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Suture Tape Augmentation in Lateral Ankle Ligament Surgery: Current Concepts Review

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Abstract

Chronic lateral ankle instability (CLAI) is a condition that is characterized by persistent disability and recurrent ankle sprains while encompassing both functional and mechanical (laxity) instability. Failure of conservative treatment for CLAI often necessitates operative intervention to restore the stability of the ankle joint. The traditional or modified Broström techniques have been the gold standard operative approaches to address CLAI with satisfactory results; however, patients with generalized ligament laxity (GLL), prior unsuccessful repair, high body mass index, or high-demand athletes may experience suboptimal outcomes. Synthetic ligament constructs have been tested as an adjunct to orthopedic procedures to reinforce repaired or reconstructed ligaments or tendons with the hope of early mobilization, faster rehabilitation, and long-term prevention of instability. Suture tape augmentation is useful to address CLAI. Multiple operative techniques have been described. Because of the heterogeneity among the reported techniques and variability in postoperative rehabilitation protocols, it is difficult to evaluate whether the use of suture tape augmentation provides true clinical benefit in patients with CLAI. This review aims to provide a comprehensive outline of all the current techniques using suture tape augmentation for treatment of CLAI as well as present recent research aimed at guiding evidence-based protocols.

Keywords: lateral ankle, instability, Brostrom repair, suture augmentation, outcomes

Introduction

Ankle sprains are one of the most common musculoskeletal injuries, with an estimated incidence rate of 2.15 per 1000 person-years in the general US population.[82] In the athletic population, the incidence of ankle sprains is even higher and can lead to lost training time, missed competition, and residual muscle weakness.[21,28,54,67,73] Lateral ankle sprains, or injuries primarily to the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL), represent the most common type of ankle sprain.[21,28,67,82] These sprains can be successfully managed with rest, ice, nonsteroidal anti-inflammatory drugs, and early functional rehabilitation.[27,34,40,81] However, a substantial number of acute lateral ankle sprains further develop into chronic lateral ankle instability (CLAI), a condition that is characterized by persistent disability and recurrent ankle sprains while encompassing both functional (sensation of ankle "giving way") and mechanical (laxity) instability.[3]

Failure of conservative treatment for CLAI often necessitates operative intervention to repair the damaged lateral collateral ligament complex.[27,36,54,81,86,87] Broström first described a direct repair technique that involved suturing the torn native ligament ends back together.[8] Such anatomical repair procedures aim to reproduce the normal anatomy and

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Table 1. Suture Tape Augmentation Techniques for Treatment of Chronic Lateral Ankle Instability (CLAI).

Technique	Overview
Open Broström repair with suture tape augmentation (BR-ST)[13,17,22,23,26,49,51,52,65,70,85]	Modified or traditional open Broström repair with knotless suture anchors augmented with nonabsorbable polyethylene/polyester suture tape used as secondary stabilizer to ATFL
Ligament augmentation reconstruction system (LARS)[63,64]	Synthetic ligament with ATFL and CFL limbs placed in extra-articular location to augment primary repair of LCL complex
Arthroscopic Broström repair with suture tape augmentation (ABR-ST)[24,79,88]	Modified or traditional arthroscopic Broström repair with knotless suture anchors augmented with non-absorbable polyethylene/polyester suture tape used as secondary stabilizer to ATFL
Suture tape augmentation only (STO)[12,15,16,76]	Percutaneous or minimally invasive approach to reinforce ATFL and/or CFL without concomitant Broström repair

Abbreviations: ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; LCL, lateral collateral ligament.

biomechanics of the ankle, and the Broström repair (BR) has since evolved to include a spectrum of modifications ranging from augmentation with extensor retinaculum (Broström-Gould)[32] to shortening of the ligaments themselves (Broström-Karlsson).[38]

Furthermore, although most repairs have focused on the ATFL, there is less clarity regarding the importance of repairing the CFL for lateral ankle stabilization. The CFL provides lateral stability to both the ankle and the subtalar joints as it crosses each joint. Hunt et al[37] demonstrated significantly increased joint contact forces, inversion of the talus and calcaneus, and medial displacement of the calcaneus after sectioning of the CFL. However, clinical studies using isolated ATFL repair have reported good outcomes, with return to sport rates from 93% to 100%, as well as one long-term study reporting good or excellent results in 91% of cases.[6,43,44,55] Surgical repair of the CFL is indicated in cases of CLAI with subtalar instability; however, the benefits of routine repair of the CFL remains unknown.

Despite the BR or modified BR procedures becoming the criterion standard for treatment of CLAI,[36,40,75,86] BR may be less successful in high-risk patients such as those with generalized ligament laxity (GLL),[59] prior unsuccessful repair,[56] high BMI,[36,86] or high-demand athletes.[43,73] Furthermore, persistence or exacerbation of ankle instability in the early rehabilitation stage has prompted an interest in additional augmentation such as with suture anchors[10,62,72] and periosteal flaps,[11,18,58] as tenodesis or other nonanatomical procedures have mixed results.[3,41,68,87] Anatomical reconstructions with autografts and allografts have also been explored in cases with poor ligamentous tissue quality, although there is a dearth of long-term clinical outcomes and risk of donor site morbidity and disease transmission.[18,60,74,87]

These concerns led to the development of the suture tape augmentation techniques for CLAI.[51] Previous synthetic ligament constructs have been tested as an adjunct to other orthopedic procedures with the hope of early mobilization, faster rehabilitation, and long-term prevention of instability.[33,42,89] Suture tape augmentation constructs have also recently been studied in deltoid ligament,[19,61] ankle dislocation,[39] and spring ligament complex.[1] The use of suture tape to augment a primary ankle ligament repair thus represents an emerging technique to treat CLAI. Although 2 recent meta-analyses have examined the efficacy of specific suture tape augmentation subtypes for CLAI,[46,47] the heterogeneity of techniques and the small number of studies analyzed in these previous reviews precludes a broad analysis. This review instead endeavors to provide a comprehensive outline of all the current techniques using suture tape augmentation for treatment of CLAI as well as present recent research aimed at guiding evidence-based protocols.

Background and Biomechanics

Mackay and Ribbans originally described suture tape augmentation of Broström or modified Broström repair via incorporation of a high-strength nonabsorbable suture tape and knotless anchors to reinforce the repaired ligaments in a "scaffold-like" manner.[51] The suture tape is first anchored to the talus using knotless anchors, followed by insertion into the fibula. A standard Broström repair is then performed, followed by tensioning and securing of the internal brace. Care must be taken in this step, as overtightening of the tape may restrict talocrural joint movement whereas undertightening may result in failure of the repair. Therefore, it is recommended to maintain the ankle in a neutral position on introduction of bone anchors to prevent overtightening.[24,51,88] In addition, placement of a hemostat or freer under the suture tape has been described in open Broström repair to adequately gauge proper tension prior to anchor placement.[51] Although the original authors only augmented the repaired ATFL,[51] other groups have used suture tape for the CFL as well (Table 1).[12,15,16,63,64] The anchors associated with CFL augmentation are tensioned in a similar fashion.

Viens et al[80] conducted biomechanical studies on 18 cadavers to compare this internal brace technique with intact ATFL. The Broström repair augmented with suture tape (BR-ST) was not significantly different from native ATFL with regard to mean load to failure (250.8 N for BR-ST vs 154.0 N for native ATFL) or mean stiffness (21.1 N/mm for BR-ST vs 14.5 N/mm for native ATFL). However, suture tape

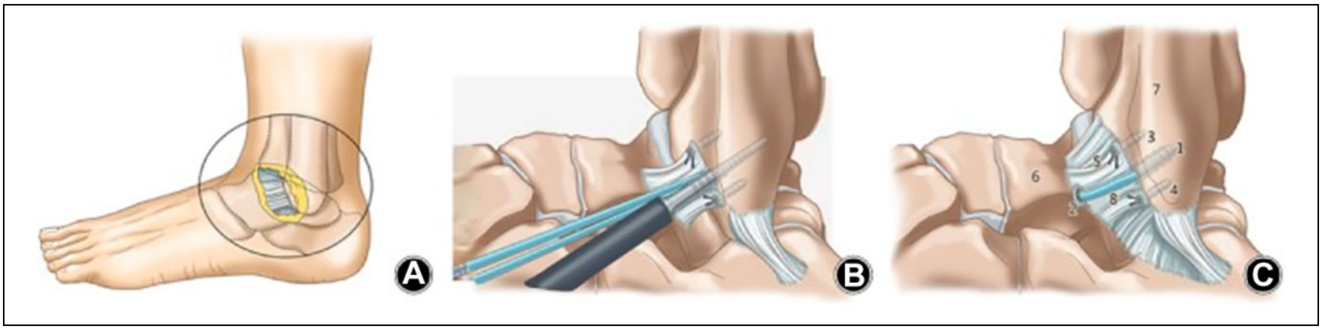

Figure 1. Schematic of open Broström repair with suture tape augmentation.[85] (A) A curved skin incision is made along the anterior and inferior borders of the lateral malleolus. The soft tissue is exposed to find the anterior talofibular ligament. (B) The anterior talofibular ligament is attached to the lateral malleolus by anchors, and two 3.5-mm anchors with suture tape are inserted into the fibula and talus. (C) The modified Broström repair with augmentation using suture tape is completed. 1-4: Anchors; 5: anterior talofibular ligament; 6: talus; 7: lateral malleolus; 8: suture tape.

augmentation of native ATFL resulted in "an approximately 50% higher mean load to failure and stiffness compared with the intact ATFL."[80] Two other cadaveric studies similarly found equal or better performance in the BR-ST group as measured by torque angle and total torque at failure.[71,83]

Other biomechanical studies have noted the restoration of midfoot and hindfoot kinematics after BR-ST.[7,50] Boey et al[7] used 3-D motion capture to measure range of motion (ROM) and average angle (AA) after rupture of suture-augmented repair of ATFL, CFL, or both. All groups repaired with suture tape augmentation were able to at least partially restore foot and ankle kinematics, with the combined ATFL-CFL repair group achieving the best results. Lohrer et al used arthrometer and bone pin marker analyses to demonstrate similar restoration of stability in suture-augmented repair groups, although only the ATFL seemed to be involved in stabilization against anterior talar drawer load.[50] Although data from biomechanical studies is promising, higher quality clinical studies are required to validate this, as most studies reporting on suture tape augmentation are currently limited to level IV data.

Open Broström Repair With Suture Tape Augmentation (BR-ST)

Many studies have described positive clinical results and early rehabilitation following the use of suture tape augmentation of open Broström repair (BR-ST) (Figure 1).[13,17,22,23,26,49,51,52,65,71,85] Suture tape augmentation of Broström repair resulted in low rates of recurrent ankle instability despite postoperative ankle sprains,[13,17,23,65] likely due to the protection from ligament elongation during recurrent inversion events, especially in the early postoperative stage.[57] Even in cases with poor ligamentous tissue quality or other contraindications for Broström repair, BR-ST has been shown to be an effective alternative to tenodesis or tendon-based reconstruction.[13,17,51]

The original Mackay and Ribbans case series described the use of BR-ST in 49 patients with CLAI, which allowed for "early mobilization, reduced pain, and early restoration of function" in a primarily athletic patient population.[51] Patients were either instructed to use a nonweightbearing cast for 2 weeks or allowed immediate partial weightbearing in a boot, and VAS scores decreased from 3.1 ± 2.3 to 1.2 ± 2.3 from presurgery to final follow-up at 2 years postsurgery. Improvements in both Foot Function Index (FFI) and Foot and Ankle Ability Measure (FAAM) scores were also noted (Table 2). All 15 "sports-oriented patients" returned to running within 12 weeks, and there were no recurrences of ankle instability.

Coetzee et al followed 81 CLAI patients treated with BR-ST for 12 months, and reported similarly positive outcomes.[23] A "very aggressive rehabilitation program" consisting of immediate postoperative weightbearing as tolerated and full weightbearing by 3 weeks was used, allowing for athletes "to return to play at an accelerated pace, even as early as 8 weeks after surgery." A mean return-to-sport time of 84 days was reported, whereas significant increases in objective clinical outcome measures including American Orthopaedic Foot & Ankle Society (AOFAS) Ankle-Hindfoot, Veterans Rand 12-Item Health Survey (VR-12), and FAAM scores were also reported (Table 2). Despite improvements in clinical outcome scores, significant differences in dorsiflexion range of motion (ROM) between injured and contralateral ankle persisted, although plantarflexion ROM was not significantly different and 86.4% of patients had a normal or near-normal result on the single-leg hop test. One patient in this study continued experiencing

Table 2. Clinical Outcomes and Complications Following Suture Tape Augmentation for Chronic Lateral Ankle Instability.

Study Name	Population	Technique	Clinical Outcomes	Complications	Postoperative Rehabilitation Protocol	Recurrence of Instability
Mackay et al, 2016[51]	n = 49	BR-ST	(n = 29) VAS: 1.2 ± 2.3 FFI: 28.8 ± 17.0 FAAM: 25.4 ± 10.3	5 cases with additional unspecified pathology, 1 revision case	(n = 29): CAM boot with immediate PWB, return to contact sports at 8-12 wk postoperatively (n = 20): NWB cast for 2 wk postoperatively	None
Sarhan et al, 2020[70]	n = 30 (mean age: 27 y)	BR-ST	AOFAS: 91.0 ± 6.03 FAAM: 90.43 ± 4.02	NR	FWB in hinged ankle brace with full ROM dorsi-/plantarflexion. Transitioned to FWB without brace at 6 wk. Return to sport after 6 mo	2/30 positive anterior drawer test
Ramirez-Gomez et al, 2020[65]	n = 28 (mean age: 33.25 ± 12.73 y)	BR-ST	VAS: 0.5 ± 0.92 AOFAS: 94.60 ± 6.88 SF-36: 80.07 ± 9.78	2/28 wound infection	WB in posterior splint for 2 wk, followed by transition to CAM boot with gradual increase in WB. CAM boot discontinued at 4 wk with aggressive rehabilitation program initiated. Return to daily activities by 8 wk.	3/28 recurrent ankle sprain
Martin et al, 2020[52]	n = 93 (mean age: 30 ± 7 y)	BR-ST	VAS: 1.3 ± 1.5 FADI: 90 ± 11	2/93 superficial peroneal nerve hypothesia, 1/93 cellulitis	PWB in U-splint for 2 wk, followed by WBAT in boot and PT. Boot discontinued at 3-4 wk with progressive increase in activity intensity. Return to full activity by 3-4 mo postoperatively	1/93 revision surgery for instability
Xu et al, 2019[85]	n = 53 (mean age: 27.4 ± 18.5 y)	BR-ST (n = 25) BR (n = 28)	VAS: BR-ST: 0.6 ± 0.7; BR: 0.7 ± 1.2 FAAM: BR-ST: 93.1 ± 2.3; BR: 90.5 ± 5.1 TTA: BR-ST: 2.4 ± 1.3; BR: 2.7 ± 1.4 ATT: BR-ST: 2.9 ± 1.6; BR: 3.1 ± 1.3	BR-ST: 3/25 abnormal dorsal foot paresthesia BR: 1/28 mechanical instability, 1/28 wound infection	NR	None
Porter et al, 2019[64]	n = 47 (mean age: 25.0 ± 7.6 y)	LARS (n = 22) BR (n = 25)	FAOS: 93.7 ± 6.0	LARS: 1/22 peroneal tendon irritation, 2/22 wound infection BR: 1/25 pseudoaneurysm, 1/25 wound infection, 3/25 recurrent ankle injuries	LARS/BR: NWB in dorsal back slab cast postoperatively, transitioned to subtalar stabilizing brace at 1 week with WBAT and active/passive ROM (except inversion-supination). Discontinuation of brace at 6-12 wk with full activity at 12-16 wk	None

(continued)

Table 2. (continued)

Study Name	Population	Technique	Clinical Outcomes	Complications	Postoperative Rehabilitation Protocol	Recurrence of Instability
DeVries et al, 2019[26]	n = 55 (mean age: 43.6 ± 13.9 y)	BR-ST (n = 12) ABR (n = 43)	RTS: BR-ST: 170.7 ± 66.4 d; ABR: 127.2 ± 96.3 d	BR-ST: 1/12 peroneal tendinitis, 1/12 wound infection ABR: 1/43 wound infection, 5/43 return to operating room for revision or debridement	BR-ST/ABR: NWB splint for 2 wk, followed by WB and ROM exercises in CAM boot. Transitioned to WB in ankle brace at 6 wk postoperatively.	None
Coetzee et al, 2018[23]	n = 81 (median age 34 y)	BR-ST	AOFAS ankle-hindfoot: 94.3 ± 9.3 VR-12 mental: 54.8 (27.4-66.3) VR-12 physical: 48.7 (20.6-57.6) FAOS-ADL: 94.5 FAOS-Sport: 85.5 RTS: mean 84 d	5 events (4 patients): Wound dehiscence, superficial infection, ankle inversion sprains (did not result in instability), ankle impingement, extensor tendinitis	WBAT in functional short leg cast. Transitioned to WBAT with CAM boot at 2 wk, with option to remove CAM boot for active ROM per patient tolerance. Formal rehabilitation started at 4 wk with a recommendation to use an ankle brace until 3 mo postoperatively	6.2% positive anterior drawer test
Cho et al, 2017[17]	n = 28 (mean age: 29.5 y)	BR-ST	FAOS (Total): 90.6 ± 5.2 FAOS-Sport: 84.5 ± 7.8 FAAM: 89.5 ± 6.7 TTA: 3.6 ± 2.2 ATT: 4.2 ± 2.8	2/28 skin irritation, 1/28 wound infection, 1/28 damage to superficial peroneal nerve	NWB in short leg splint for 2 wk. Transitioned to PWB in elastic ankle bandage with ROM. FWB at 4 wk. Return to sport at 12 wk postoperatively given adequate ankle stability on examination and radiographically.	6/28 mild ankle sprain, 1/28 recurrence of instability
Cho et al, 2017[13]	n = 26 (mean age: 31.8 y)	BR-ST	FAOS (Total): 75.4 ± 11.9 FAOS-Sport: 78.2 ± 12.9 FAAM: 85.1 ± 9.8 TTA: 2.8 ± 1.9 ATT: 4.1 ± 2.5	2/26 wound problems (1 infection, 1 marginal necrosis), 1/26 superficial nerve injury, 1/26 local cutaneous irritation	NWB short leg cast for 4 wk, followed by PWB in ankle bandage with ROM exercises. FWB resumed at 8 wk postoperatively	9/26 mild ankle sprain, 1/26 recurrence of instability
Porter et al, 2015[63]	n = 21 (mean age: 26.1 y)	LARS (n = 21) BR (n = 20)	FAOS (Total): 94.0 ± 3.0 FAOS-Sport: 94.9 ± 4.0	LARS: 1/21 peroneal tendon irritation, 1/21 wound infection BR: 1/20 pseudoaneurysm	LARS/BR: dorsal back slab for 1-2 wk, followed by WBAT in subtalar stabilizing brace with return to preinjury activity by 3-4 mo postoperatively	NR
Vega et al, 2020[79]	n = 15 (median age 30 y)	ABR-ST	AOFAS: 95	2/15 ankle flexion deficit	PWB in CAM for 2-3 wk with initiation of PT thereafter	None

(continued)

Table 2. (continued)

Study Name	Population	Technique	Clinical Outcomes	Complications	Postoperative Rehabilitation Protocol	Recurrence of Instability
Cottom et al, 2018[24]	n = 110 (mean age: 46.1 ± 17.9)	ABR-ST (n = 35) ABR with additional suture anchor (n = 75)	AOFAS: ABR-ST: 84 ± 15.4; ABR: 88.2 ± 10.1 VAS: ABR-ST: 1.8 ± 2.0; ABR: 1.1 ± 1.4 FFI: ABR-ST: 26.1 ± 20.4; ABR: 19.6 ± 14.9 KP score: ABR-ST: 82.2 ± 17.8; ABR: 85.3 ± 11.6	ABR-ST: 2/35 ankle impingement, 1/35 nerve entrapment, 1/35 wound healing, 1/35 deep vein thrombosis, 1/35 chronic regional pain syndrome ABR: 4/75 ankle impingement, 1/75 nerve entrapment, 2/75 wound healing, 1/75 deep vein thrombosis	NR	NR
Yoo et al, 2016[88]	n = 85 (mean age: 23 y)	ABR-ST (n = 22) ABR (n = 63)	AOFAS: ABR-ST: 98.0 ± 16.8; ABR: 96.5 ± 5.4 Anterior drawer test grade: ABR-ST: 0.1 ± 0.4; ABR: 0.1 ± 0.4	ABR-ST: 2/22 inversion deficit ABR: 2/63 intermediate dorsal cutaneous neuritis, 3/63 inversion deficit	ABR-ST: Progressive WB in compression bandage. Physical therapy initiated at 2 wk, with return to sports at 4 wk. ABR: NWB short leg cast for 2 wk; thereafter, transitioned to progressive WB. Transitioned to brace at 4 wk, with initiation of PT with active ROM. Return to sports at 12 wk.	NR
Ulku et al, 2020[76]	n = 61 (mean age: 28.2 y)	STO (n = 30) ABR (n = 31)	FAOS: STO: 91.5 ± 7.7; ABR 90.6 ± 5.2 FAAM: STO: 93 ± 13; ABR: 89.3 ± 15 TTA: STO: 4.5 ± 4.4 degrees; ABR: 4.7 ± 4.8 degrees ATT: STO: 4.3 ± 4.5 mm; ABR: 4.6 ± 4.1	STO: none ABR: 1/31 wound infection	ABR: NWB short leg cast for 4 wk. Transitioned to PWB and PT thereafter. FWB after 6 wk. STO: PWB with elastic ankle brace. Transitioned to FWB and PT at 2 wk	STO: 1/30 recurrent mechanical instability ABR: 2/31 recurrent mechanical instability

(continued)

Table 2. (continued)

Study Name	Population	Technique	Clinical Outcomes	Complications	Postoperative Rehabilitation Protocol	Recurrence of Instability
Cho et al, 2019[15]	n = 55 (mean age: 27.4)	STO (n = 28) BR (n = 27)	FAOS: STO: 91.9 ± 6.7; BR: 93.3 ± 6.1 FAAM: STO: 89.4 ± 7.4; BR: 92.2 ± 6.5 TTA: STO: 4.6 ± 2.6 degrees; BR: 3.9 ± 2.3 degrees ATT: STO: 4.5 ± 2.3 mm; BR: 4.2 ± 2.2 mm	STO: 1/28 damage to sural nerve BR: 1/27 wound infection, 1/27 damage to superficial peroneal nerve	STO/BR: NWB short leg cast for 3 wk. Transitioned to PWB with ROM exercises in elastic ankle bandage. FWB and proprioception training resumed at 6 wk.	STO: 2/28 recurrent mechanical instability BR: 1/27 recurrent mechanical instability
Cho et al, 2019[12]	n = 24 (mean age: 29.2 y)	STO	CAIT: 27.2 ± 3.5 FAAM: 86.7 ± 9.3	2/24 decreased inversion	NWB short leg cast for 3 wk, followed by PWB in air cast brace with ROM exercises. FWB at 6 wk postoperatively.	6/24 recurrent sprain(s), 1/24 recurrent mechanical and subjective instability
Cho et al, 2015[16]	n = 34 (mean age: 26.2 y)	STO	FAOS: 93.2 ± 6.5 FAAM: 92.5 ± 6.1 TTA: 4.3 ± 3.5 degrees ATT: 4.1 ± 2.8 mm	1/34 chronic inflammation due to foreign body reaction	NWB short leg splint for 2 wk, followed by PWB in elastic ankle bandage with ROM exercises. FWB at 4 wk postoperatively.	NR

Abbreviations: ABR, arthroscopic Broström repair or modified Broström repair; ADL, activities of daily living; CAIT, Cumberland Ankle Instability Tool; FFI, Foot Function Index; VR-12, Veterans Rand 12-Item Health Survey; ABR-ST, arthroscopic Broström or modified Broström repair with suture tape augmentation; AOFAS, American Orthopaedic Foot & Ankle Society; ATT, anterior talar translation; BR, Broström or modified Broström repair; BR-ST, Broström or modified Broström repair with suture tape augmentation; CAM, controlled ankle motion; FAAM, Foot and Ankle Ability Measure; FADI, Foot and Ankle Disability Index; FAOS, Foot and Ankle Outcome Score; FWB, full weightbearing; KP Score, Karlsson-Peterson ankle score; LARS, ligament augmentation reconstruction system; NR, not reported; NWB, nonweightbearing; PT, physical therapy; PWB, partial weightbearing; ROM, range of motion; RTS, return to sport; SF-36, 36-Item Short Form Health Survey; STO, suture tape augmentation only without concomitant ligament repair; TTA, talar tilt angle; VAS, visual analog scale; WB, weightbearing; WBAT, weight bearing as tolerated.

ankle inversion sprains at 1 year postoperatively; however, this did not result in the recurrence of subjective or mechanical instability.

Two recent case series have further demonstrated excellent clinical and functional results following BR-ST.[52,65] A 3-year follow-up study of 28 patients with CLAI found significant improvements in VAS, AOFAS, and Short Form of Quality of Life Survey (SF-36) scores (Table 2)[65]; however, this study excluded patients with concomitant procedures such as arthroscopic debridement and synovectomy[65] and may therefore skew the results by excluding patients with poor prognostic factors.[20,29,35] Three patients had a recurrent ankle sprain, but all 3 made a full recovery without resulting in functional or mechanical instability.[65] Furthermore, 93 CLAI patients in the military population reported significant improvements in the Foot and Ankle Disability Index (FADI), VAS, and satisfaction scores following BR-ST.[52] Almost all (96%) patients were able to complete single-leg hop and single-leg raise at 6 weeks postsurgery.[52] Both studies instructed patients to wear a partial weightbearing splint for 2 weeks, followed by progressive rehabilitation and running at approximately 6 weeks postsurgery.[52,65]

Although many initial studies examined clinical outcomes of relatively uncomplicated CLAI patients, other groups have explored the use of BR-ST in patients where Broström or modified Broström repair is relatively contraindicated.[13,17,51] Poor remnant ligament tissue quality, high body mass index, generalized ligamentous laxity (GLL),[59] and previous failed Broström repair[56] are all potential contraindications to the further anatomical repair.[3,4,36,59,69,86] Suture tape augmentation may therefore allow for primary anatomical repair of the ligament while avoiding nonanatomical procedures such as tenodesis or ligament reconstruction.[41,68]

Cho et al reported on 30 revision BR-ST cases for a mean 38.5 months and found significant increases in FAOS and FAAM outcome score (Table 2).[13] Additional improvements in radiologic stability assessments such as anterior talar translation (ATT), talar tilt angle (TTA), and stress radiographs were also noted (Table 2). Although 9 patients had a further sprain of the ankle postoperatively, this may have been due to the initial poor quality of the ligamentous tissue. Furthermore, only 1 of these patients progressed to recurrent subjective and mechanical instability, and this patient was treated with revision reconstruction using allograft tendon. Another 2-year follow-up study examined the use of BR-ST in 28 patients with GLL, and found increases in FAOS, FAAM score, TTA, and ATT (Table 2).[17] The authors reported 6 patients with an additional ankle sprain after operation, with only 1 progressing to recurrence of subjective and mechanical instability (patient refused reoperation).

Retrospective comparative studies have been carried out to compare BR-ST with BR[85] and BR-ST with arthroscopic Broström repair (ABR).[26] Xu et al compared 25 BR-ST patients with 28 BR patients after 2 years postsurgery.[85] They found that the BR-ST group had significantly greater FAAM-Sport and FAAM-Total scores, although AOFAS, VAS, TTA, ATT, and other FAAM subscores were not significantly different between the 2 groups (Table 2).[85] Moreover, although both groups underwent the same rehabilitation protocol, the BR group had 1 case of recurrent mechanical instability whereas the BR-ST did not have any. On the other hand, DeVries et al compared 43 patients who underwent ABR with 12 patients who underwent BR-ST.[26] At approximately 2 years postsurgery, the ABR group had a significantly faster return to sport but also a much higher revision surgery rate (11.6%) compared with the BR-ST group (0%) (Table 2).[26] Thus, the authors noted that although "preservation of tissues with arthroscopic approach" may result in a faster return to sport, "stabilization with suture tape augmentation is a much stronger construct," as evidenced by the revision surgery rate. However, longer-term studies are needed to elucidate the long-term effectiveness of the BR-ST procedure.

The BR-ST procedure is not without its drawbacks. Complications stemming from the insertion of the nonabsorbable suture tape include local cutaneous irritation and peroneal nerve damage.[13,17,52,63,64,85] Xu et al found 3 cases of abnormal dorsal foot paresthesia as a result of damage to the superficial peroneal nerve in the BR-ST group compared with none in the BR group.[85] Wound infection is also a commonly cited complication[13,17,52,85] and may be due to the additional dissection needed to place the anchors and tape.[22] Despite these complications, serious foreign body immunologic responses to the suture tape construct, as seen in other sites such as ACL,[45] have not been reported. Additional medium- and long-term follow-up studies are required to ensure that the suture tape construct remains inert.[16,51]

Additional questions remain over whether augmentation techniques using suture tape can ultimately lead to biological healing and eventual maturation of attenuated ligaments.[13,22] Although Mackay and Ribbans confirmed "complete integration of the internal brace into the healed lateral ligament" on a second look for subtalar irritation, additional long-term clinical and histologic studies are needed to determine how the healed augmented ligament differs from scar tissue or original ligament.[51] Some groups have called into question the cost-effectiveness of the BR-ST technique in noncontraindicated CLAI patients, as BR-ST requires additional expenses in knotless anchor fixation and suture tape.[15,17,65]

The BR-ST procedure for anatomical lateral ankle ligament repair has been shown through multiple studies to be a safe and effective treatment for CLAI, especially in high-risk patient populations such as athletes and members of the military.[23,51,52] Furthermore, BR-ST can be used in patients that are relatively contraindicated for traditional or modified Broström repair, including revision surgeries[13,51] and patients with GLL.[17] However, most studies to date have been short-term (2 years or less), and longer-term follow-up is needed to assess the safety and longevity of the suture tape construct.[3,87] Further comparative studies are also needed to elucidate the cost-effectiveness of such augmented repair and determine what patient types can best benefit from the BR-ST procedure.[3,14,52]

Arthroscopic Broström Repair With Suture Tape Augmentation (ABR-ST)

Ankle arthroscopy is a common adjunct procedure performed alongside traditional open Broström or modified Broström repair.[2,3,35,36,87] The high rate of intra-articular symptoms in CLAI patients oftentimes necessitates arthroscopy to treat synovitis, intra-articular lesions, osteophytes, and other intra-articular pathology.[20,29,35] Technological advancements have prompted some groups to also perform the Broström or modified Broström repair arthroscopically (ABR); previous studies have demonstrated comparable biomechanical and clinical results to the open Broström repair.[25,31,55,84] A recent meta-analysis found higher short-term AOFAS functional outcome scores with ABR compared to open BR, although Karlsson functional outcome score, total complication rate, and nerve or wound complication did not significantly differ between the 2 procedures.[9] Earlier weightbearing and lower rates of incision complications are commonly cited benefits of the ABR procedure, although technical skill remains a barrier for wider adoption.[9,66,84]

Arthroscopic Broström repair with suture tape reinforcement (ABR-ST) has been explored as a augmentation procedure to facilitate a quick return to sport and resist injury recurrence (Figure 2).[24,79,88] Yoo and Yang adapted the suture tape augmentation technique for arthroscopic Broström repair by comparing 22 ABR-ST patients with 63 ABR patients in a military population setting.[88] They found significantly increased AOFAS scores for the ABR-ST group compared to the ABR group at the 6- and 12-week follow-ups; however, this difference was not present at the 24-week follow-up (Table 2). Furthermore, the ABR-ST group was allowed to return to running and high-impact sports at 4 weeks, whereas the ABR group was restricted until 3 months postsurgery. No wound complications or recurrences of ankle stability were reported in either group, although 2 patients in the ABR-ST group had an inversion deficit of >10 degrees that was attributed to overtightening of the suture tape.

Cottom et al retrospectively compared 75 modified ABR patients with 35 ABR-ST.[24] The modified ABR procedure used an additional suture anchor (3 in total) whereas the ABR-ST group used a "crossed suture anchor fixation" construct. At a mean follow-up time of 13.2 months, no difference was found between the 2 groups in AOFAS score, FFI, or return to weightbearing. Although the ABR-ST had a higher complication rate (17.1%) vs the ABR group (10.7%), this effect was not significant. Complications in the modified ABR group included ankle impingement (5.33%), nerve entrapment (1.33%), wound healing problems (2.66%), and deep vein thrombosis (1.33%). Complications in the ABR-ST group included ankle impingement

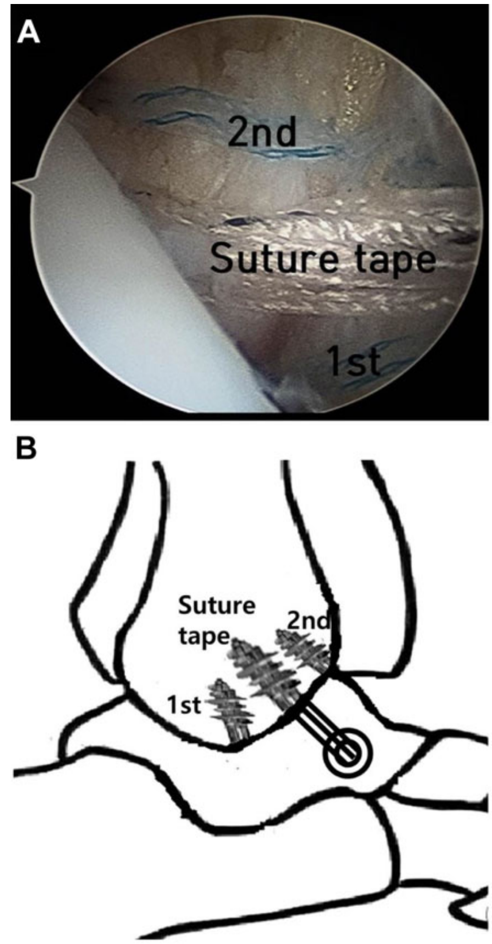

Figure 2. Schematic of arthroscopic Broström repair with suture tape augmentation (ABR-ST).[88] (A) Arthroscopic images demonstrating use of anterolateral portals for anchor placement. The first anchor is inserted at 1 cm superior to its position on the fibula. The second anchor is placed into the fibula more superiorly and level with the lateral shoulder of the talus. The fibular tunnel is created for suture tape insertion in the fibula between 2 all-suture anchors through the anterolateral portal. (B) Schematic drawing of an arthroscopic modified Brostrom procedure with an internal brace. Source: Adapted from Yoo and Yang.[88] Copyright © 2016 The Author(s), published with open access at Springerlink.com. Used under CY BY 4.0 / modified through changing text from past tense to present.

(5.71%), nerve entrapment (2.86%), wound healing problems (2.86%), deep vein thrombosis (2.86%), and chronic regional pain syndrome (2.86%). The authors noted that the suture tape construct's larger footprint may lead to "greater incidence of soft tissue impingement, nerve entrapment, and other common complications," but further long-term and comparative studies are needed to validate this theory.

Recently, Vega et al followed 15 patients with "poor quality ligament-tissue remnant" who underwent ABR-ST.[79] By building on an "arthroscopic all-inside ATFL repair" that used an accessory anterolateral portal,[77,78] the authors used the remnants of the FiberWire suture after ligament repair to create a suture tape construct over the ATFL.[79] Significant increases in AOFAS scores were recorded after mean 17.4 months' follow-up, and all athletic patients returned to sports following early rehabilitation at 3 weeks. No revision surgeries, peroneal nerve complications, or recurrences of ankle instability were found, although 2 patients experienced ankle plantar flexion deficits, again attributed to potential overtensioning of sutures.

Ankle arthroscopy represents a new modality of Broström repair that may allow for early rehabilitation and lower rates of wound complications.[3,36,86] ABR-ST represents an additional augmentation of this technique that may allow for earlier rehabilitation in high-demand populations or patients with contraindications to traditional Broström repair.[79,88] Despite encouraging results, there is considerable heterogeneity in the techniques used to augment ABR, necessitating a need for additional comparative studies. Complications such as peroneal nerve injury and plantarflexion deficit due to overtightening of suture tape may be due to the technical skill required to perform the procedure.[3,88] Additional long-term research is therefore required to validate the usefulness of ABR-ST over other similar techniques.

Ligament Augmentation Reconstruction System (LARS)

Porter et al described open repair of the lateral collateral ligament (LCL) ankle complex augmented with a synthetic ligament augmentation reconstruction system (LARS).[63] Though not a "true" suture tape augmentation construct akin to the BR-ST procedures described in previous studies, LARS nevertheless incorporates many similar concepts such as extra-articular placement, anatomical repair, and synthetic suture tape material. This system incorporates both an ATFL and CFL limb. At the 2-year follow-up, the authors found that the LARS group had significantly greater improvements in FAOS and FAOS subscale scores when compared to the BR group, although 1 LARS patient reported irritation of the peroneal tendons, with resolution of symptoms on removal of the fibular anchor removal at 6 months postoperatively (Table 2).[63] A longer-term RCT by the same group also found higher FAOS values in the LARS group at 5-year follow-up and similar rates of complications between the 2 groups (Table 2).[64] Another case of peroneal tendon irritation was reported because of the anchor at the posterior cortex of the fibula, with complete resolution of symptoms on removal. In both studies, there were no cases of peroneal tendon irritation from the calcaneal anchor used to reconstruct the CFL.[63,64] Despite heterogeneity in suture tape augmentation techniques, these 2 studies demonstrate continued interest in the use of synthetic materials to augment lateral ankle ligament repairs with promising results.

Suture Tape Augmentation Without Concomitant Ankle Ligament Repair (STO)

With the advent of new techniques such as ABR and ABR-ST,[24,25,55,79,84,88] there has been an increased focus on minimally invasive procedures despite a recent systematic review reporting mixed results.[53] Patient populations may differ with regard to lifestyle demand and the degree of ankle stability needed, thus necessitating patient-specific treatment options.[30,40,48,54] One such option is minimally invasive suture tape augmentation without concomitant repair of lateral ankle ligaments (STO), which may be used in populations where open Broström repair is high-risk or an overtreatment, such as young female patients with low-demand lifestyles (Figure 3).[15,16]

Cho et al used a "mini-open ligament augmentation" technique to treat 34 young female patients who were <70 kg in body weight and in nondemanding professions (no athletes or heavy laborers).[16] This technique also involved augmentation of CFL, with care taken to avoid impingement between the suture tape and peroneal tendons. This method resulted in significantly increased FAOS, FAAM, ATT, TTA, and Sefton functional scale measurements (Table 2). Moreover, use of STO avoided wound infection and skin irritation commonly found in "young female patients with thin subcutaneous tissue," although 1 case of chronic inflammation was noted. Other advantages cited included "fewer surgical dissections and postoperative complications, technical ease, no donor site morbidity, and decreased operation time."

Another study used a similar STO technique in a case series of 24 patients with functional ankle instability (FAI).[12] The definition of FAI is still somewhat controversial, but seems to encompass "proprioceptive deficits, neuromuscular deficits, postural control deficits, and muscle weakness" and may represent a risk factor for recurrence of mechanical ankle instability (MAI).[5,40] When STO was used to treat FAI patients, the authors found improvements in Cumberland Ankle Instability Tool (CAIT) and FAAM scores, but also residual deficits in peroneal strength, proprioception, and postural control after the 2-year follow-up (Table 2).[12] Thus, although functional outcome scores improved after STO, lingering deficits in other proprioceptive and isokinetic measurements stress the need for continued patient-specific rehabilitation and follow-up. No patients reported peroneal tendon irritation in this cohort.

Randomized control trials have compared the minimally invasive STO procedure to BR[15] and arthroscopic STO (A-STO) to ABR.[76] When 28 young, nonoverweight, female patients who underwent STO were compared to 27 similar patients who underwent BR, no significant differences in FAOS score, FAAM score, recurrence of instability, stress radiograph findings, TTA, or ATT were found at 2-year follow-up (Table 2).[15] The STO procedure had medical expenses 1.3 times that of the BR procedure, as cost

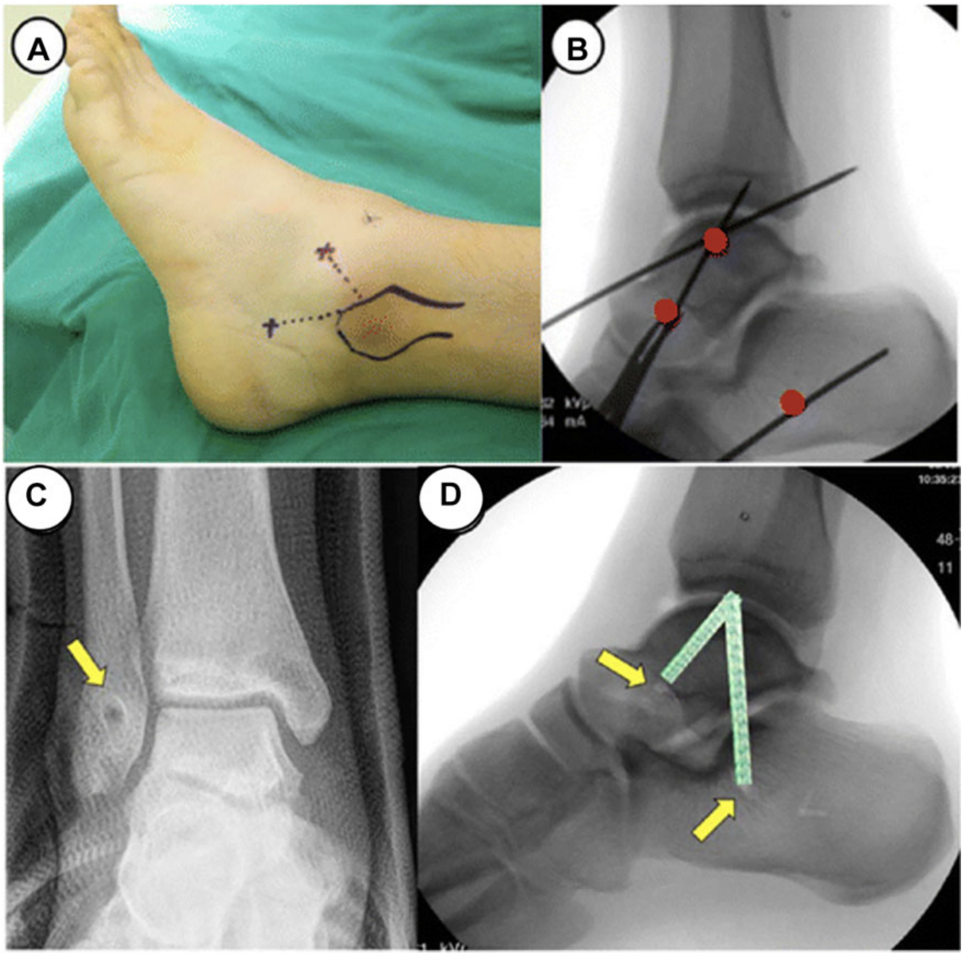

Figure 3. Schematic of suture tape augmentation only (STO).[16] (A) Intraoperative photograph showing the pathway and anatomic origin of the anterior talofibular and calcaneofibular ligaments. (B) Confirmation of entry points (dots) of suture anchors through temporary K-wires inserted under fluoroscopic guidance. (C, D) Postoperative radiographs showing the location of anchors and suture tape (arrows indicate the entry points of anchors).
Source: Reprinted from Cho et al.[16] Used under STM Permissions Guidelines 2020.

associated with the use of a fluoroscope in the STO procedure outweighed the shorter operating time. Ulku et al followed 31 ABR patients and 30 A-STO patients for approximately 3 years and similarly reported no significant differences in FAOS, FAAM-Total, FAAM-Daily, ATT, or TTA measurements (Table 2).[76] There was a significant difference in FAAM-Sport score in favor of the A-STO procedure, and the A-STO group underwent an accelerated rehabilitation featuring no casts postoperatively and progression to full weightbearing at 2 weeks.

Although suture tape augmentation-only procedures may result in lower rates of wound complications and faster rehabilitation time, cost-effectiveness and chronic inflammation due to foreign body reaction to the tape construct are concerns that must be addressed through medium- and long-term studies.[15,16,76] Additionally, there is a question of whether the augmentation without repair truly allows for the underlying ligament tissue to repair, and if so, does this biological healing differ from that of original tissue or scar tissue.[15]

Conclusion

Suture tape augmentation has shown promising short-term outcomes in patients with CLAI. Recent literature supports its use in a variety of patient populations, including patients that are relatively contraindicated for traditional or modified Broström repair. Arthroscopic Broström repair with suture tape augmentation has been implicated in earlier rehabilitation in patients with contraindications to traditional Broström repair; however, the degree of heterogeneity in surgical technique necessitates further investigation to fully elucidate the benefits of this procedure. In situations where there is direct repair of the ATFL (and possibly CFL) such as BR and ABR, the suture tape serves as an augmentation and as such may not necessitate placement across both the ATFL and CFL. Conversely, in cases where direct repair is not performed such as STO and LARS, it may be prudent to reconstruct both the ATFL and CFL limbs of the ligament as this is not necessarily an augmentation but rather a substitution of the ligament. Although peroneal tendon irritation may occur with CFL suture tape augmentation, larger studies are needed to better establish the risk of such events and patient selection strategies. In addition, medium- and long-term follow-up studies are needed to ensure the stability of the suture tape construct and that no long-term complications occur. Cost-effectiveness and clinical benefit over existing operative procedures are other concerns that must be addressed in relevant randomized controlled trials. Although the open modified Broström repair remains the gold standard for treatment of CLAI, newer suture tape augmentation may allow for faster and more aggressive rehabilitation protocols without compromising ligament stability.

Ethical Approval

Ethical approval was not sought for the present study because It was a review article and no human subjects were involved.

Declaration of Conflicting Interests

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