.78 (0.89-2.67)	1.69 (0.74-2.63)**	1.83 (0.98-3.10)**	1.76 (0.45-3.48)**	
Time to Peak Force, %					
M1					
Nonoperative	68.6 (62.2-75.1)	69.0 (60.4-77.7)	67.9 (63.4-76.8)	66.7 (58.5-75.1)	.871
Operative	66.9 (59.9-74.0)	69.0 (62.3-77.4)	73.6 (61.1-85.0)	72.9 (63.3-80.2)	
M2					
Nonoperative	76.2 (70.9-81.5)	63.5 (55.4-71.2)*,**	77.5 (72.7-82.2)	76.2 (73.1-79.2)	**.049**
Operative	74.2 (68.4-80.0)	73.2 (68.2-78.4)**	77.3 (67.5-86.9)	76.6 (73.3-80.0)	
M3					
Nonoperative	71.1 (65.3-76.8)	74.4 (67.4-81.5)	70.4 (66.6-72.9)	73.9 (70.6-77.4)	.582
Operative	72.2 (65.8-78.3)	70.9 (62.5-77.9)	71.4 (67.9-74.9)	71.5 (67.9-75.2)	
M4					
Nonoperative	58.5 (47.2-69.8)	58.2 (46.4-70.1)	62.2 (53.9-70.5)	56.4 (46.3-66.6)	.662
Operative	63.8 (51.4-76.2)	59.1 (46.1-72.1)	64.4 (55.3-73.5)	60.0 (48.9-71.2)	
M5					
Nonoperative	51.4 (41.1-60.5)	52.8 (43.3-63.2)	54.5 (45.5-63.3)	52.1 (41.4-62.8)	.695
Operative	56.6 (45.9-67.2)	56.6 (42.9-70.2)	53.2 (43.9-63.5)	50.2 (37.7-62.9)	
HL					
Nonoperative	16.7 (13.4-20.1)	17.0 (11.8-22.2)	17.4 (10.9-23.9)**	17.6 (14.0-21.1)**	**.015**
Operative	16.6 (12.9-20.2)	16.8 (11.1-22.5)	11.2 (7.5-18.2)*,**	11.5 (6.7-19.5)*,**	
HM					
Nonoperative	16.4 (12.6-20.2)	25.8 (3.9-17.7)*,**	26.1 (5.1-18.1)*	26.3 (5.6-19.0)*	**.032**
Operative	17.9 (10.5-25,4)	17.1 (9.7-24.5)**	12.5 (6.6-19.3)*	11.7 (5.9-20.3)*	
T1					
Nonoperative	77.7 (72.8-82.4)	79.1 (73.2-84.9)	75.9 (68.6-82.8)	75.8 (69.9-81.8)	.758
Operative	74.4 (69.2-79.6)	78.4 (72.1-84.8)	77.3 (67.8-86.7)	73.1 (66.7-79.6)	

[a]Data are shown as mean (95% CI). Boldface P values indicate statistically significant group × time interaction effect for that variable ($P < .05$). CI, confidence interval; HL, lateral heel; HM, medial heel; M1, first metatarsal head; M2, second metatarsal head; M3, third metatarsal head; M4, fourth metatarsal head; M5, fifth metatarsal head; T1, toes.

*Statistically significant difference compared with preintervention value ($P < .05$).

**Statistically significant difference between groups for that timepoint ($P < .05$).

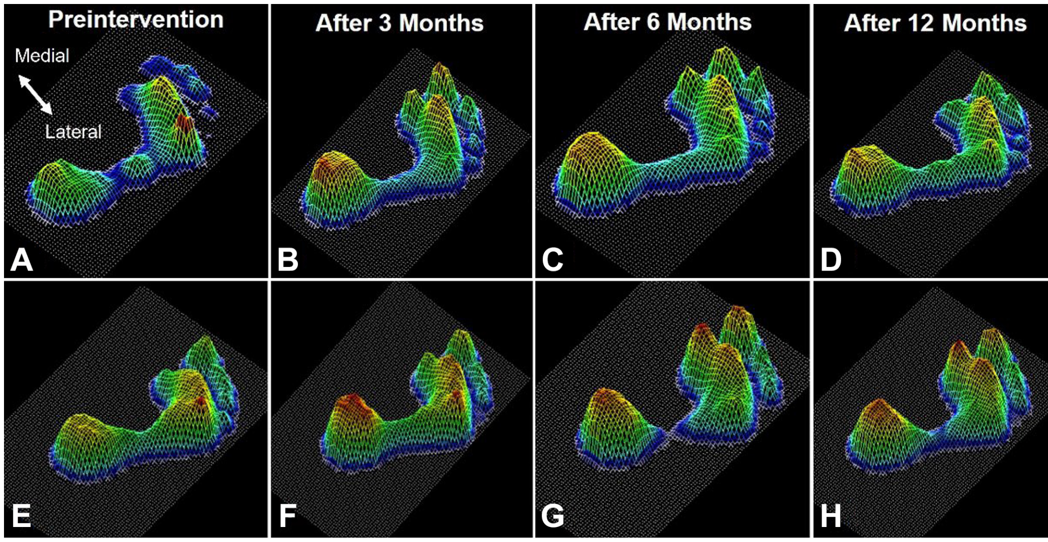


Figure 4. Three-dimensional models from Footscan 7.0 software showing the foot pressure distribution changes in (A-D) a participant from the nonoperative group and (E-H) a participant from the operative group from preintervention to 12 months postintervention.

group focused on the medial forefoot and hindfoot until 6 months postintervention and persisted until 12 months (Figure 4, G and H).

Regarding postural stability, a significant group × time interaction effect was observed in AP absolute-minimum TTB (P = .043), AP mean-minimum TTB (P = .019), and ML mean-minimum TTB (P = .008) (Table 4). The nonoperative group showed significantly increased AP absolute-minimum, AP mean-minimum, and ML mean-minimum TTB after 3 months versus baseline, while the operative group showed significantly increased AP mean-minimum TTB after 6 months. At 12 months postintervention, the nonoperative group had a higher ML mean-minimum TTB than the operative group (1.72 seconds [95% CI, 1.39-2.07 seconds] vs 1.07 seconds [95% CI, 0.58-1.56 seconds]; P = .041). Both groups presented similar increases in AP COP velocity and AP mean-minimum TTB after 6 months compared with baseline (Table 4).

DISCUSSION

The most important finding in the study was that both proprioceptive training and modified Broström-Gould surgery were able to improve subjective functional scores, foot pressure distribution during walking, and postural stability during standing for patients with CAI but with different biomechanical patterns. Proprioceptive training led to an earlier recovery of sport function and better ML stability recovery, while surgery provided more persistent results.

Patients in both treatment groups reported increased self-reported outcome scores after the intervention. The nonoperative group had significantly better FAAM-Sports scores at 3 months postintervention compared with the operative group (79.4 [95% CI, 69.8-87.8] vs 63.3 [54.7-67.7], respectively), which might relate to a shorter period to return to sport. This is consistent with previous studies,[25,31] which reported return to sport time of 15 ± 19 days for nonoperative treatment in professional football players,[31] 77 days for isolated lateral ligamentous injuries, and 105 days for those with concomitant injuries in athletes undergoing surgical ligament repair.[25] However, at 12 months postintervention, the FAAM-Sports scores in the operative group were significantly better compared with the nonoperative group (92.3 [95% CI, 88.5-96.1] vs 84.7 [95% CI, 80.9-88.4], respectively). This is in line with previous studies indicating that operative treatment might result in better long-term outcomes in terms of residual pain, recurrent sprains, stability, and mechanical stability.[17,26] The reason may be due to the surgery stabilizing the lateral ankle structure and restoring mechanical stability, leading to better performance during sport.[34] However, the relationship between mechanical stability and sport performance requires further study.

In terms of foot pressure measurements, both groups demonstrated increased peak force under the medial regions of the foot during walking, indicating a reduced risk of inversion ankle sprain.[12] The difference in timing of the medial shift was observed at different time (3 months in the nonoperative group and at 6 and 12 months in the operative group), which might be due to the trauma of the operation making it difficult to restore biomechanics in the ankle joint immediately after surgery, so more time was required to reverse the over-varus position during walking. The time to peak force was used to analyze the rate of loading under specific foot subregions.[24] This study found that the nonoperative group had a shorter weight translation period from foot strike to midstance and that the operative group had a shorter weight translation period during the foot strike. A longer weight translation time is often associated with ankle instability,[24] as patients may be hesitant to put weight on the forefoot,

TABLE 4
Comparison of Postural Stability Between Groups and Different Timepoints[a]

	Preintervention	Postintervention 3 months	6 months	12 months	$P_{Group \times Time}$
Time to Boundary, s					
AP, mean minimum					
Nonoperative	2.44 (1.42-3.47)	5.11 (2.13-8.11)*,**	5.09 (3.15-7.02)*,**	5.90 (3.08-8.72)*	**.019**
Operative	2.89 (2.27-3.53)	3.82 (3.12-4.53)**	4.28 (3.95-6.59)*,**	5.16 (4.01-6.32)*	
AP, absolute minimum					
Nonoperative	0.61 (0.10-1.12)	0.94 (0.63-1.25)*,**	0.78 (0.23-1.33)	0.62 (0.17-1.07)	**.043**
Operative	0.56 (0.23-0.89)	0.63 (0.30-0.99)**	0.67 (0.30-1.04)	0.68 (0.15-1.23)	
AP, standard deviation					
Nonoperative	2.15 (1.95-2.34)	1.94 (1.53-2.15)	1.89 (1.62-2.27)	1.89 (1.35-2.43)	.465
Operative	2.22 (1.94-2.49)	1.96 (1.52-2.40)	2.05 (1.53-2.57)	1.86 (1.09-2.62)	
ML, mean minimum					
Nonoperative	1.32 (1.05-1.60)	2.36 (2.08-2.67)*,**	1.83 (1.53-2.14)*,**	1.72 (1.39-2.07)*,**	**.008**
Operative	1.33 (0.93-1.71)	1.26 (0.85-1.67)**	1.25 (0.81-1.68)**	1.07 (0.58-1.56)**	
ML, absolute minimum					
Nonoperative	0.09 (0.06-0.13)	0.16 (0.10-0.21)	0.15 (0.08-0.21)	0.16 (0.08-0.24)	.377
Operative	0.08 (0.03-.0.13)	0.12 (0.05-0.19)	0.10 (0.01-0.19)	0.12 (0.05-0.17)	
ML, standard deviation					
Nonoperative	1.51 (1.30-1.71)	1.66 (1.15-1.71)	1.47 (1.14-1.80)	1.54 (1.20-1.87)	.761
Operative	1.54 (1.25-1.83)	1.33 (0.61-2.05)	1.41 (0.93-1.88)	1.29 (0.82-1.76)	
COP Velocity, cm/s					
AP					
Nonoperative	8.89 (3.86-14.1)	7.11 (4.13-10.11)	4.09 (3.15-5.02)*	3.90 (3.08-4.72)*	.553
Operative	10.1 (4.87-15.3)	8.71 (4.49-12.9)	5.28 (3.95-6.59)*	5.16 (4.01-6.32)*	
ML					
Nonoperative	7.27 (4.79-9.74)	5.85 (2.45-9.25)	5.44 (3.48-7.41)	4.73 (2.82-6.63)	.549
Operative	7.71 (4.15-10.6)	8.38 (3.57-13.1)	7.13 (4.35-9.91)	6.98 (4.28-9.91)	

[a]Data are shown as mean (95% CI). AP, anterior-posterior; CI, confidence interval; COP, center of pressure; ML, medial-lateral.
*Statistically significant difference compared with preintervention value ($P < .05$).
**Statistically significant difference between groups for that timepoint ($P < .05$).

a position considered unstable due to the shape of the talus.[24] Both groups showed different loading-accelerating adjustment patterns during walking. Collectively, the results add credence to the theory that both treatments could restore ankle stability during walking but with different biomechanical patterns.

The study results also demonstrated different levels of persistence in outcomes between the nonoperative and operative groups. The altered foot distribution and postural stability decreased significantly after 6 months in the nonoperative group, while those changes were maintained in the operative group until 12 months. This difference may be attributed to a different mechanism of restoring the lateral ankle stability for these 2 interventions. Previous studies have shown that the loss of mechanoreceptors following ligament injury can affect ankle stability.[19] Proprioception training has been successful in improving balance, stability, and postural control,[2] potentially by facilitating the mechanoreceptors around the ligament remnant,[19] which could explain the improvement at 3 months and 6 months in AP and ML postural stability control of CAI patients after training. Unfortunately, the facilitation of mechanoreceptors caused by training may not be long lasting, which could explain the transient nature of exercise in the nonoperative group. Further investigation is needed to determine the minimum frequency of exercise needed to maintain rehabilitation benefits. On the other hand, modified Broström-Gould surgery not only restored mechanical joint stability[19,20] but also reconstructed the insertional structure of the ligament where more mechanoreceptors aggregated.[1] This might be one of the reasons why the effects of the surgery lasted longer.

The results showed that the operative group had a better persistent effect on foot pressure compared with the nonoperative group, with effects lasting until 12 months. However, deficits in ML postural stability were still present at the same time. The results indicated that the isolated Broström-Gould surgery was unable to restore the normal ankle joint function despite tightening or augmenting the anterolateral structure of the ankle joint, which may be due to incomplete reconstruction of natural ligament structure. Compared with the ATFL, the stability of the CFL is more difficult to reconstruct.[23] Previous reports have demonstrated that, although inferior extensor retinaculum reinforcement could replace part of the function of the CFL, it still could not restore the varus structure anatomically.[29] Further research is needed to investigate the possibility of improving ML stability through anatomic tendon reconstruction or more robust fixation strategies for the CFL. In addition, postoperative specialized training for ML stability could also be considered, highlighting the importance of a combination of surgery and rehabilitation.

To our knowledge, this is the first prospective study to provide evidence for time-related biomechanics and functional outcomes and between nonoperative and operative treatment for CAI patients. The results provide valuable insights into the mechanisms of proprioception training and modified Broström-Gould surgery and improving outcomes after treatments. The findings suggest that reinforcement training may be necessary to maintain the effect of proprioception training after 6 months. Meanwhile, targeted training, such as ML stability training, may be required even after operative treatment to restore ML postural control. These results may guide the selection of personalized and targeted treatment plans for CAI patients, with nonoperative training being a suitable option for those seeking a short-term return to exercise and operative treatment being more appropriate for those seeking to restore high-level sports function with long-term persistence. Future research should focus on the mechanism of biomechanical adjustments and how to incorporate the benefits of different treatment in restoring functional and mechanical ankle instability.

Limitations

There are some limitations of the present study that should be acknowledged. First, the scope of the study was limited to evaluating biomechanics during walking and single-leg standing, and future research should include more high-demand movements such as drop-landing and cutting. Second, the study focused on biomechanical changes in terms of foot pressure and COP, without considering joint kinematics and kinetics, which could have added further insight into the results. Last, although this study suggests that either nonoperative or operative treatment can achieve considerable self-report questionnaire scores at 12 months, the follow-up period was relatively short, and the long-term outcomes of these treatment outcomes require further investigation.

CONCLUSION

In this study, both proprioceptive training and modified Broström-Gould surgery led to improved subjective functional scores, foot pressure distribution during walking, and postural stability during standing for patients with CAI but with different biomechanical patterns. Proprioceptive training led to an earlier recovery of sports function and better ML stability recovery, whereas surgery provided more persistent results.

ORCID iD

Dong Jiang https://orcid.org/0000-0003-4380-7683

REFERENCES

1. Çabuk H, Kuşku Çabuk F. Mechanoreceptors of the ligaments and tendons around the knee. *Clin Anat*. 2016;29(6):789-795. doi:10.1002/ca.22743
2. Cain MS, Ban RJ, Chen YP, Geil MD, Goerger BM, Linens SW. Four-week ankle-rehabilitation programs in adolescent athletes with chronic ankle instability. *J Athl Train*. 2020;55(8):801-810. doi:10.4085/1062-6050-41-19
3. Cao Y, Hong Y, Xu Y, Zhu Y, Xu X. Surgical management of chronic lateral ankle instability: a meta-analysis. *J Orthop Surg Res*. 2018;13(1):159. doi:10.1186/s13018-018-0870-6
4. Coetzee JC, Ellington JK, Ronan JA, Stone RM. Functional results of open Broström ankle ligament repair augmented with a suture tape. *Foot Ankle Int*. 2018;39(3):304-310. doi:10.1177/1071100717742363
5. Cox JS. Surgical and nonsurgical treatment of acute ankle sprains. *Clin Orthop Relat Res*. 1985;198:118-126.
6. Feger MA, Hart JM, Saliba S, Abel MF, Hertel J. Gait training for chronic ankle instability improves neuromechanics during walking. *J Orthop Res*. 2018;36(1):515-524. doi:10.1002/jor.23639
7. Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. *Sports Med*. 2007;37(1):73-94. doi:10.2165/00007256-200737010-00006
8. Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *Br J Sports Med*. 2014;48(13):1014-1018. doi:10.1136/bjsports-2013-093175
9. Hale SA, Fergus A, Axmacher R, Kiser K. Bilateral improvements in lower extremity function after unilateral balance training in individuals with chronic ankle instability. *J Athl Train*. 2014;49(2):181-191. doi:10.4085/1062-6050-49.2.06
10. Hale SA, Hertel J, Olmsted-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *J Orthop Sports Phys Ther*. 2007;37(6):303-311. doi:10.2519/jospt.2007.2322
11. Hertel J, Olmsted-Kramer LC. Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait Posture*. 2007;25(1):33-39. doi:10.1016/j.gaitpost.2005.12.009
12. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.
13. Hertel J, Corbett RO. An updated model of chronic ankle instability. *J Athl Train*. 2019;54(6):572-588. doi:10.4085/1062-6050-344-18
14. Hou ZC, Su T, Ao YF, et al. Arthroscopic modified Broström procedure achieves faster return to sports than open procedure for chronic ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(10):3570-3578. doi:10.1007/s00167-022-06961-0
15. Kim T, Kim E, Choi H. Effects of a 6-week neuromuscular rehabilitation program on ankle-evertor strength and postural stability in elite women field hockey players with chronic ankle instability. *J Sport Rehabil*. 2017;26(4):269-280. doi:10.1123/jsr.2016-0031
16. Konradsen L, Hølmer P, Søndergaard L. Early mobilizing treatment for grade III ankle ligament injuries. *Foot Ankle*. 1991;12(2):69-73. doi:10.1177/107110079101200202
17. Korkala O, Rusanen M, Jokipii P, Kytomaa J, Avikainen V. A prospective study of the treatment of severe tears of the lateral ligament of the ankle. *Int Orthop*. 1987;11(1):13-17. doi:10.1007/BF00266052
18. Kosik KB, McCann RS, Terada M, Gribble PA. Therapeutic interventions for improving self-reported function in patients with chronic ankle instability: a systematic review. *Br J Sports Med*. 2017;51(2):105-112. doi:10.1136/bjsports-2016-096534

19. Lee JH, Heo JW, Lee DH. Comparative postural stability in patients with lateral meniscus versus medial meniscus tears. *Knee*. 2018;25(2):256-261. doi:10.1016/j.knee.2018.01.012
20. Li HY, Zheng JJ, Zhang J, Cai YH, Hua YH, Chen SY. The improvement of postural control in patients with mechanical ankle instability after lateral ankle ligaments reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(4):1081-1085. doi:10.1007/s00167-015-3660-2
21. Martin RL, Irrgang JJ, Burdett RG, Conti SF, Van Swearingen JM. Evidence of validity for the Foot and Ankle Ability Measure (FAAM). *Foot Ankle Int*. 2005;26(11):968-983. doi:10.1177/107110070502601113
22. McKeon PO, Wikstrom EA. The effect of sensory-targeted ankle rehabilitation strategies on single-leg center of pressure elements in those with chronic ankle instability: a randomized clinical trial. *J Sci Med Sport*. 2019;22(3):288-293. doi:10.1016/j.jsams.2018.08.017
23. Michels F, Pereira H, Calder J, et al. Searching for consensus in the approach to patients with chronic lateral ankle instability: ask the expert. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(7):2095-2102. doi:10.1007/s00167-017-4556-0
24. Nyska M, Shabat S, Simkin A, Neeb M, Matan Y, Mann G. Dynamic force distribution during level walking under the feet of patients with chronic ankle instability. *Br J Sports Med*. 2003;37(6):495-497. doi:10.1136/bjsm.37.6.495
25. Pearce CJ, Tourne Y, Zellers J, et al. Rehabilitation after anatomical ankle ligament repair or reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(4):1130-1139. doi:10.1007/s00167-016-4051-z
26. Pijnenburg AC, Bogaard K, Krips R, Marti RK, Bossuyt PM, van Dijk CN. Operative and functional treatment of rupture of the lateral ligament of the ankle. A randomised, prospective trial. *J Bone Joint Surg Br*. 2003;85(4):525-530. doi:10.1302/0301-620x.85b4.13928
27. Schmidt H, Sauer LD, Lee SY, Saliba S, Hertel J. Increased in-shoe lateral plantar pressures with chronic ankle instability. *Foot Ankle Int*. 2011;32(11):1075-1080. doi:10.3113/FAI.2011.1075
28. Schmidt R, Benesch S, Friemert B, Herbst A, Claes L, Gerngross H. Anatomical repair of lateral ligaments in patients with chronic ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2005;13(3):231-237. doi:10.1007/s00167-004-0562-0
29. Su T, Zhu YC, Du MZ, et al. Anatomic reconstruction using the autologous gracilis tendon achieved less sprain recurrence than the Broström-Gould procedure but delayed recovery in chronic lateral ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(12):4181-4188. doi:10.1007/s00167-022-07011-5
30. Vuurberg G, Hoorntje A, Wink LM, et al. Diagnosis, treatment and prevention of ankle sprains: update of an evidence-based clinical guideline. *Br J Sports Med*. 2018;52(15):956. doi:10.1136/bjsports-2017-098106
31. Walden M, Hagglund M, Ekstrand J. Time-trends and circumstances surrounding ankle injuries in men's professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med*. 2013;47(12):748-753. doi:10.1136/bjsports-2013-092223
32. Walker JF Jr. Surgical treatment of chronic lateral instability of the ankle joint - a new procedure. *Am J Sports Med*. 1989;17(6):849. doi:10.1177/036354658901700628
33. Wright CJ, Linens SW. Patient-reported efficacy 6 months after a 4-week rehabilitation intervention in individuals with chronic ankle instability. *J Sport Rehabil*. 2017;26(4):250-256. doi:10.1123/jsr.2016-0044
34. Wu X, Song W, Zheng C, Zhou S, Bai S. Morphological study of mechanoreceptors in collateral ligaments of the ankle joint. *J Orthop Surg Res*. 2015;10:92. doi:10.1186/s13018-015-0215-7