UNIVERSITAT DE BARCELONA

Ankle lateral instability: arthroscopic treatment strategy

Guillaume Cordier

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PHD THESIS PROJECT

''Medicine and Translational Research" Program

ANKLE LATERAL INSTABILITY:

ARTHROSCOPIC TREATMENT STRATEGY

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6. **Abbreviations and acronyms :**

- ATFL: Anterior talo fibular ligament
- ATFLif: ATFL’s inferior fascicle
- ATFLsf: ATFL’s superior fascicle
- BG: Broström Gould
- CFL: Calcaneo fibular ligament
- CLAI: Chronic lateral ankle instability
- DL: Deltoid ligament
- LCL: Lateral collateral ligament
- LFTCL: lateral fibulotalocalcaneal ligament complex
- PRP: Platelet rich plasma
- PTFL: Posterior talofibular ligament

7. **List of articles in the thesis:**

Thesis in compendium of publications format. The thesis consists of 3 objectives and 7 articles.

1. Cordier G, Lebecque J, Vega J, Dalmau-Pastor M. Arthroscopic ankle lateral ligament repair with biological augmentation gives excellent results in case of chronic ankle instability. Knee Surg Sports Traumatol Arthrosc. 2020 Jan;28(1):108-115. doi: 10.1007/s00167-019-05650-9. Epub 2019 Aug 6. PMID: 31388694.
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2. Cordier G, Ovigue J, Dalmau-Pastor M, Michels F. Endoscopic anatomic ligament reconstruction is a reliable option to treat chronic lateral ankle instability. Knee Surg Sports Traumatol Arthrosc. 2020 Jan;28(1):86-92. doi: 10.1007/s00167-019-05793-9. Epub 2019 Nov 14. PMID: 31728603.
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3. Guelfi M, Nunes GA, Malagelada F, Cordier G, Dalmau-Pastor M, Vega J. Arthroscopic-Assisted Versus All-Arthroscopic Ankle Stabilization Technique. Foot Ankle Int. 2020 Nov;41(11):1360-1367. doi: 10.1177/1071100720938672. Epub 2020 Jul 14. PMID: 32660270.
    a. Impact factor FAI 2020: 2,827
    b. 2nd quartile in category: orthopedics (32/82).

4. Guiraud K, Nunes GA, Vega J, Cordier G. High body mass index is not a contraindication for an arthroscopic ligament repair with biological augmentation in case of chronic ankle instability. Knee Surg Sports Traumatol Arthrosc 31, 5222–5227 (2023). https://doi.org/10.1007/s00167-023-07557-y
    a. Impact factor KSSTA 2023: 3,3
    b. 1st quartiles in 3 categories: orthopedics (17/136), surgery (37/290), sport sciences (19/127).

5. Thès A, Andrieu M, Cordier G, Molinier F, Benoist J, Colin F, Elkaïm M, Boniface O, Guillo S, Bauer T, Lopes R; Francophone Arthroscopy Society (SFA). Five-year clinical follow-up of arthroscopically treated chronic ankle instability. Orthop Traumatol Surg Res. 2023 Dec;109(8S):103649. doi: 10.1016/j.otsr.2023.103649. Epub 2023 Jun 25. PMID: 37364821.
    a. Impact factor Orthop Traumatol Surg Res 2023: 2,3
    b. 2nd quartile in 2 categories: orthopedics (38/136), surgery (19/290).

6. Colin F, Barbier O, Cordier G. Role of surgery in the management of lesions of the medial collateral ligament of the ankle. Orthop Traumatol Surg Res. 2020 Dec;106(8S):S195-S199. doi: 10.1016/j.otsr.2020.08.005. Epub 2020 Sep 6. PMID: 32900668.
    a. Impact factor Orthop Traumatol Surg Res 2023: 2,3
    b. 2nd quartile in 2 categories: orthopedics (38/136), surgery (19/290).

7. Cordier G, Boudahmane S, Ovigue J, Michels F, Araujo Nunes G, Dallaudiere B. MRI Assessment of Tendon Graft After Lateral Ankle Ligament Reconstruction: Does Ligamentization Exist? Am J Sports Med. 2024 Mar;52(3):721-729. doi: 10.1177/03635465231225487. Epub 2024 Feb 11. PMID: 38343192.
    a. Impact factor AJSM 2023: 4,2
    b. 1st quartiles in 2 categories: orthopedics (11/136, sport sciences (9/127).

8. Thesis summary:

ANKLE LATERAL INSTABILITY: ARTHROSCOPIC TREATMENT STRATEGY.

- Introduction :

Lateral Ankle sprain is the most common injury of the lower limb. It can lead to chronic ankle instability (CAI) in 20 to 30% of cases with an impact on public health. Surgical treatment is recommended in case of failure of conservative treatment to avoid functional sequels. Until now, 2 « gold standards » surgical was practiced with open surgery: repair with retinaculum augmentation called « Broström- Gould » and anatomical reconstruction with a graft.

- Hypothesis :

Surgical treatment has evolved a lot during last decade with the development of the arthroscopic techniques. Repair or reconstruction of the ligament can be performed arthroscopically.

We hypothesize that arthroscopic treatments are safe and give equivalent or better result than open surgery treatment.

- Objectives :

The goal of the thesis is to study data of cohorts of patients with 2 years follow-up after Arthroscopic Ankle lateral Ligaments Repair with Retinaculum augmentation (Broström-Gould arthroscopique) and after endoscopic ankle lateral ligaments reconstruction. Then it becomes possible to compare obtained data with the published literature for both techniques.

- Material, methods and results :

Patients operated for CAI in our surgery center are systematically registered. Surgical indication is deciding according to the preoperative assessment: Arthroscopic ligaments repair is the first intention treatment while endoscopic ligaments reconstruction is performed in case of contraindication. The data which includes the referal ankle clinical scores (AOFAS and Karlsson-Peterson) are recorded pre and postoperatively. Two studies analyze retrospective evaluation of a prospective database. Secondarily, a research of postoperative results for open surgery is performed in bibliographic databases. Finally, a comparison of the results of arthroscopic and open surgery may help answer the hypothesis.

The 1st serie of patients with chronic ankle instability included fifty-five patients (55 ankles). They underwent an arthroscopic all-inside talofibular ligament repair with biological augmentation, and were all retrospectively recruited during follow-up assessment. No loss of patients was observed at final follow-up. At follow-up, the median preoperative AOFAS score of 74 (SD 7, mean 72, range 48–84) increased to 90 (SD 8, mean 91, range 63–100) (n.s). According to the Karlsson score, the median preoperative average of 65 (SD 7, mean 64, range 42–82) increased to 95 (SD 9, mean 92, range 65–100) (n.s). Two patients described ankle instability feeling or explained some episode of ankle sprain at follow-up. However, when explored, no instability was demonstrated (negative anterior ankle drawer test and talar tilt) in any case. One case (1.8%) required a new ankle surgery at 23 months of follow-up because of a severe ankle sprain during sports activity. Range of motion was evaluated and compared with the preoperative ankle motion, and a mean reduction of 1° in ankle dorsiflexion (n.s.) was observed, while no changes were observed in ankle plantarflexion (n.s.). Patients reported that they were satisfied or very satisfied with the procedure in 47 cases (85%), and were non-satisfied in eight cases (15%). Complications were reported in five patients (9.1%). One patient presented a complex regional pain syndrome, and two a deep venous thrombosis that was resolved at final follow-up in all patients. Two patients presented neurological complications (3.6% of patients).

The second serie of patients with chronic ankle instability was treated with an arthroscopic reconstruction of the lateral ligament using a tendinous graft. 53 patients were assessed with an average follow-up of months 31.5 ± 6.9 months (range 24–51). The mean overall AOFAS score improved from 76.4 ± 15 (median 82.5, range 18–92) to 94.7 ± 11.7 (median 100, range 34–100), ($p = 0.0001$). The mean preoperative Karlsson–Peterson score was 73.0 ± 16.0 (median 73, range 7–95) and the mean postoperative Karlsson–Peterson score was 93.7 ± 10.6 (median 97, range 57–100) ($p = 0.0001$). The mean VAS score improved of 1.9 ± 2.5 (range 0–7) to 0.8 ± 1.7 (range 0–7) from preoperative to postoperative status ($p < 0.001$). At final follow-up, there was a significant loss of range of motion (ROM) compared with preoperative measurements of passive dorsal flexion [mean loss of 2.7°; 95% confidence interval (CI) 1.5°–3.9°; $p < 0.05$] and passive plantar flexion (mean loss of 1.4°; 95% CI 0.5°–2.2°; $p < 0.05$). Thirty-five patients practiced sports activities prior to the onset of symptoms of instability. Postoperatively, thirty- one patients (89%) returned to sports activity. Patients reported that they were satisfied or very satisfied with the procedure in 46 cases (92%). Two major complications were observed and consisted of two cases with failure of the reconstruction (4%). No neurological complications were reported. One patient sustained a removal of the endobutton during the post-operative period. There were no wound problems or infections related to the surgery.

- Conclusion:

The study of a cohort of patient treated by arthroscopic repair with retinaculum augmentation (Broström-Gould arthroscopic) demonstrated that postoperative results were at least equivalent to open techniques.

Similarly, the postoperative results of a cohort of patient treated with an endoscopic lateral ligament reconstruction confirmed results at least equivalent to open techniques.

These conclusions are supported by studies published in the literature.

INESTABILITAT LATERAL DEL TURMELL : ESTRATÈGIA DE TRACTAMENT ARTROSCÒPIC.

- Introducció:

L'esquinç lateral de turmell és la lesió més freqüent de l'extremitat inferior. Pot provocar inestabilitat crònica del turmell (CAI) en un 20 a 30% dels casos amb un impacte en la salut pública. Es recomana el tractament quirúrgic en cas de fracàs del tractament conservador per evitar seqüeles funcionals. Fins ara, amb cirurgia oberta es practicaven 2 "estàndards d'or" quirúrgics: reparació amb augment del retinàcul anomenat "Broström-Gould" i reconstrucció anatòmica amb empelt.

- Hipòtesi:

El tractament quirúrgic ha evolucionat molt durant la darrera dècada amb el desenvolupament de les tècniques artroscòpiques. La reparació o reconstrucció del lligament es pot realitzar artroscòpicament. Presentem la hipòtesi que els tractaments artroscòpics són segurs i donen un resultat equivalent o millor que el tractament de cirurgia oberta.

- Objectius:

L'objectiu de la tesi és estudiar les dades de cohorts de pacients amb 2 anys de seguiment després. Reparació artroscòpica dels lligaments laterals del turmell amb augment del retinàcul (Broström-Gould artroscòpica) i després de la reconstrucció endoscòpica dels lligaments laterals del turmell. Aleshores, és possible comparar ambdues dades amb la literatura publicada per a tècniques.

- Material, mètodes i resultats:

Els pacients operats de CAI al nostre centre quirúrgic es registren sistemàticament. La indicació quirúrgica és determinant segons la valoració preoperatòria: la reparació artroscòpica dels lligaments és el tractament de primera intenció mentre que la reconstrucció endoscòpica dels lligaments es realitza en cas de contraindicació. Les dades que inclouen les puntuacions clíniques del turmell de referència (AOFAS i Karlsson-Peterson) es registren pre i postoperatori. Dos estudis analitzen l'avaluació retrospectiva d'una base de dades prospectiva. En segon lloc, es realitza una recerca de resultats postoperatoris per a cirurgia oberta en bases de dades bibliogràfiques. Finalment, una comparació dels resultats de la cirurgia artroscòpica i oberta pot ajudar a respondre la hipòtesi.

La 1a sèrie de pacients amb inestabilitat crònica del turmell va incloure cinquanta-cinc pacients (55 turmells). Es van sotmetre a una reparació artroscòpica del lligament talofibular amb augment biològic i es van investigar retrospectivament durant l'avaluació de seguiment. No es va observar cap pèrdua de pacients en el seguiment final. En el seguiment, la puntuació AOFAS preoperatòria mitjana de 74 (SD 7, mitjana 72, rang 48-84) va augmentar fins a 90 (SD 8, mitjana 91, rang 63-100) (n.s). Segons la puntuació de Karlsson, la mitjana preoperatòria mitjana de 65 (DE 7, mitjana 64, rang 42–82) va augmentar fins a 95 (DE 9, mitjana 92, rang 65–100) (n.s). Dos pacients van descriure una sensació d'inestabilitat del turmell o van explicar algun episodi d'esquinç de turmell durant el seguiment. Tanmateix, quan es va explorar, no es va demostrar cap inestabilitat (prova negativa del calaix del turmell i inclinació de l'astragal) en cap cas. Un cas (1,8%) va requerir una nova cirurgia de turmell als 23 mesos de seguiment a causa d'un esquinç greu de turmell durant l'activitat esportiva. Es va avaluar el rang de moviment i es va comparar amb el moviment preoperatori del turmell, i es va observar una reducció mitjana d'1 ° en la dorsiflexió del turmell (n.s.), mentre que no es van observar canvis en la flexió plantar del turmell (n.s.). Els pacients van informar que estaven satisfets o molt satisfets amb el procediment en 47 casos (85%), i no estaven satisfets en vuit casos (15%). Es van notificar complicacions en cinc pacients (9,1%). Un pacient presentava una síndrome de dolor regional complexa i dos una trombosi venosa profunda que es va resoldre en el seguiment final en tots els pacients. Dos pacients van presentar complicacions neurològiques (3,6% dels pacients).

La segona sèrie de pacients amb inestabilitat crònica del turmell es va tractar amb una reconstrucció artroscòpica del lligament lateral mitjançant un empelt tendinós. Es van avaluar 53 pacients amb un seguiment mitjà de mesos 31,5 ± 6,9 mesos (rang 24-51). La puntuació global mitjana d'AOFAS va millorar de 76,4 ± 15 (mediana 82,5, rang 18-92) a 94,7 ± 11,7 (mediana 100, rang 34-100), (p = 0,0001). La puntuació mitjana de Karlsson-Peterson preoperatòria va ser de 73,0 ± 16,0 (mediana 73, rang 7-95) i la puntuació mitjana de Karlsson-Peterson postoperatòria va ser de 93,7 ± 10,6 (mediana 97, rang 57-100) (p = 0,0001). La puntuació mitjana de l'EVA va millorar d'1,9 ± 2,5 (rang 0-7) a 0,8 ± 1,7 (rang 0-7) de l'estat preoperatori a postoperatori (p <0,001). En el seguiment final, hi va haver una pèrdua significativa de l'amplitud de moviment (ROM) en comparació amb les mesures preoperatòries de la flexió dorsal passiva [pèrdua mitjana de 2,7 °; Interval de confiança (IC) del 95% 1,5°–3,9°; p <0,05] i flexió plantar passiva (pèrdua mitjana d'1,4 °; IC del 95% 0,5 °–2,2 °; p <0,05). Trenta-cinc pacients van practicar activitats esportives abans de l'aparició dels símptomes d'inestabilitat. En el postoperatori, trenta-un pacients (89%) van tornar a l'activitat esportiva. Els pacients van informar que estaven satisfets o molt satisfets amb el procediment en 46 casos (92%). Es van observar dues complicacions importants i van consistir en dos casos amb fracàs de la reconstrucció (4%). No es van reportar complicacions neurològiques. Un pacient va patir l'eliminació de l'endobutton durant el període postoperatori. No hi va haver problemes de ferides ni infeccions relacionades amb la cirurgia.

- Conclusió:

L'estudi d'una cohort de pacients tractats per reparació artroscòpica amb augment del retinàcul (artroscòpica Broström-Gould) va demostrar que els resultats postoperatoris eren almenys equivalents a les tècniques obertes.

De la mateixa manera, els resultats postoperatoris d'una cohort de pacients tractats amb una reconstrucció endoscòpica del lligament lateral van confirmar resultats almenys equivalents a les tècniques obertes.

Aquestes conclusions estan recolzades per estudis publicats a la literatura.

9. Introduction :

1.1. Background

The ankle, or tibiotalar joint (between the tibial and talus bone) is an articulation that joins the leg and the foot. Like other joints of the lower limb, it is a supporting joint. Its normal function depends on periarticular ligaments (passive stabilisers) and muscles (dynamic stabilisers). Its uniqueness is that the joint surface is small compared to the knees or hips. It supports the weight of the body linked to human bipedalism. The pressures applied to the joint surface depend on the load and velocity of any impacts.

The most common trauma to the ankle is a sprain, affecting the periarticular structures. The evolution of sporting practices among the general population has increased the risk of sprained ankles in comparison to the risk of other injury types. Ankle sprains have long been considered as benign trauma, and the persistence of pain or a sensation of instability post-sprain has long been described as normal by general practitioners. There was no systematic treatment to face these symptoms. Patients were often told to modify or stop their sporting activity and sometimes to adapt their footwear with, for example, the wearing of ankle braces. Post-traumatic instability of the ankle could therefore lead to severe functional handicap. However, this pathology can benefit from medical and sometimes surgical treatment, which can result in significant improvements in functional recovery of the ankle.

1.2. Anatomy of the ankle

The ankle is formed by the two bones of the leg, the tibia and the fibula, which articulate with the talus bone of the foot. The ligaments are the anatomic structures that stabilise the bones while at the same time allowing their mobility. The ligaments supporting the ankle can be divided into three main groups: (i) the medial collateral ligament; (ii) the lateral collateral ligament (LCL); and (iii) the tibiofibular ligament.

Our study concerned the LCL, which is classically described as consisting of three parts: (i) the anterior talofibular ligament (ATFL), which joins the anterior edge of the fibula to the anterior part of the lateral face of the talus. This ligament is the most often damaged in an ankle sprain; (ii) the calcaneofibular ligament (CFL), which links the fibula to the calcaneus (heel bone); (iii) the posterior talofibular ligament, which joins the inferior aspect of the fibula to the posterior aspect of the lateral surface of the talus. The muscles of the ankle allow active movements of the foot and are attached to the bone by tendons.

1.2.1. Description of the lateral collateral ligaments (1)

The Anterior Talofibular ligament (Figure 1)

The ATFL is a flat and quadrilateral ligament in close contact with the capsule. He is described an intrinsic ligament reinforcing the joint capsule and composed most frequently of two bands separated by an interval that allows penetration of the vascular branches from the perforating peroneal artery and its anastomosis with the lateral malleolar artery; the upper band is larger than the lower one. The number of bands described in the literature may vary from 1 to 3.

The upper band, the ATFL's superior fascicle (ATFLsf) reaches the insertion on the fibula of the anterior tibiofibular ligament. The inferior band, ATFL's inferior fascicle (ATFLif) reaches the origin of the calcaneofibular ligament. ATFL and CFL are joined by arciform fibers at the malleolar origin. In its entirety, the ATFL originates at the anterior margin of the lateral malleolus. The center of this fibular insertion is an average 10 mm proximal to the tip of the fibula as measured along the axis of the fibula. From its origin, the ATFL runs anteromedially to the insertion points at the talus body, immediately anterior to the joint surface occupied by the lateral malleolus, consisting of two small tubercles corresponding to the insertion sites of each of the bands. The ligament is virtually horizontal to the ankle in the neutral position but inclines upward in dorsiflexion and downward in plantar flexion. The bands of this ATFL have a different behavior during the ankle movements. In plantar flexion, the inferior band of the ligament remains relaxed, while the superior band becomes tight. In dorsiflexion, the superior band remains relaxed, and the inferior band becomes tight. Since the superior band of the ATFL restricts inversion in plantarflexion, it may be the most important of the two bundles.

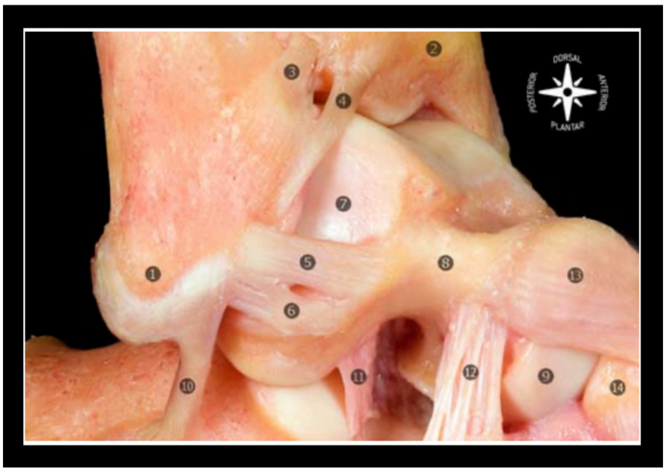

Fig.1: Osteoarticular anatomic dissection of the lateral ligament by Golano (1):

1 Tip of the lateral malleolus; 2 tibia; 3 anterior tibiofibular ligament; 4 distal fascicle of the anterior tibiofibular ligament; 5 superior band of the anterior talofibular ligament; 6 inferior band of the anterior talofibular ligament; 7 lateral articular surface of the talus; 8 neck of the talus; 9 head of the talus; 10 calcaneofibular ligament; 11 talocalcaneal interosseous ligament; 12 cervical ligament; 13 talonavicular ligament; 14 navicular

The Calcaneofibular ligament (Figure 2)

The calcaneofibular ligament is a thick, cord-like ligament that originates at the anterior edge of the lateral malleolus, right below the origin of the lower band of the ATFL. In cross-section, the ligament is rounded and has a diameter of 6–8 mm, and its length is about 20 mm. Arciform fibers connect it to the inferior ATFL band. CFL origin does not reach the tip of the malleolus, which remains free from ligamentous insertions. In the neutral position, the ligament courses backward, downward, and medially and inserts in a small tubercle in the posterior region of the lateral calcaneus, posterior to the peroneal tubercle. This ligament is superficially crossed by the peroneal tendons and sheaths, which can leave a concavity over the ligament. In addition, the CFL is separated from the subtalar joint by the lateral talocalcaneal ligament and is separated from this ligament by adipose tissue. The CFL controls two joints, the talocrural joint and the subtalar joint, unlike the other two elements comprising the LCL, which only affect the talocrural. He becomes horizontal during extension and vertical in flexion, remaining tense throughout its entire arc of motion. A valgus or varus position of the talus considerably changes the angle formed by the ligament and the longitudinal axis of the fibula. The ligament is relaxed in the valgus position and tensed in the varus position. This would explain the potential for injury even without dorsi or plantar flexion movement in the ankle. Isolated rupture of the CFL remains very rare and usually is combined with a rupture of the ATFL.

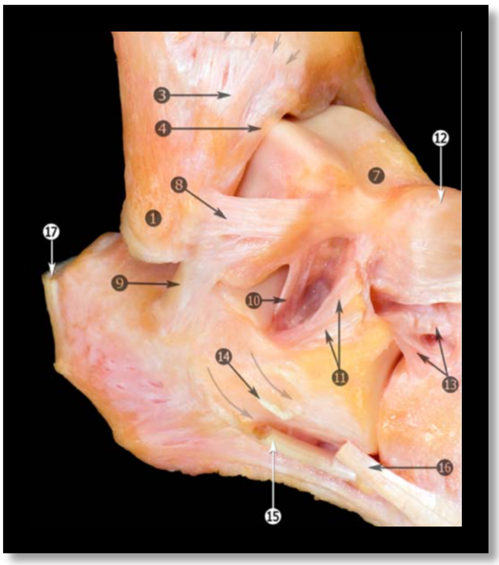

Fig.2: Anatomic dissection of the lateral region of the ankle showing the morphology and relationship of the anterior talofibular with the calcaneofibular ligaments by Golano (1).

1 Fibula and tip of the fibula; 2 tibia (anterior tubercle with arrows); 3 anterior tibiofibular ligament; 4 distal fascicle of the tibiofibular ligament; 5 interosseous membrane; 6 foramen for the perforating branch of the peroneal artery; 7 talus; 8 anterior talofibular ligament; 9 calcaneofibular ligament; 10 talocalcaneal interosseous ligament; 11 inferior extensor retinaculum (cut); 12 talonavicular ligament; 13 bifurcate ligament; 14 peroneal tubercle (arrows showing the peroneal tendons sulcus); 15 peroneus longus tendon; 16 peroneus brevis tendon; 17 calcaneal tendon.

The Posterior Talofibular ligament (Figure 3)

The posterior talofibular ligament is a strong, thick, fascicled, trapezoidal ligament in an intracapsular but extrasynovial location, found in an almost horizontal plane. It originates on the medial surface of the lateral malleolus in the malleolar fossa and courses toward the posterolateral talus. In the posterior view, the overall structure is triangular in shape, with the vertex located laterally and the base medially. The fibers of the ligament are inserted along the lateral aspect of the talus, on a rough, grooved surface situated along the posteroinferior border of the talar lateral malleolar surface. Other fibers are inserted in the posterior surface of the talus and may reach the lateral talar tubercle, trigonal process, or os trigonum by expansion. The PTFL is tight during dorsiflexion and relaxed during plantarflexion of the ankle and is usually not injured after an ankle sprain.

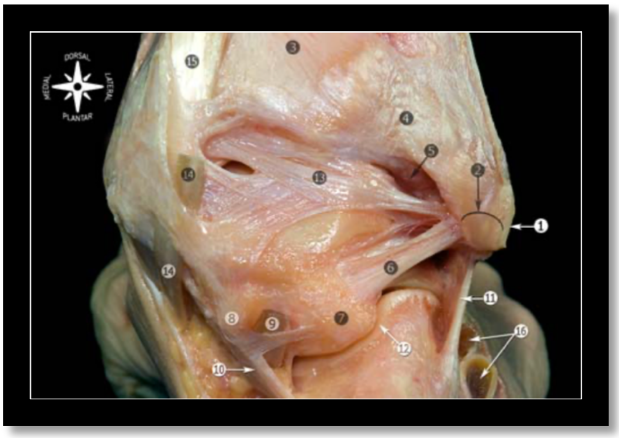

Fig.3: Posterior view of the anatomic dissection of the ankle ligaments by Golano (1).

1 Tip of the fibula; 2 peroneal groove of the fibula; 3 tibia; 4 superficial component of the posterior tibiofibular ligament; 5 deep component of the posterior tibiofibular ligament or transverse ligament; 6 posterior calcaneofibular ligament; 7 lateral talar process; 8 medial talar process; 9 tunnel for flexor hallucis longus tendon; 10 flexor hallucis longus retinaculum; 11 calcaneofibular ligament; 12 subtalar joint; 13 posterior intermalleolar ligament; 14 flexor digitorum longus tendon (cut); 15 tibialis posterior tendon; 16 peroneal tendons.

1.2.2. Evolution of anatomic knowledge

Recent anatomic studies have shown that this description should be revised. Dalmau-Pastor et al. (2) and Araujo Nunes et al. (3) demonstrated that connections exist between the different fascicles of the LCL on their medial surfaces with a common insertion (Figure 4).

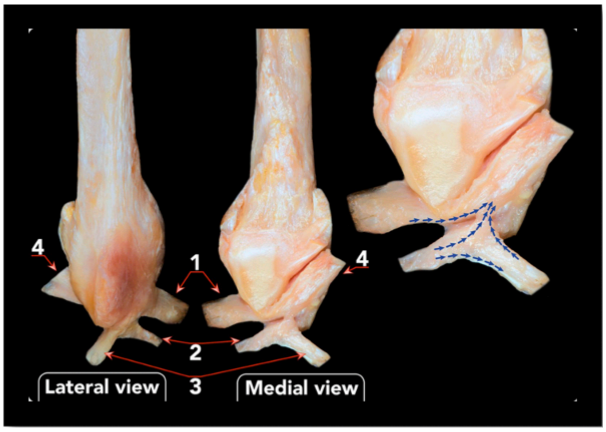

Fig.4: Lateral and medial view of the fibular malleolus in a specimen with ATFLsf, ATFLif, CFL and PTFL connections by Dalmau Pastor (2).

(1) ATFLsf. (2) ATFLif. (3) CFL. (4) PTFL

Vega et al. (4) reported that the superior fascicle of the ATFL is a distinct intra-articular anatomic structure. As explained in the article, if data from other intra-articular ligaments is extrapolated, ATFL's superior fascicle would not be able to heal when injured because intra-articular ligaments do not heal by themselves. This study also confirmed that the inferior fascicle of the ATFL has a common origin with the CFL on the fibula and that they are connected by "arciform" fibres. This lateral fibulotalocalcaneal ligament complex (LFTCL) forms an isometric functional unit (Figure 5).

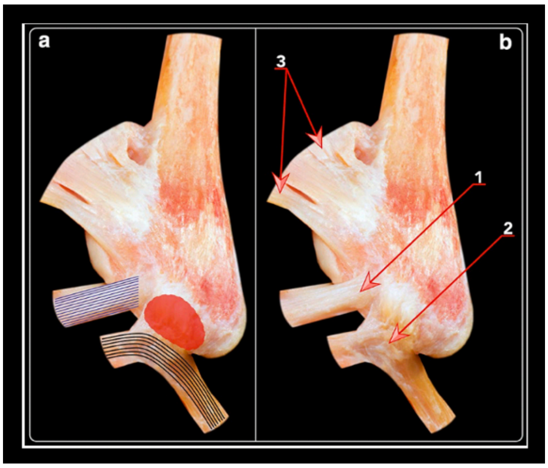

Fig.5: Schematic view of the LFTCL complex with the lateral malleolus disarticulated from the ankle by Vega (4).

a View with the lateral ankle ligaments highlighted: ATFL superior fascicle (blue lines), LFTCL com- plex (black lines) and area showing the common origin of the LFTCL complex (red area). **b** Classic view of the LFTCL complex. (1) ATFL superior fascicle. (2) LFTCL complex. (3) Anterior tibiofibular ligament and distal fascicle.

Finally, in a previous research not included in this PhD Thesis, Cordier et al. (5) demonstrated that the common arciform fibres between the inferior ATFL and CFL can transmit a mechanical force between these structures. The improvement in our knowledge of the LCL has a direct impact on our understanding of the mechanisms of damage and consequently on their management. Adaptation of the surgical technique is also based on these data.

1.2.3. Biomechanics of the ankle

Knowledge of the biomechanical factors involved in stability of the ankle is crucial to the clinician. Stability is not restricted to the role of ligaments. Not taking other factors into account could result in the failure of treatment of chronic ankle instability (CAI).

The stabilisers of the ankle can be classified into two categories: passive stabilisers and active stabilisers.

1.2.3.1. Passive stabilisers

The bones

The bony anatomy of the tibiofibular syndesmosis and the talus is a key-factor in stability. In the sagittal plane, primary stability is supported by the convex aspect of the talus on a concave tibial surface. In the horizonal plane, there is a posterior convergence of the two malleoli allowing the posterior attachment of the talus, with the posterior malleolus reinforcing this stability. The two malleoli stabilise the talus in the frontal plane. Uchiyama et al. (6) demonstrated the importance of the length of the lateral malleolus in stabilisation during inversion movements. All acquired or congenital abnormalities of this bony site should be identified and taken into account.

The ligaments and joint capsule

From a general point of view, the joint capsule and ligaments of the ankle have a similar role as passive stabilisers. They orientate movement and protect against excess mobility when they are put under stress. They also have a major proprioceptive role.

The ligaments are composed of an extracellular matrix contained mainly type I collagen fibres in which the fibroblasts are embedded. In contrast to the tendons, the collagens fibres follow the same direction, but are not strictly parallel in orientation. This characteristic enables the ligaments to be subjected to traction forces in one main direction, but also to lesser traction forces in secondary directions. Cooper (7) and Misol (8) described the attachment of the extra-articular ligaments onto bone through four zones (Figure 6).

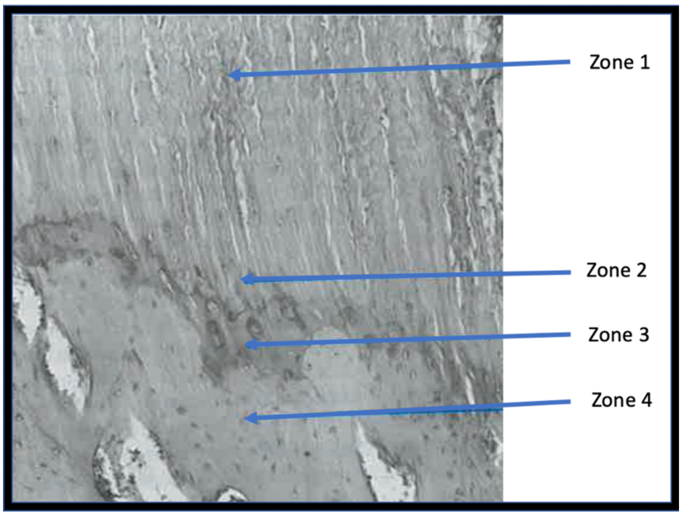

Fig. 6: Histology of the ligament insertion (*25000) by Misol (8)

Zone 1 consists of collagen fibres. Zone 2 is composed of non-mineralised fibrocartilage and Zone 3 of mineralised fibrocartilage. Zone 4 is made up of cortical bone. The four zones evolve progressively from a ligamentous structure to a bony structure, allowing the progressive absorption of stress. The aim of repair is to recreate this enthesis.

In addition to their mechanical action, the ligaments have a role as proprioceptor and nociceptor messengers, which is important for good functioning of the ankle. Three types of mechanoreceptors have been found in all ligaments of the ankle (Ruffini, Pacini and Golgi) as well as free nerve endings (9).

1.2.3.2. *Active stabilisers*

The short and long peroneal muscles are the main ankle evertor muscles, they oppose inversion movements. Karlson (10) demonstrated the increased reaction time of the fibularis muscles in patients with chronic lateral ankle instability (CLAI) (11). Rehabilitation of the fibularis muscles by strengthening, as well as neuromuscular reprogramming, has been shown to be effective as first-line treatment. The other factor of instability to investigate is a static varus alignment of the hindfoot during monopedal support. It lateralises the centre of gravity facilitating supination of the ankle. This puts the CFL under tension, as well as the fibularis muscles, and favours ankle instability. A wedged plantar insole is the first-line treatment. In the case of failure, a calcaneal osteotomy will correct this static problem and its consequences. Hindfoot varus may also be associated with hindfoot equinus. The Silfverskiöld test (12) can differentiate isolated tightness of the gastrocnemius from a short Achilles tendon. Correction of this tightness is an important step in treatment. The sub-talar joint can also be the site of instability, either isolated or associated with talocrural instability. Testing of this joint is difficult however and remains unreliable and unreproducible except in the case of major laxity.

From normal biomechanics to rupture:

Inman (13) compared the biomechanics of the ankle with those of the knee. According to this author, the ATFL is a stabiliser of internal rotation like the anterior cruciate ligament, the centre of rotation being localised at the level of the internal malleolus and the deltoid ligament. This hypothesis was verified by Caputo et al. (14), who demonstrated, in an *in vivo* study, that during loading of an ankle with a ruptured ATFL, at 100% body weight, there is an anterior translation of the talus of 0.9 ± 0.5 mm and an internal rotation of 5.7 ± 3.6°. These studies support the idea of rotary instability of the ankle secondary to certain lesions of the lateral ligament complex.

This instability, when it is chronic, is the cause of intra-articular lesions. Ferkel and Chams (15) found 93% intra-articular lesions 25 months after a first episode of instability, ranging from synovitis to chondral lesions with the presence of free osteochondral fragments. Bichof et al. (16) demonstrated, in an *in vivo* biomechanical study with 3D solid modelling, an antero-medial translation of cartilage strain, as well as an average 8% increase in peak strain when subjected to a full load (Figure 7).

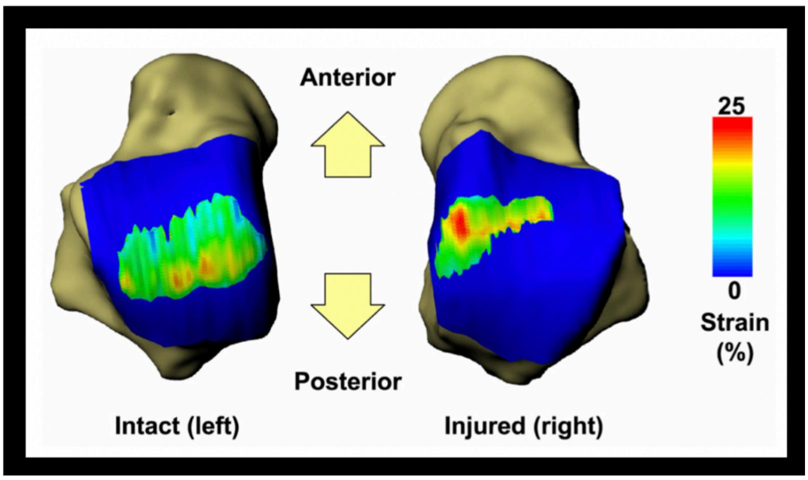

Fig. 7: Bichof modelling of talar stresses under load (16).

1.3. Concept of a sprained ankle

1.3.1. Clinical evaluation during an acute lateral ankle sprain is an important challenge for the clinician:

The International Society of Biomechanics has described a classification of acute extra-articular ligament lesions based on the biomechanical competences of the ligaments (Figure 8). 3 stages have been described (17):

- Stage 1: Benign sprain with elastic deformation
- Stage 2: Sprain of intermediate severity with plastic deformation
- Stage 3: Severe sprain with full body rupture

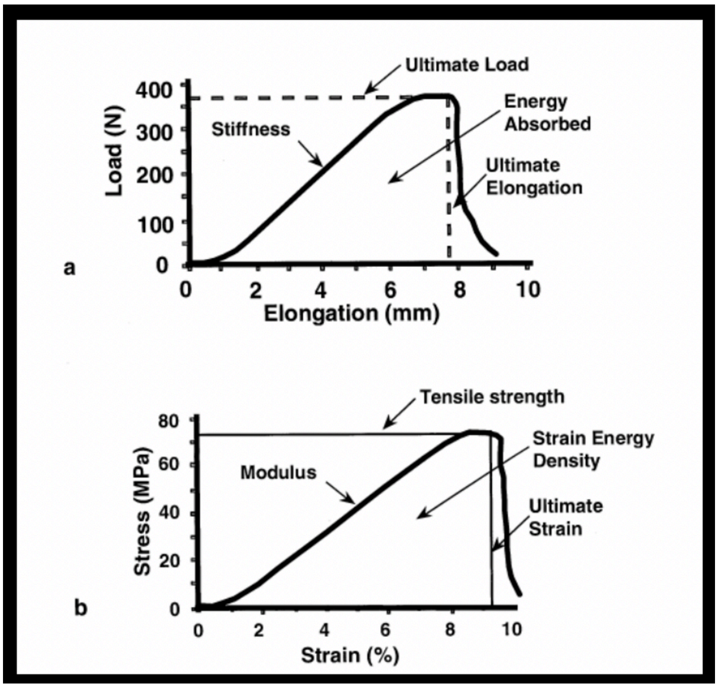

Fig. 8: Typical load-elongation curve a bone-ligament-bone complex (a) and typical stress-strain curve (b) describing the mechanical properties of the ligament substance from Woo (17).

Van dijk et al. (18) showed that a delay of 2–5 days is necessary to carry out a reliable clinical examination of a traumatised ankle. This examination allows the number of damaged structures to be counted as well as the severity of the damage. The demonstration of an anterior drawer allows the diagnosis of a stage 3 sprain of the ATFL with a sensitivity of 73% and a specificity of 97%. The presence of a talar tilt points towards a lesion of the CFL.

Associated lesions:

It is important that concomitant lesions are not overlooked, and this will have an impact on the functional prognosis of the ankle at medium-term. Around 25% of sprains also have an acute lesion of the tibiofibular syndesmosis (19). Pain on palpation, a positive squeeze test or a Cotton test may orientate the diagnosis. Although the main mechanism of acute luxation of the fibular tendons is eversion (20), some authors have described luxation during an inversion movement associated with a brutal contraction of the tibialis muscles (21). An acute tear of the fibularis tendons can also occur during inversion (22). It is necessary to diagnose and treat these lesions because they can become chronic. Ankle inversion can cause various fractures (malleolus, base of the fifth metatarsal, navicular), which can be detected on clinical examination by applying the Ottawa criteria (23). Finally, a type F osteochondral lesion of the talus should be diagnosed according to the FOG classification because large fragments could be released (24, 25).

Prognostic factors for progression to chronic instability

Approximately 20% of acute ligament lesions of the lateral compartment of the ankle progress to chronic instability, which is resistant to medical treatment and leads to repeated sprains (23, 24, 25). Factors favouring CAI have been identified. The literature is not clear-cut on this subject, with recent reviews demonstrating a lack of proof requiring new investigations (26, 27). However, some mechanical factors are frequently found:

- Practice of sport more than 3 times a week (28).
- Varum or varus alignment of the hindfoot with the knee (29).
- An intra-articular foreign body (30).
- A deficit of dorsal flexion of the ankle (short gastrocnemius, anterior conflict of the ankle) (31).

The search for these factors is an important step in the diagnostic process because certain intrinsic and extrinsic factors can be corrected.

Long-term challenges:

Long-term, the natural history of an acute ankle sprain can result in major functional handicap in the absence of appropriate treatment. A first sprain can result in functional and/or mechanical instability leading to recurrences. These repeated sprains can lead to CAI that is deleterious to the chondral talocrural complex. The final stage of the pathology consists of disabling talocrural arthritis with varus deformity due to lateral ligament insufficiency (Figure 9). The incidence varies from 25–95% in patients with CAI (28, 47, 48) depending on the study. Treatment of this arthritis usually requires sacrifice of the joint by arthrodesis.

Fig.9: Talocrural arthritis post CAI (original figure).

Furthermore, ATFL lesion causes an anterior translation of the talus. Translation is probably the cause of dynamic anterolateral conflict with the consequence of painful synovitis. This idea questions the idea of primary anterolateral tissue conflict proposed by Molinier et al. (32) and supports the concept of micro-instability (33). Also, a partial lesion of the deltoid ligament (DL) can also be found in 40% of patients (34). Vega et al. (35) developed the concept of rotary instability of the ankle in this context and proposed the concomitant repair of the ATFL and DL.

1.3.2. Mechanisms

Even though our understanding of the anatomy of the lateral plane is evolving, different bundles of the LCL are damaged with different traumatic elements.

Damage to the ATFL, and most likely the superior fascicles of the ATFL (tension in plantar flexion, little resistant), is associated with a mechanism in plantar flexion with a component of varus and supination resulting in inversion. ATFLsf plays an important role in limiting anterior displacement of the talus and plantar flexion of the ankle. Because most ankle injuries occur by inversion with the foot in plantar flexion, the ATFL is the most vulnerable to injuries. Injury of his superior band is always present after an inversion ankle sprain. Although an injury to the ATFL may not be severe enough to cause a major instability, a partial lesion affecting the superior band may cause symptoms dominated by chronic pain and not ankle instability resulting in a minor instability or microinstability of the ankle. This partial injury of the ATFL is not severe enough to cause an instability detected in stress explorations. However, these patients describe complaints similar to those to the ankle instability. A complete or nearly complete injury of the ATFL results in a major instability.

If the constraint in varus is greater, the lesion will extend towards the calcaneofibular ligament, an adduction stabilizer, also affecting the lateral fibulotalocalcaneal complex. The degree of ligament damage will be dependent on the energy of the trauma. More rarely, a mechanism of internal rotation will lead to a lesion of the ATFL while a mechanism of pure varus will result in damage to the CFL. Understanding the mechanism of the sprain is essential to orientate the diagnosis and eliminate differential diagnoses. Thus, the mechanism of the lesion of the medial ligament will be forced valgus whereas the distant tibiofibular syndesmosis will be damaged in dorsal flexion and lateral rotation.

1.3.3. Lesions associated with an acute sprain

Several entities can be damaged at the same time as the lateral ligament:

- Lesions of the tendons:

Luxation of the fibular tendons by rupture of the superior retinaculum is often underdiagnosed at the acute stage. It represents 1% of all ankle traumas. Acute orthopaedic treatment can be discussed in a person who does not play sport, but surgical treatment is often necessary in active patients. The risk of non-surgical treatment is relapse (mean rate of 50%). Any delay in management is associated with a poor functional prognosis.

- Lesions of the cartilage:

Osteochondral lesions of the talus are found in 6% of sprains in the lateral plane, but represent 80% of painful ankles long-term (6). Post-traumatic osteochondral lesions of the talus will be located primarily in the supero-lateral zone and increase morbidity considerably. It is important to look for these lesions via a paraclinical examination during a severe sprain (radiography and/or Arthro-CT).

- Lesions of the ligaments:

Multi-ligament damage with associated lesions of the medial plane, the distal tibiofibular syndesmosis, the sub-talar joint or the midfoot is an aggravating factor.

- Lesions of the bones:

Bimalleolar fractures or fractures of the tibial plafond are serious injuries, notably in the case of joint shear, with a poor functional prognosis long-term. In view of the diversity of this injury, specialist advice is necessary to discuss the indications for surgery. Fractures of the base of the fifth metatarsal are also frequently associated with lateral sprains of the ankle.

1.4. Statistical data for ankle sprains

1.4.1. Epidemiology

In the USA, Herzog et al. (36) and Waterman et al. (37) found an incidence of ankle sprains in the general population of 2.5–7 /1000 persons per year with the number of acute lateral sprains estimated at 2 million per year. In the UK, Cooke et al. estimated that there were around 5600 acute sprains daily (38).

In sports players, a meta-analysis of 181 studies showed an incidence of 0.93 per elite athlete exposure (corresponding to the involvement of an athlete in a competition) (39). Lateral sprains are also frequent among military personnel, with an incidence of 58.4/1000 at the American Military Academy, with a sex ratio of 1.83 in favour of a significantly higher incidence among women (40).

The risk of recurrence after a lateral ankle sprain is high (41, 42). After 1-year, a systematic review of 31 studies reported that 34% of patients had at least one repeat sprain (43). Herzog et al. (36) found a rate of recurrence of lateral sprains of 12–47% in their literature review carried out on six studies on the epidemiology of ankle sprains. More than 9% of professional football players had a repeat lateral ankle sprain during the same season and 34% in 3 years.

1.4.2. Economic impact

Treatment of ankle sprains is a worldwide public health problem. Management of the initial sprain is no longer consensual. The cost of treatment of sprains represents a considerable expense to the public health system, which varies from one country to another. The global cost comprises the initial medical treatment but also the indirect costs such as days absent from work. In the USA, the direct cost linked to a lateral sprain is estimated as 1008$ (44).
The indirect cost linked to the loss of productivity is much more significant but is not often considered by the healthcare system. In the Netherlands, this cost is estimated as 35.88 million$ per 520 000 sprains annually (45). The average length of absence from work is around 2.5 weeks. (46)

1.5. Treatment of a first ankle sprain

The treatment of a lateral ankle sprain has two objectives: (i) to treat the pain; and (ii) to obtain healing of the lesions (47 - 51). The first priority immediately following a sprain is to reduce the inflammatory reaction with the use of ice (D0-D5) (52). Initial treatment follows the RICE (Rest, Ice, Compression, Elevation) protocol, which was modified as PRICE (Protection, Rest, Ice, Compression, Elevation) and then POLICE (Protection, Optimal loading, Ice, Compression, Elevation). All have the same aim, compression with the application of cold and overelevation of the lower leg. Clinical re-evaluation is advised around D5. The objective from hereon is healing of the lesions. The treatment proposed on D5 will be different depending on the severity of the sprain. The absence of consensus to define a “severe” sprain makes this evaluation difficult. Once the period of immobilisation is over, physiotherapy should be proposed systematically with three major aims: (i) to combat residual pain; (ii) to recover passive and active joint range; and (iii) to carry out proprioceptive work for all of the lower limb (53).

The value of physiotherapy has been demonstrated with literature supporting it to prevent the recurrence of lesions in the lateral ligament plane. The exercises carried out should fulfil the objectives cited above, adapted to the experience of the physiotherapist.

i. Immobilisation and rest

The literature is very heterogeneous on the type of immobilisation to adopt, ranging from functional treatment without immobilisation to a boot or cast for 6 weeks. A consensus has emerged around immobilisation day and night with a brace with lateral reinforcements (Figure 10a) or a boot (Figure 10b) for a short duration (around 10 days) with possible support from two crutches (54-56). Concerning this immobilisation, removal may be complete or progressive. It should be adapted to the clinical condition of the patient and may be prolonged if the symptoms cause functional weakness.

Figure 10: type of immobilisation (original figure).

ii. Physiotherapy

The role of physiotherapy is to limit recurrences and to permit the patient to return to his/her activity in the best condition. Early physiotherapy is strongly indicated after a sprain (57). It can be started immediately after the trauma has been evaluated, at 2–3 sessions per week. The main aim is to decrease the immediate consequences of the sprain: stiffness, pain, muscle inhibition and post-traumatic bruising.

Individualisation of physiotherapy for each patient is necessary in order to best target the deficits occurring after a sprain, as recommended in the International Consensus on Lateral Ankle Sprains in 2018 (Rehabilitation-Oriented-ASsessmenT or ROAST) (58). Initially, an evaluation of any deficits using clinical tests will help the physiotherapist to act precisely. The deficits could be situated in the joint (usually a deficit in dorsal flexion under load and/or in inversion which could be risk factors for CAI), at the muscular level with a strength deficit and of reactivity to activation of the fibularis muscles (Figures 11a and 11b), or they could involve proprioception. The latter is represented by the difficulty in perceiving the position of the ankle in space (statesthesia) and/or moving the ankle in space (kinesthesia). The overall level of static and dynamic postural balance should also be evaluated and treated. During the following phase, the physiotherapist is focussed on functional activities in agreement with the demands of the patient (59). These are evaluated as a function of the advancements made after physiotherapy in the other domains and should demonstrate any difficulties in performing jumps or changes in direction, which are essential requirements for all sporting activities. The neurocognitive deficits associated with injuries to the leg have also been studied (Figure 11c). Deafferentation along the length of the cortico-motor chain long-term can modify preventative motor responses and lead to the risk of recurrence. Exercises consist of deviating the attention of the patient from their ankle when faced with exterior stimuli, to reproduce conditions in the field during sport activity.

An early return to sport after a first sprain is a risk factor for recurrence and should be guided (60-65). Running can be started 2 months after the trauma, but should be adapted depending on the recovery from any deficits. The return to sport practiced by the patients should be done progressively in three phases over 3 months: (i) a phase of participation with adapted training; (i) a phase of return to sport without competition; and (iii) a final phase of a higher level of practice. The objective is to progressively increase the tolerance of the tissues to the loads demanded during competition. Apprehension and kinesiophobia are also important elements to evaluate before returning to sport. Validated questionnaires are available for this (FAAM, ALR-RSI) (60,66).

Fig. 11a (original figure).

Strengthening of the fibularis under load

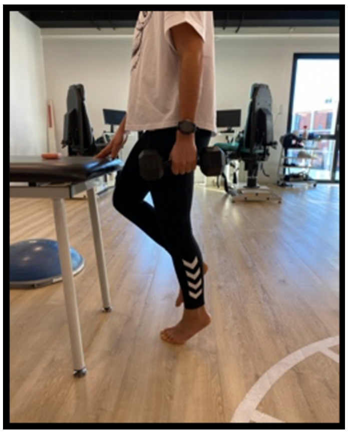

Fig. 11b (original figure).

Strengthening of the gastrocnemius

Fig. 11c (original figure).

Balance work with neurocognitive exercises

iii. Associated actions:

Medical treatment also includes the management of risk factors: hindfoot varus should benefit from orthopaedic insoles with a wedge or heel ring. Long-term, the patients should stretch the short posterior chain muscles during self-rehabilitation using stretching type exercises.

1.6. Recurrence and chronic instability

Despite progress in physiotherapy, clinicians continue to be faced with patients who have failed rehabilitation. These patients present with several types of clinical picture.

During an initial period, probably from 10–20 years, individuals will present with repeated sprains. This is due to CLAI. Sometimes this instability may express as a painful syndrome on the lateral side of the ankle. The risk, in the case of failure of medical treatment during this period, is recurrence of a sprain. Each recurrence leads to a risk of associated lesions of which the main ones are: osteochondral lesions of the talus, lesions of the medial ligaments and/or lesions of the retinacula with secondary tendon instability. Despite progress in their treatment, all of these lesions can lead to functional sequalae, short-, medium- or long-term.

A second period of appearance of symptoms linked to ligament lesions can also be described. These lesions cause abnormal biomechanical functioning of the ankle joint, a source of early osteoarthritis on the joint surfaces. Tibiotalar arthropathy or arthrosis of the ankle will occur due to a decrease in joint cartilage. Joint hypermobility, or laxity, will also result in the production of bone spurs known as osteophytes. During movements, these bone spurs will cause lesions of the tissues surrounding the joint and cause painful inflammation and sometimes loss of mobility. Mechanical insufficiency of the lateral ligaments will also lead to significant stress on the lateral muscles of the ankle. The fibular tendons will, with time, deteriorate to tendinopathy. This may be accompanied by fissure syndrome leading, sometimes, to tendon rupture.

These lesions, secondary to CLAI do not, in the majority of cases, benefit from conservative treatment. They will be a source of handicap with more or less severe functional limitation depending on their severity.

1.6.1. Definition of instability

CAI in a patient is generally defined by repeated episodes of lateral sprains. However, this is a restrictive definition since chronic instability can manifest with different symptoms:

- Recurrent sprains are an objective manifestation which can be quantified. However, there is no consensus on the number of sprains a patient needs to suffer to indicate a diagnosis of chronic instability. It should probably be considered that a patient who has a first episode of sprain recurrence has CAI; the question is to know whether conservative treatment has failed in order to decide on the best therapeutic management. Often, during questioning in a medical consultation, the patient does not mention these repeated sprains; they are perceived by the patients as a normal and non-pathological evolution of their ankle. The clinician should be precise when questioning the patient on this point.
- Lateral ankle pain can also be a symptom of chronic instability. Lateral ligament insufficiency causes synovitis of the lateral joint capsule responsible for pain. In addition, overstressing the fibular tendons, which are dynamic lateral stabilisers of the ankle, can lead to tendinopathy, a source of pain, by excess mechanical restraint. These patients do not systematically feel that they have instability of their ankle.

Growing interest in this pathology and the improvements in our understanding of CLAI have allowed the progressive classification of ankle instability:

- Lateral macro-instability of the ankle, objective instability, corresponds to repeated lateral sprains.

- Micro-instability of the ankle, corresponds to patients with lateral pain, who might or might not feel instability, and without objective findings of instability in clinical examination.

In addition, lateral ankle instability will lead progressively to other ligament lesions on the medial side on the joint. These have been described by Vega et al. under the name "open book lesions". This name is linked to the fact that these lesions are caused by detachment of the ligament from its insertion into the malleolus bone (35).

1.6.2. Complications of instability and associated lesions

In around 93% of cases, an intra-articular lesion is found in patients with CLAI (16). Some of these lesions, such as intra-articular foreign bodies, can favour instability, while other lesions such as osteochondral lesions are the cause of pain. The diagnosis and treatment of these lesions associated with ligament instability are essential for the success of ligament repair.

- Several types of chondral or osteochondral lesions can be found: cartilaginous flaps, degenerative chondral lesions linked to asymmetric functioning of the mortise, osteochondral lesions of the talus (67).
- Tibiotalar osteophytes can lead to compression of the soft tissue, the cause of pain in the context of bone conflict.
- Chronic tibiofibular instability can be linked to decompensation of acute ligament lesions of the syndesmosis.
- A lesion of the ATFL causes anterior translation of the talus. Recently, Dalmau demonstrated in a robotic study, that only the section of the inferior fascicle of the ATFL leads to excessive internal rotation of the talus (68). This translation is probably the cause of dynamic anterolateral conflict leading to painful synovitis. This idea questions the concept of primary tissue anterolateral conflict by Molinier (32) and supports the concept of micro-instability (33).
- A partial lesion of the deltoid ligament (DL) can also be found in 40% of patients (34). Vega et al. (35) developed the concept of rotary instability of the ankle in this context and proposed concomitant repair of the ATFL and DL.

1.7. Conservative treatment of chronic instability of the ankle

1.7.1. Basis of medical treatment

Despite the improvements in management, CAI is common following a first severe ankle sprain (69). The long-term consequences of this chronic instability no longer need to be demonstrated, with the appearance of talocrural cartilaginous lesions, responsible for a poor long-term functional prognosis. This instability develops progressively, often in relation to various parameters: rehabilitation that is not adapted to the activities of patient, under-estimation of the recovery time by the patients, who only have the criterion of pain to estimate recovery of the ankle.

The consequences of instability are two-fold: there are physical consequences concerning the somato-sensory system, with an increase in proprioceptive problems, but also neuro-motor consequences, which are related to problems with activation of the stabilising muscles of the ankle and intrinsic muscles of the foot. This increases a person's visual dependence to carry out motor tasks.

The biomechanical consequences during functional tasks are also important in patients with CAI, notably the lack of dorsal flexion of the ankle during landing jumps and/or significant stiffness of the knee in flexion. This decreases the efficacy of protective strategies of the ankle during at risk situations and can contribute to chronic instability (70,71). There are also psychological consequences, with a loss of confidence and a reduction in physical activity due to the fear of a new episode of instability.

Medical treatment is considered to have failed if there are frequent recurrences of instability, with the aggravating factor of associated lesions, notably cartilaginous, responsible for pain.

i. Immobilisation and rest

There is no recommendation on the type of immobilisation to perform during repeated instability. This could be strict immobilisation if the ligament damage is more serious than in previous episodes. This requires the availability of reliable imaging techniques. Immediately after this new episode, the wearing of an ankle brace (supple or rigid) may help with proprioception. This is not obligatory but can be proposed if the patient feels it is necessary.

ii. Physiotherapy

A large variety of stimulation and repetition exercises should be performed. This is related to the type of physical activities practiced by the patient. Self-rehabilitation is important in order to have good long-term joint health.

iii. Associated actions

Naturally, medical treatment should treat associated lesions, notably cartilaginous. In the case of intra-articular effusion or pain, a corticosteroid injection should be proposed to decrease pain and make physiotherapy possible. The role of visco-supplementation and concentrated platelets (platelet rich plasma; PRP) is open to debate for cartilaginous lesions. A recent literature review found encouraging results for PRP; results that need to be confirmed in a therapeutic trial (72). The treatment of factors favouring instability is also necessary. The axis of the hindfoot should be studied and treated in the case of calcaneal varus. This could be corrected by wearing wedged orthopaedic insoles.

1.7.2. Concept of failure of medical treatment

It is impossible to define the failure of medical treatment in a consensual way; according to the point of view of the clinician, medical treatment should allow the patient to recover a painless ankle, stable (during the practice of activities on uneven ground or requiring the execution of movements likely to cause a sprain), and which do not result in a swelling, including after efforts (that is the sign of articular disorders). The patient will thus recover a normal ankle functionally. The persistence of one of the previous symptoms or inability to resume an activity is synonymous with the failure of medical treatment.

What happens in the case of recurrence of an ankle sprain? If this new sprain occurs after a period of normal functioning of the ankle, this recurrence can be considered as an "equivalent primary episode" and further medical treatment can be envisaged. However, the discussion between the patient and the doctor should determine the subsequent functional risk. This will depend on many factors (age, professional activity, sports practices) and the lesions of the ankle (ligament lesions and "associated lesions" to other anatomic structures). If there is a risk of recurrence, surgical management should be discussed with the patient. Besides the reestablishment of normal ankle function, surgery is the best treatment to prevent arthritic degeneration of the tibiotalar joint. To date, there is no 'number' of sprains that can be stablished as a minimum to define the failure of medical treatment.

1.8. Surgical treatment of instability

1.8.1. Historical

More than a hundred procedures have been described for the surgical treatment of ankle instability, demonstrating the absence of a technical consensus. Their objective is similar: to stabilise the ankle. In short- and medium-term series, they give between 80 and 95% good and very good results. Long-term results in terms of stability and assessment of joint impact are few. The risks of this surgery are mainly cutaneous, in case of extensive subcutaneous tissue detachments, and neurological, which may lead to sensitive lesions. These techniques can be grouped into different categories.

- Ligaments repair: this preserves joint mobility. Initially described by Broström in 1966 who performed suturing of the LTFA and LCF (73). This technique was later modified to shorten ligaments that are often distended after a sprain. The ligament suture is then replaced by bone reinsertion in the fibular malleolus. These techniques have shown their limitations, as they cannot be used in cases of poor quality ligament reattachment or associated subtalar instability.
- Ligaments repair with augmentation: This could be a periosteal flap or the use of the inferior extensor retinaculum proposed by Gould (74). This addition limits ankle inversion and stabilizes the tibiotalar and subtalar joints. Other surgeons even used the retinaculum to create a neo ligament. The use of additional reinforcement was therefore the norm.
- Anatomic ligamentoplasty: in some cases, like severe laxity indication could be a ligamentoplasty, and therefore use a tendon graft. A wide range of tendons can be used for the graft: plantaris, peroneal (including peroneus tertius), gracilis, Achilles, etc and allograft. The transplant is fixed by transosseous tunnels in the lateral malleolus, talus and calcaneus. Depending on the technique, different options are used to reconstruct 1 or 2 bundles for the LTFA and LCF, and sometimes a subtalar joint ligament.
- Non anatomic lateral tenodesis: they mainly use the peroneus brevis tendon, either totally or partially, to stabilize the ankle.

For many years, the surgical procedures were invasive with limited functional results and did not allow the treatment of associated osteoarticular lesions. Some techniques using a lateral stabiliser muscle of the ankle as a tendon graft decreased the postoperative capacity of the joint. Surgery was therefore reserved for the most severe cases. It was often practised as a last resort to treat a severe handicap, which made the benefit/risk ratio favour surgery. Given the delay between the start of instability and surgery, most patients also had important concomitant lesions. Patients with CLAI without a major functional impact on their daily life were not treated.

1.8.2. Gold standard and open techniques

To date, conventional open surgery, with a large skin incision, remains the reference technique for surgical treatment.

The most widely used technique is that described by Broström and modified by Gould to strengthen mechanical solidity. It consists of ligament repair where the ATFL and CFL are reattached to the lateral malleolus. This reattachment is strengthened by fixation of the extensors on the retinacula, thickened areas of crural fascia.

The other reference technique is ligament reconstruction. As described by Takao et al. (75) in 2004, the surgeon uses a tendon graft to replace the LCL. The technique requires the boring of tunnels at the zones of insertion of the ligaments to the talus, fibula and calcaneus. The graft will then be fixed in these tunnels to recreate the anterior and median bundles of the LCL.

1.8.3. Indications

The indication for surgical treatment depends on the failure of medical treatment. There has been no recommendation from learned societies to propose a surgical procedure during a first isolated lateral sprain in the acute phase.

1.8.4. Advantages of anatomic techniques

The literature has shown that the surgical techniques used should be anatomic. This signifies that the surgery should reflect or recreate a normal anatomy to respect the physiological biomechanics of the joint. Non-anatomic techniques, principally lateral tenodesis, carry the risk of articular hyper pressure with, as a result, secondary arthropathy of the subtalar and /or tibiotalar joints (76-79). Another complication is the limitation of joint range. In their review of the literature, Vuurberg et al. (80) found that anatomic techniques, that is to say techniques that repair or reconstruct the LCL by conserving the anatomy, resulted in better postoperative clinical scores. Mabit et al. (81) were the first to compare anatomic repair techniques with non-anatomic reconstruction techniques. They demonstrated better short-term results for the anatomic techniques. Other studies have reported similar results (82-85).

1.8.5. Advantages of arthroscopic techniques

The ankle has not always been a classic site for arthroscopy. Indeed, in 1931 Burman considered this joint "unsuitable for arthroscopy", because of its anatomy. In 1939, Takagi was the first to describe a systematic technique for ankle arthroscopy. In the 1970s, the first publications popularising these techniques appeared. Van Dijk modernised these techniques at the end of the 1990s by describing the approach of the posterior arthroscopy and questioning the systematic use of distraction in anterior ankle arthroscopy. The use of distraction is associated with greater co-morbidity and may be a limit to the performance of certain procedures, such as the treatment of ligament injuries. At the same time, endoscopy techniques have been developed and are now used in the treatment of lateral ankle instability and associated injuries. Arthroscopy has been a major development in ankle surgery over the past 10 years. Faced with the therapeutic impasse due to the link between secondary lesions and ankle instability, surgeons have progressively combined arthroscopy with conventional ligament surgery. Arthroscopy is a technique that uses a camera to visualise the interior of the joint. It enables an evaluation of the joint but also the treatment of some coexisting lesions. Initially, arthroscopy was followed by a second open surgery to repair the ligaments. The aim was to treat the ligament lesions and any associated lesions. Some surgeons initially used arthroscopy as an operative assistant to control the gesture of ligament repair which was done using a mini-invasive technique. Ankle arthroscopy has developed progressively, leading to renewed interest in it for dedicated scientific studies. Specific anatomic studies allowed a better understanding of the articular structures. Over the years, this progress has allowed a better understanding of the physiopathology of lateral instability, but also the precise identification of the ligament structures concerned. Thus, it was progressively possible to treat all the associated lesions by arthroscopy, but also to treat the ligament lesions. These techniques, allowing complete arthroscopic repair to have been developed over the past 10 years or so and are improving following their evaluation medium- and long-term.

There are many advantages of arthroscopy; to date, the complementary examinations of imaging are not sufficiently precise to evaluate ligament lesions and associated lesions completely. During assessment of the joint, arthroscopy allows confirmation or correction of the conclusions of imaging. Above all, it enables less invasive surgical procedures to be carried out and therefore decreases the risk of postoperative complications. The risk of sepsis and cutaneous complications is particularly low after arthroscopy. Arthroscopy also has advantages compared to percutaneous surgery: it enables each step of the intervention to be controlled visually. It improves the positioning of the medical devices used to repair the ligaments and bone tunnels made during ligament reconstruction by allowing better visualisation of the zones of ligament insertion. Finally, arthroscopy results in fewer lesions to the peripheral tissues. The literature also shows that recovery is quicker after arthroscopic surgery (86).

Future

Henceforth, ankle surgeons should be able to carry out arthroscopic anatomic ligament surgery. The arthroscopic techniques used enable equivalent gestures to be carried out to those performed during open surgery while benefiting from the advantages of arthroscopy. With time, new generations of surgeons will use arthroscopic techniques routinely. Until then, the indications for arthroscopic surgery should be identified clearly and the results validated by comparing them with reference open surgery techniques.

10. Hypothesis :

Arthroscopic ankle lateral instability treatments are safe and give equivalent or better results than open surgery treatment.

11. Objectives :

This thesis will study the postoperative results with a minimum follow-up of two years of cohort of patients who have benefited from arthroscopic techniques to treat ankle lateral instability. As two main procedures exists (repair and reconstruction), these thesis objectives are to assess both. therefore, the objectives are:

1. to study the postoperative result of a cohort of patient treated by arthroscopic repair with retinaculum augmentation (Broström- Gould arthroscopic).
2. to study the postoperative result of a cohort of patient treated by an endoscopic lateral ligament reconstruction.
3. to compare the obtained data with the published literature for both techniques.

12. Material, methods, and results

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Knee Surgery, Sports Traumatology, Arthroscopy
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ANKLE

Arthroscopic ankle lateral ligament repair with biological augmentation gives excellent results in case of chronic ankle instability

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Abstract

Purpose The open "Broström-Gould" procedure has become the gold standard technique for the treatment of chronic ankle instability. Although arthroscopic techniques treating ankle instability have significantly evolved in the last years, no all arthroscopic Broström-Gould has been described. The aim of the study was to describe the all-arthroscopic Broström-Gould technique [anterior talofibular ligament (ATFL) repair with biological augmentation using the inferior extensor retinaculum (IER)], and to evaluate the clinical results in a group of patients.

Methods Fifty-five patients with isolated lateral ankle instability were arthroscopically treated. Arthroscopic ATFL repair with biological augmentation was performed through a two-step procedure. First, the ligament is reattached through an arthroscopic procedure. Next, the ligament is augmented with the IER that is endoscopically grasped. Both the ligament repair and its augmentation with IER were performed with the help of an automatic suture passer and two soft anchors. Characteristics of the patients, and pre- and postoperatively AOFAS and Karlsson scores were recorded.

Results The median preoperative AOFAS score increased from 74 (range 48–84) to 90 (range 63–100). According to the Karlsson score, the median preoperative average increased from 65 (range 42–82) to 95 (range 65–100). No major complications were reported. Only one case (1.8%) required a revision surgery at 23 months of follow-up.

Conclusion The arthroscopic all-inside ATFL repair with biological augmentation using the IER is a reproducible technique. Excellent clinical results were obtained. The technique has the advantage of its minimally invasive approach and the potential to treat concomitant ankle intra-articular pathology.

Level of evidence Retrospective case series, Level IV.

Keywords Ankle instability · Arthroscopy · Ligament · Inferior extensor retinaculum · Treatment

Introduction

Ankle sprain incidence has an important impact on public health, and chronic ankle instability (CAI) can result in 20–30% of the cases [24]. CAI leads to activity restriction, pain and at the end stage, severe ankle osteoarthritis [4].

The open "Broström" procedure has become the gold standard technique treating CAI [15]. Although isolated lateral ligament repair provides goods results, cadaveric studies have proved that Gould modification improves the resistance to ankle inversion and rotation [3].

With the aim to reduce surgical aggression and recovery time, surgeons improved the technique. Both anchor development [22, 25], and the use of an arthroscopic procedure [13] were introduced for improvement. A recent systematic

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review demonstrated favourable clinical outcome in the short term of arthroscopic lateral ankle ligament repair [6].

The aim of the study was to describe the arthroscopic lateral ligament repair with biological augmentation (inspired by the Broström-Gould open procedure), and to evaluate the clinical results in a group of patients. The hypothesis of the study was that the described arthroscopic technique improves AOFAS and Karlsson scores with a low rate of complications and an early patient recovery.

To the best of our knowledge, this is the first clinical study of the arthroscopic all-inside lateral collateral ligament repair with a biological augmentation using the inferior extensor retinaculum (IER).

Materials and methods

Between January 2015 and November 2016, all patients treated with an arthroscopic ankle ligament repair and biological augmentation were included in the study. All patients reported one or more ankle inversion sprain, anterolateral complaints, and ankle instability demonstrated on clinical exploration (positive anterior ankle drawer test and talar tilt). Conservative treatment failed to resolve patients' complains after a minimum of 6 months in all cases.

Exclusion criteria for the study was the presence of associated ankle lesions requiring treatment during same operative procedure, including patients with subfibulare ossicle bigger than 5 mm on radiographs, chondral or osteochondral defect, bony impingement, deltoid ligament tear, fibular tendons pathology or posterior ankle impingement. Patients with contributing ankle instability factors as varus hindfoot or constitutional hyperlaxity were also discharged from the study. Absence of ligament remnant, or presence of a poor ligament quality remnant was also an exclusion criterion. Poor ligament quality remnant was described as a clearly hypoplastic ligament with poorly defined margins, and ligament friability that makes it difficult to grasp.

Systematic preoperative plain radiographs, ultrasonography and arthro-CT were obtained in all patients.

The AOFAS and the Karlsson scores were recorded by an independent observer preoperatively and at final follow-up [17]. Characteristics of the patient as age, side, job, sports, and preoperative and postoperative ankle range of motion were recorded in a table. Postoperative complications were also recorded in a table.

Arthroscopic procedures were performed by the senior author.

The Ethics and Research Committee of Clinique du Sport, Bordeaux-Merignac, France approved the study (No. 09.2017.12.).

Surgical technique

Patients were treated in a day surgery. Regional anesthesia was applied, and a tight tourniquet was used. Patient was positioned in lateral decubitus.

Instruments used for the technique were a 4.0 mm 30° scope, 4.0 mm motorized shaver and standard arthroscopic instruments. Specific instruments required were two soft anchors (FiberTAK 2.0 mm, Arthrex, Naples, FL), and an automatic suture passer (Mini Scorpion DX, Arthrex, Naples, FL). A beaver blade, a push-knot and a knot-cutter were also useful. No arthroscopic pump system was used.

The arthroscopic technique, a non-distraction procedure, was performed in two steps.

First step: anterior ankle arthroscopy and ligament repair

With the patient in lateral decubitus position, the distal extremity was externally rotated. The anterior ankle landmarks were highlighted.

Two portals were performed, the anteromedial (portal 1) and modified anterolateral (portal 2) (Fig. 1).

Portal 1 was placed at the level of the tibio-talar joint line and just medial to the tibialis anterior tendon. The arthroscope was introduced through this portal. Portal 2 was placed 1.5 cm proximal to the tip of the lateral malleolus and about 1.5 cm anterior to it. Portal 2 is usually placed lateral to the superficial peroneal nerve. Instruments were introduced through this portal.

The ankle joint was arthroscopically inspected, and associated ankle intra-articular lesions were addressed before lateral ligaments were treated. The anterior talofibular ligament

Fig. 1 Anatomical landmarks and location of arthroscopic lateral portals. Superficial peroneal nerve indicated with dotted line

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(ATFL) was located in continuity with the fibular insertion of the distal fascicle of the anterior tibiofibular, and on the floor of the lateral gutter [28]. When ATFL is ruptured, its fibular footprint is observed. With the help of a shaver used as a stick, the capsule joint located close to the ATFL was separated from the ligament. Then, ATFL lesion—ligament laxity or fibular ligament detachment—was observed, and ligament quality remnant was evaluated with probe.

In case of ligament laxity, fibular attachment was separated from bone with the help of a beaver blade (Fig. 2). Care was taken to not injure the ligament connections between ATFL and calcaneofibular ligament (CFL) [29]. In case of fibular ligament detachment, footprint was debrided with shaver.

One Soft Anchor was introduced through portal 2, and inserted at the level of the ATFL footprint. Next, the automatic suture passer charged with one of the anchor sutures was introduced and the ATFL was penetrated. Once the ligament was penetrated, it was grasped with a "lasso-loop" technique as described [23]. Then, the free suture was pulled and the ligament tensioning as a consequence. Finally a knot was made and the ligament reattached to its fibular footprint (Fig. 3).

Next, a second anchor was introduced through the portal 2, and inserted just proximal to the superior ATFL. This second anchor was used to biologically augment the ligament repair (Fig. 4).

Second step: lateral ankle endoscopy and biological augmentation

Without modified patient positioning, the distal extremity was internally rotated.

A blind trocar was introduced through the portal 2. The trocar was introduced in the subcutaneous space, and with a distal and anterior direction, it was moved from lateral to medial to create a working subcutaneous area. The created working area was medially limited for the superficial peroneal nerve skin landmark. Next, a third portal (portal 3) was placed in the lateral aspect of the ankle. The portal

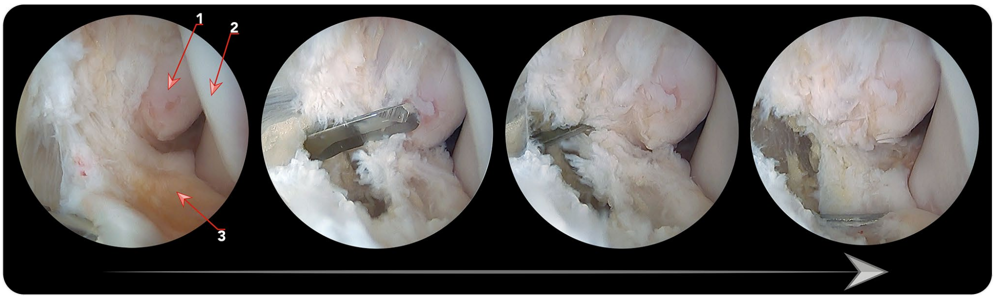

Fig. 2 Arthroscopic vision showing the arthroscopic ligament repair (right ankle). Scope introduced through the anteromedial portal and directed to the lateral gutter. The ATFL remnant is separated from the bone with the help of a beaver blade introduced through the anterolateral portal. 1. Fibula. 2. Lateral wall of the talus. 3. ATFL remnant

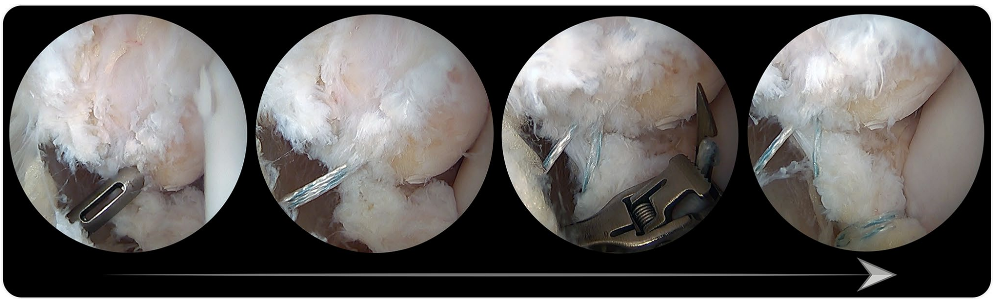

Fig. 3 Arthroscopic vision showing anchor introduction, and ligament grasping with the help of an automatic suture passer

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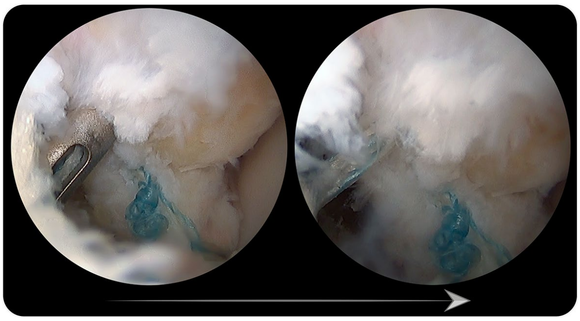

Fig. 4 After ligament repair, a second anchor is arthroscopically introduced

3 was located at mead-distance of the line connecting lateral malleolus tip and base of the fifth metatarsal, and 1 cm proximal to this point (Fig. 1). The arthroscope was introduced through portal 3, and vision directed to anterior. Soft-tissue was debrided with shaver introduced through portal 2 (Fig. 5). Attention is mandatory to not cut sutures, or remove capsule joint and IER. The capsule joint is observed as a white homogenous structure, while the IER can be identify as a white structure with transversal fibbers (Fig. 6). Next, an automatic suture passer (Mini Scorpion DS Arthrex, Naples, FL) charged with one of the suture limbs from the second anchor was introduced through portal 2. The suture passer was directed distally and the IER penetrated. The IER was penetrated again with the second suture limb. Once both suture limbs penetrated the IER, sutures were tense, and a slighting knot was made to finish the biological augmentation. Finally, sutures were cut (Fig. 7).

Portals were closed and a compressive bandage was applied. A removable walking boot was used day and night to immobilize the ankle during a period of 4 weeks. No weight bearing was allowed during this period. Antithrombotic prophylaxis was used for these 4 weeks. At 4 weeks postoperatively, the walking boot was removed an ankle bracing was used during day-time for 2 weeks. Physiotherapy started after walking boot was removed. Ankle range of motion, muscle strengthening and proprioception exercises were stimulated. Progressive weight bearing was allowed. Non-contact sports were expected 2 months, and without restriction at 3–5 months postoperative.

Statistical analysis

Statistical analyses were performed using Prism Graphpad serial 7™software (GraphPad Software, San Diego, USA). The Student *t* test was used to evaluate the variations in AOFAS and Karlsson scores, and the difference between the pre- and postoperative ankle range of motion. A significance level of 0.05 ($\alpha = 5\%$) was adopted in all statistical tests. The sample size calculation was performed and results suggested a sample size for the study group of eight patients for a statistical power of 0.9. To achieve a more robust conclusion and to account for potential measuring

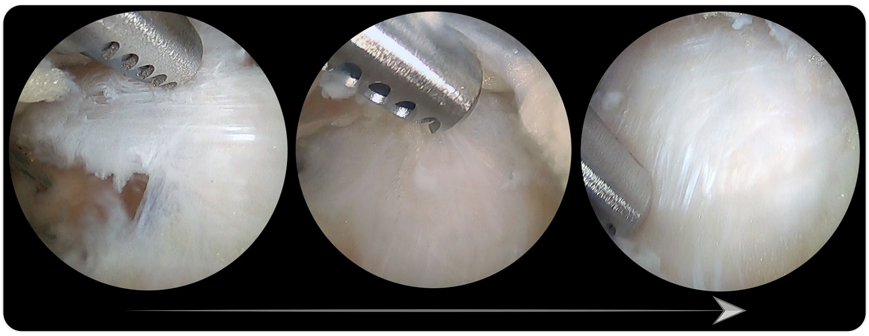

Fig. 5 Endoscopic creation of working lateral ankle area with arthroscopic shaver. Arthroscope introduced through the portal 3, and shaver through the portal 2

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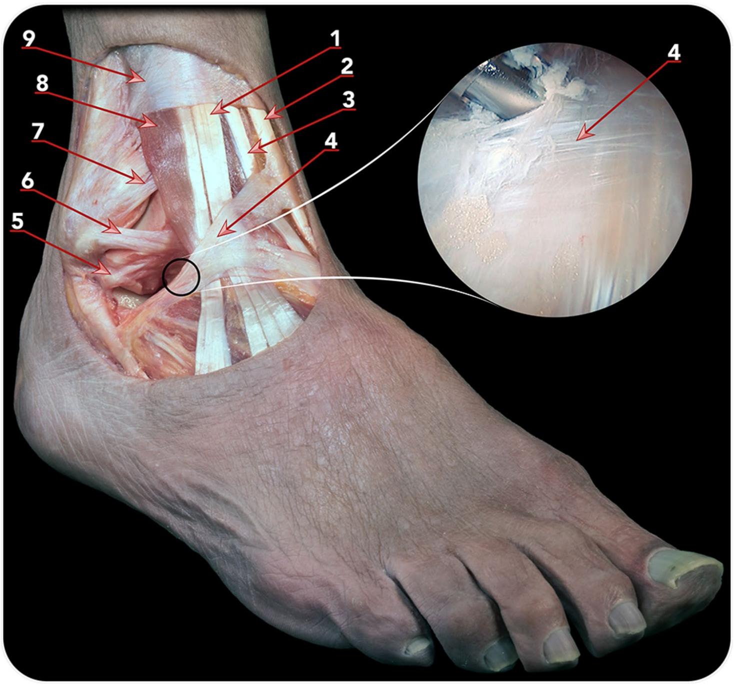

Fig. 6 Anatomic dissection of anterolateral area of the ankle. Endoscopic vision of the inferior extensor retinaculum. 1. Extensor digitorum longus tendon. 2. Tibialis anterior tendon. 3. Extensor hallucis longus tendon. 4. Inferior extensor retinaculum. 5. ATFL's inferior fascicle. 6. ATFL's superior fascicle. 7. Anterior tibiofibular ligament. 8. Peroneus tertius muscle. 9. Superior extensor retinaculum

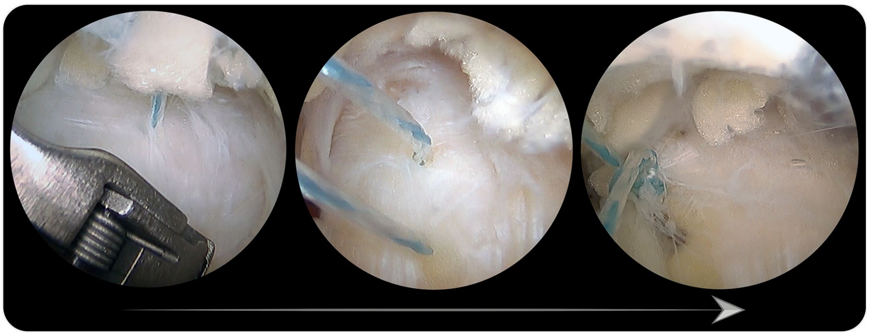

Fig. 7 Endoscopic vision showing inferior extensor retinaculum grasping with the help of an automatic suture passer introduced through the portal 2. Arthroscope introduced through portal 3

errors, it was decided to include 55 subjects in the study, the whole patients group included in the study. Descriptive results were presented as median and range.

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Results

Fifty-five patients (55 ankles) underwent an arthroscopic all-inside ATFL repair with biological augmentation, and were all retrospectively recruited during follow-up assessment. No loss of patients was observed at final follow-up. Patients were followed up for a median time of 28 (SD 6.4, mean 29, and range 18–43) months. The group was formed by 36 men and 19 women. The left ankle was affected in 35 patients and the right one in 20. The median age was 24 (SD 8.4, mean 26, range 15–50) years.

During the arthroscopic procedure, all patients were diagnosed with an isolated fibular detachment of the ATFL. No CFL or deltoid ligament lesion was observed in any case.

At follow-up, the median preoperative AOFAS score of 74 (SD 7, mean 72, range 48–84) increased to 90 (SD 8, mean 91, range 63–100) (n.s). According to the Karlsson score, the median preoperative average of 65 (SD 7, mean 64, range 42–82) increased to 95 (SD 9, mean 92, range 65–100) (n.s).

Two patients described ankle instability feeling or explained some episode of ankle sprain at follow-up. However, when explored, no instability was demonstrated (negative anterior ankle drawer test and talar tilt) in any case. Both patients described more than 10 years of ankle instability symptoms at time of surgery.

One case (1.8%) required a new ankle surgery at 23 months of follow-up because of a severe ankle sprain during sports activity. A rupture of the ligament repaired was diagnosed, and after 3 months of failed conservative treatment, an arthroscopic lateral collateral ligament reconstruction using a gracilis autograft was performed as previously described in the literature [14].

Range of motion was evaluated and compared with the preoperative ankle motion, and a mean reduction of 1° in ankle dorsiflexion (n.s.) was observed, while no changes were observed in ankle plantarflexion (n.s.).

Patients returned to job at a median time of 3 (SD 1.6, mean 3.6, range 2–11) months, and to sports of 4.5 (SD 1, mean 4.5, range 3–6) months.

Patients reported that they were satisfied or very satisfied with the procedure in 47 cases (85%), and were non-satisfied in eight cases (15%).

Complications were reported in five patients (9.1%). One patient presented a complex regional pain syndrome, and two a deep venous thrombosis that was resolved at final follow-up in all patients. Two patients presented neurological complications (3.6% of patients). One of them presented neuralgia of the superficial peroneal nerve that resolved with conservative treatment. The other patient presented dysesthesia in the area of the sural and superficial peroneal nerve that was not solved at final follow-up.

Discussion

The most important contribution of this study is the detailed description of the arthroscopic lateral ankle ligament repair with a biological augmentation using the IER, along with a series of patients demonstrating positive outcomes.

Repairing ankle ligaments through an arthroscopic all-inside technique has become a common ankle procedure [27]. However, when the injured ligament remnant is found to be of suboptimal quality to allow for repair, reconstruction procedures have been recommended [26]. Recently, the development of an arthroscopic augmentation of the repaired ligament allowed treatment of those cases with excellent results [30]. As a consequence indications for arthroscopic ligament repair have been expanded, and ligament reconstruction should probably be used only in patients with absence of ligament remnant.

Arthroscopic evaluation of the ligament remnant is mandatory, and care should be taken when lateral gutter debridement to avoid iatrogenic injury. ATFL's superior fascicle can be evaluated without opening the capsule joint, because it is an intra-articular ligament [29]. However, when injury affects the lateral fibulotalocalcaneal ligament complex [29], capsule joint needs to be resected to perform a full evaluation and treatment. If lateral gutter capsule joint is resected the use of high-resistance sutures to reinforce the ligament repair is not recommended because sutures can occasionally lead to chronic inflammation followed by a foreign body reaction when placed intra-articular [7]. To minimize this risk biological augmentation is recommended when capsule joint is removed during procedure.

As in high-resistance suture reinforcement [8, 31], biological augmentation of the ligament repair with IER allows for a more aggressive rehabilitation without the need of extended protection. In the present case series early rehabilitation was applied, non-contact sports encouraged at 2 months, and sports without restriction at 3–5 months postoperative. In addition, the resulted ankle stability allows patients' return to sports at the same level than before injury. The postoperative increase of the AOFAS and Karlsson scores illustrates the excellent results of the procedure. Similar postoperative results—mean postoperative AOFAS score between 85 and 97—have been observed in the international literature [9, 10, 18, 19, 21, 28]. Brown et al. [6] compared the open an arthroscopic Broström-Gould technique, and observed lower postoperative AOFAS score in the open group than in the arthroscopic group.

In addition to the excellent clinical results, a complication rate of 9.1% has been observed in the present study, most of them minor complications. Neurological complaints are the most common complication after ankle arthroscopy, mainly the injury of the superficial peroneal nerve [27]. In

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the present study, it was observed in 3.6% of patients, and only in one case the neurological symptoms persisted at follow-up. Brown et al. observed similar neurological complication rate in their review study [6]. Only Vega et al. [28] do not observed neurological disorders in their arthroscopic "all inside" technique. This may be due to the fact that they use a cannula introduced through the anterolateral portal protecting the superficial peroneal nerve during passage of instruments, sutures and anchors. More recently, Vega et al. [30] described a non-biological augmentation with sutures and they observed equally no neurological complications since they use a cannula introduced through the anterolateral portal. The use of a cannula introduced through the portal 2 will probably reduce the risk of neurological lesion during procedure described here, especially during the lateral ankle endoscopy and biological augmentation step. Creation of a working space in the lateral aspect of the ankle and the soft-tissue debridement to localize the IER can put in risk the superficial peroneal nerve, the sural nerve or the communicating branch between both nerves. However, the use of a non-specifically designed cannula for the ankle could make the procedure difficult because it is not stable enough when introduced, and our experience is that the cannula easily comes out when instruments are used through it.

Chronicity of the ligament injury is an important aspect to be considered during treatment. In the present study two patients reported ankle instability feeling at follow-up. However, when clinically explored, both patients presented a negative anterior ankle drawer test and talar tilt. Both patients described more than 10 years of ankle instability symptoms at time of surgery. A loss of proprioception as a result of the chronicity of the process could explain the ankle instability feeling in these two patients. However, more studies are required to confirm this point.

Study limitations include the lack of a comparative control group of study subjects who underwent an isolated arthroscopic all-inside ATFL repair without biological augmentation. As a consequence, it is not possible to confirm whether the results obtained are the result of the ATFL repair or because of the ATFL repair plus biological augmentation. The inclusion of a control group would certainly improve the validity of the study. Another limitation is that it is not possible to know if the amount of IER grasped is enough to augment and protect the ligament repair. Some studies discourage the use of the IER due to the little effect its reinforcement has on ankle stability [5, 16], or due to the anatomical variants of the IER that makes difficult its reinforcement in lateral ankle ligament ruptures [1, 11, 12]. The anatomical IER variants can vary the amount of retinaculum tissue grasped. In contrast with percutaneous techniques grasping the IER [2, 18, 20, 21], a tissue that is identified as the IER can be arthroscopically visualized and grasped. An anatomical and biomechanical study of the arthroscopic biological ligament repair augmentation is required to validate the technique.

The clinical relevance of the study is the description of the first arthroscopic all-inside anatomic lateral collateral ligament repair with biological augmentation using the IER that offers the benefit of maintaining the native ligament while reinforcing the repair with a local biological tissue.

Conclusion

The arthroscopic all-inside ATFL repair with biological augmentation using the IER is a viable option for surgical treatment of chronic ankle instability. The use of a cannula in the anterolateral portal is encouraged to avoid neurological complications. This technique has the advantage of its minimally invasive approach and the potential to treat concomitant ankle intra-articular pathology in the same procedure.

Funding No funding was received for this study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The Ethics and Research Committee of Clinique du Sport, Bordeaux-Merignac, France approved the study (No. 09.2017.12.).

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ANKLE

Endoscopic anatomic ligament reconstruction is a reliable option to treat chronic lateral ankle instability

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Abstract

Purpose Anatomic reconstruction of the anterior talofibular ligament and calcaneofibular ligament is a valid treatment of chronic hindfoot instability. The purpose of this study was to investigate the outcomes of this procedure performed by an all-inside endoscopic technique.

Methods This study is a retrospective evaluation of a prospective database. Subjects were all patients who underwent an endoscopic lateral ligament reconstruction between 2013 and 2016. All patients had symptoms of ankle instability with positive manual stress testing and failed nonoperative treatment during at least 6 months. At final follow-up the outcome was assessed using the visual analogue score (VAS), American Orthopaedic Foot and Ankle Society (AOFAS) score and Karlsson–Peterson scores.

Results After an average follow-up of 31.5 ± 6.9 months, all patients reported significant improvement compared to their preoperative status. The preoperative AOFAS score improved from 76.4 ± 15 to 94.7 ± 11.7 postoperatively ($p = 0.0001$). The preoperative Karlsson–Peterson score increased from 73.0 ± 16.0 to 93.7 ± 10.6 postoperatively ($p = 0.0001$). The VAS score improved from 1.9 ± 2.5 to 0.8 ± 1.7 ($p < 0.001$). Two patients had complaints of recurrent instability.

Conclusion Endoscopic ligament reconstruction for chronic lateral ankle instability is a safe procedure and produces good clinical results with minimal complications. In addition, the endoscopic approach allows an assessment of the ankle joint and treatment of associated intra-articular lesions.

Level of evidence II.

Keywords Ankle ligament · Ankle instability · Ligament reconstruction · Calcaneofibular ligament · Anterior talofibular ligament · Arthroscopy · Autograft · Endoscopic reconstruction

Introduction

Ankle sprains remain the most common injuries of the lower extremity. Inversion lateral ankle injuries account for 85% of ankle sprains and affect anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL) [2]. Despite the efficacy of non-surgical treatment with physical rehabilitation, 10–30% of patients develop chronic ankle instability (CAI) [5, 22]. Surgical treatment is indicated to avoid persistent complaints of instability, osteochondral lesions of the talar dome or osteoarthritis [11, 25, 28]. Different surgical options exist to treat CAI. The non-anatomical techniques have lost

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favour because they may result in limitation of joint motion and long-term development of degenerative arthritis [12, 15, 23]. Currently, anatomic repair and anatomic reconstruction are the two preferred surgical techniques [20, 21]. Arthroscopic repair, sometimes with addition of an augmentation procedure, gives good results with a low rate of complications [6, 31]. This technique is currently the gold standard procedure. However, lateral ligament reconstruction (with grafting) of both the ATFL and CFL should be considered in revision cases, patients with generalised laxity or poor ligament quality [10, 13, 21]. In recent years minimally invasive and endoscopic procedures have been described [4, 17, 18]. Despite this increase in publications, a recent systematic review demonstrates the need for studies assessing the outcome of these techniques [17].

The purpose of this study was to evaluate clinical outcomes in a group of patients with at least 2 years follow-up after an all-inside ankle lateral ligament endoscopic autograft reconstruction. The hypothesis of this study is that this technique offers a good functional outcome with a low risk of complications. To our knowledge, this is the first study that describes the results of an endoscopic lateral ligament reconstruction with a follow-up at more than 2 years.

Materials and methods

All consecutive patients who underwent endoscopic lateral ligament reconstruction between 2013 and 2016 were screened for eligibility. Finally, 53 patients (54 ankles) from the 71 screened patients, were included. Table 1 summarizes demographic data of all patients included. 50 (94%) patients had complete follow-up at a minimum of 2 years after surgery while 3 (6%) patients were lost to follow-up. Data are shown as mean with ± standard deviation and (range) unless otherwise indicated. All patients had sustained at least one inversion injury of the ankle. Despite a period of conservative treatment of at least 6 months they still had complaints of hindfoot instability. Clinical examination revealed in every case a positive anterior drawer and talar tilt test. Before surgery standard antero-posterior and lateral radiographs of the feet and ankles, Meary view, Antero Medial Impingement (AMI) view, ultrasound and arthro-CT were obtained. Ultrasound confirmed a complete lesion of ATFL and complete or partial lesion of CFL in all patients. During the period of inclusion 19 patients underwent additional procedures: gastrocnemius lengthening, calcaneus osteotomy for varus hindfoot, treatment of associated intra-articular lesions (osteophytes or cartilage lesion). All these patients were excluded from the study.

All patients were examined at a minimum of 2 years follow-up by an independent fellowship-trained examiner. Examination included pre and postoperative range of motion, anterior ankle drawer test and talar tilt, visual analogue score (VAS) system, American Orthopaedic Foot and Ankle Society (AOFAS) and Karlsson/Peterson score.

Table 1 Demographic data of all included patients

Variable	Data
Age (years)	38.1 ± 9.3 (21–58)
Gender	Male n = 34/female n = 16
Side	Left n = 23/right n = 27
Level of sports, n (%)	
Competitive	15 (30)
Recreational	20 (40)
No sports	15 (30)

Surgical technique

All surgical procedures were performed by one single surgeon using a standardized technique based on the technique described by Guillo et al. [10]. Patients were operated in day surgery. Patients were placed in lateral position, which allowed to perform graft harvesting, anterior arthroscopy and lateral endoscopy by mobilizing the lower limb. A tight tourniquet was applied. A 4.0 mm 30° arthroscope and a 4.5 mm full-radius synovial shaver were used. Three portals were made: an anteromedial portal, an anterolateral portal and a lateral portal. The endoscopic technique was performed in four steps.

The first step was the anterior arthroscopy. A first anteromedial portal was used as a viewing portal. A second portal was placed 1.5 cm proximal and 1.5 cm anterior to the tip of the lateral malleolus. The ankle joint was inspected and associated lesions were treated. The anterior tibiofibular ligament was used as a first landmark and to find the insertion of the ATFL. The remnants of the ATFL were removed to expose the proximal insertion of the CFL.

The second step was the harvesting and preparing of the gracilis graft. One of the ends was folded and sutured around a guidewire to enter in the calcaneal tunnel. The graft was cut at 11 cm.

The third step was the drilling of the tunnels during lateral endoscopy. A third endoscopic portal was performed just above the sinus tarsi on the intersection of the fibular tunnel axis and the superior border of the peroneal tendons (Fig. 1) [10]. Using this third portal as a working portal, the dissection was continued to expose the talar footprint of the ATFL and the calcaneal footprint of the CFL (Fig. 2). A guide pin allowed to drill a 6 mm diameter calcaneal tunnel from the calcaneal footprint to the anterior medial edge of the calcaneal tuberosity. An oblique fibular tunnel (diameter of 4 mm) was drilled with a guide pin starting at the confluent insertion of the ATFL and CFL (Fig. 3). The first

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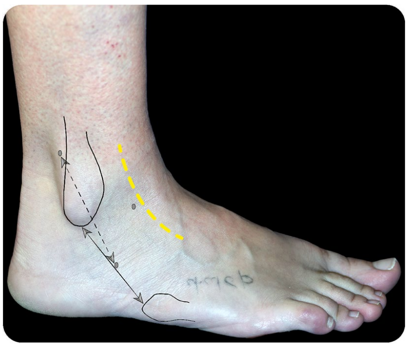

Fig. 1 Position of the portals

10–15 mm was overdrilled with a diameter of 6 mm creating space for the folded graft. To drill the talar tunnel, the scope was placed in portal 3 and the instruments in portal 2. The tunnel entrance was located below the triangular region of the talus on the midpoint between the superolateral edge of the talar body and the subtalar joint. A guidepin was used to drill a tunnel in a dorsal medial direction to a depth of 20 mm [19].

The last step corresponded to the positioning and fixation of the graft. Guidewires were placed in every tunnel using a K-wire with an eyelet. The graft was introduced by the second portal and fixed in the talar tunnel using a Tenodesis Screw (Tenodesis Screw Biocomposite 5.5 × 15 mm, Arthrex, Naples, FL, USA) (Fig. 4). Then the other end of the graft was retrieved by the third portal and passed through the loop of the adjustable endobutton (ACL Tightrope RT, Arthrex, Naples, FL, USA), which was introduced, in the fibular tunnel using a guidewire (Fig. 5). The button was positioned on retromalleolar side of the fibula [20]. A small retromalleolar approach was added to avoid lesions of the peroneal tendons. The other end of the graft was pulled inside the calcaneal tunnel. During endoscopic visualization, the central part of the graft was pulled inside the fibular tunnel to create a bone-tendon interface (Fig. 6). The endobutton was adjusted to improve graft position while tightening was avoided. The free end of the graft was fixed in the calcaneal tunnel using an interference screw (Tenodesis Screw

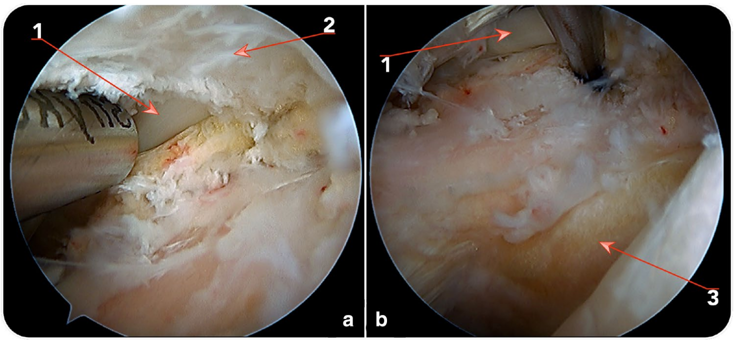

Fig. 2 CFL footprint. **a** Visualization of the distal CFL footprint behind fibular tendons. **b** Introduction of the K-wire on the footprint before drilling at 1 cm to the subtalar joint. 1 Peroneal tendons. 2 CFL footprint. 3 Posterior facet subtalar joint

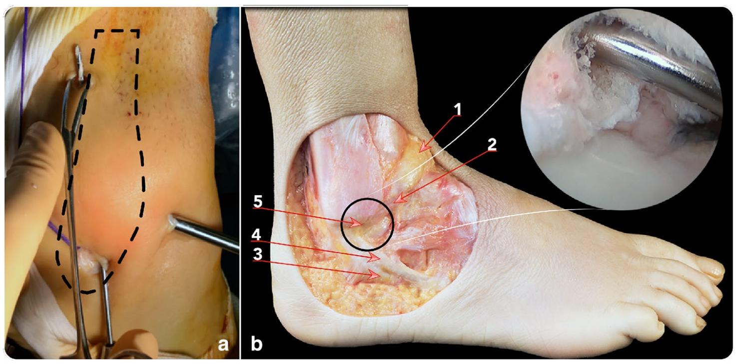

Fig. 3 Fibular tunnel. **a** Exit of K-wire trough a retromalleolar incision. **b** Insertion of the K-wire in the fibula. 1 Anterior ankle joint capsule. 2 ATFL's inferior fascicle. 3 Peroneus longus tendon. 4 Peroneus brevis tendon. 5 CFL footprint on fibula

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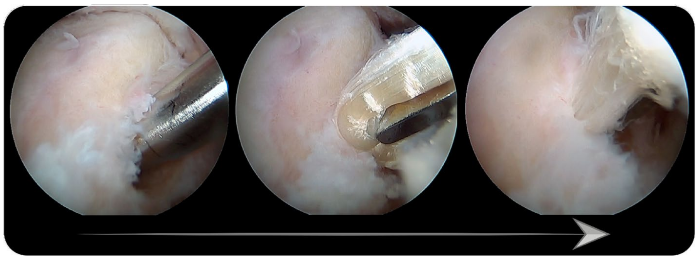

Fig. 4 Fixation of the graft in the talar tunnel

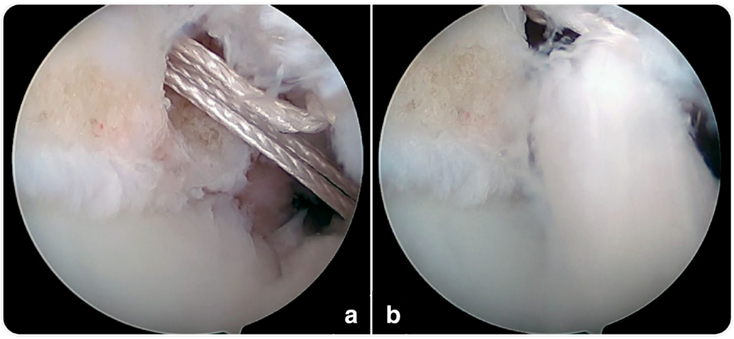

Fig. 5 Introduction of the doubled graft in the fibular tunnel. **a** Tunnel and guidewire. **b** Adjustable endobutton and graft

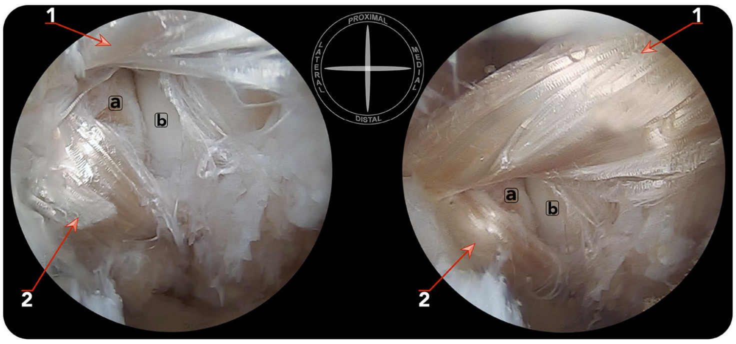

Fig. 6 Final result with reconstructed ATFL and CFL. **a** Fibular malleolus. **b** Lateral talar wall. 1 ATFL reconstruction. 2 CFL reconstruction

Biocomposite 6.25 × 15 mm, Arthrex, Naples, FL, USA) after pretensioning with the guidewire. Holding the ankle in a valgus position at 90°, the endobutton was tightened. Guidewires were cut or removed and the portals were closed. A compressive bandage was applied.

Postoperatively, a walking boot was indicated day and night for 4 weeks and ankle brace for 2 weeks during day. Antithrombotic prophylaxis was used for 4 weeks. Partial weight-bearing was allowed after 4 weeks and progressively to have full weight-bearing at 6 weeks. Physiotherapy was started at 4 weeks with a strict protocol. Non-weight-bearing sports (swimming or biking) were allowed at 6 weeks postoperatively. Running was allowed at 3 months. Sports without limitations were allowed between 5 and 6 months after surgery.

The Ethics and Research Committee of Clinique du Sport, Bordeaux–Merignac, France, approved the study (No. 09.2017.13).

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Statistical analysis

Statistical analysis was performed using the online application EasyMedStat (http://www.easymedstat.com; Neuilly-Sur-Seine; France). The Wilcoxon signed-rank test for paired samples was used for comparison of continuous variables between preoperative and postoperative results. Statistical significance was set at a p value of 0.05. The sample size calculation was performed and results suggested a sample size for the study group of eight patients for a statistical power of 0.9. To achieve a more powerful conclusion and to account for potential measuring errors, it was decided to include all 53 subjects in the study.

Results

Patients were assessed with an average follow-up of months 31.5 ± 6.9 months (range 24–51). All patients reported the disappearance of the instability complaints that they had experienced prior to the operation. An overview of the results is given in Table 2. The mean overall AOFAS score improved from 76.4 ± 15 (median 82.5, range 18–92) to 94.7 ± 11.7 (median 100, range 34–100), (p = 0.0001). The mean preoperative Karlsson–Peterson score was 73.0 ± 16.0 (median 73, range 7–95) and the mean postoperative Karlsson–Peterson score was 93.7 ± 10.6 (median 97, range 57–100) (p = 0.0001). The mean VAS score improved of 1.9 ± 2.5 (range 0–7) to 0.8 ± 1.7 (range 0–7) from preoperative to postoperative status ($p < 0.001$).

At final follow-up, there was a significant loss of range of motion (ROM) compared with preoperative measurements of passive dorsal flexion [mean loss of 2.7°; 95% confidence interval (CI) 1.5°–3.9°; $p < 0.05$] and passive plantar flexion (mean loss of 1.4°; 95% CI 0.5°–2.2°; $p < 0.05$). No patient expressed dissatisfaction with the slight reduction in ROM.

Thirty-five patients practiced sports activities prior to the onset of symptoms of instability. Postoperatively, thirty-one patients (89%) returned to sports activity. Twenty-six patients (84%) returned at the same level, three returned to a lower level, and two changed to a different sports activity. Patients returned to work at a mean time of 3 months (range 0.5–7). Patients reported that they were satisfied or very satisfied with the procedure in 46 cases (92%). Two major complications were observed and consisted of two cases with failure of the reconstruction (4%). Those patients, including 1 patient with generalised hyperlaxity, had a new traumatic ankle sprain with graft rupture and developed again chronic ankle instability. However, none of them needed a new surgical procedure, as the remaining symptoms were very limited. No neurological complications were reported. One patient presented neuralgia of the superficial peroneal nerve that resolved with conservative treatment. One patient sustained a removal of the endobutton during the post-operative period. There were no wound problems or infections related to the surgery.

Table 2 Distribution of AOFAS Ankle scores and Karlsson–Peterson scores in the pre- and post-operative evaluations of the 50 included in the sample

	AOFAS, *n* (%)		Karlsson–Peterson, *n* (%)	
	Pre	Post	Pre	Post
Excellent (90–100)	0	43 (86)	0	39 (79)
Good (80–89)	30 (60)	3 (6)	17 (34)	5 (10)
Fair (70–79)	10 (20)	3 (6)	15 (30)	3 (6)
Poor (< 70)	10 (20)	1 (2)	18 (36)	3 (6)

Discussion

The most important finding in this study is that endoscopic anatomic reconstruction of the lateral ligaments is a safe, reliable and efficient technique, at 2-year follow-up. In addition, it allows the treatment of associated intra-articular lesions.

Different surgical techniques exist to treat CAI. Tenodesis is the oldest but no longer recommended technique [33]. Anatomic repair has been seen as the gold standard with excellent results [33]. However, this technique can only be used when the tissue quality of the elongated ligament is sufficient for repair [21, 33]. In addition, some studies with longer follow-up report 16% and 17% of remaining instability after a ligament repair [1, 16]. Other contraindications to perform a ligament repair have been described: (1) failed anatomical repair; (2) high body mass index; (3) congenital ligament laxity; (4) heavy labour occupation or sports requirements; and (5) an ossicle with size ≥ 1 cm [8, 9, 18, 21].

A reconstruction refers to the replacement of the irreparable or chronically deficient lateral ligaments with other tissue, which can be local tissue, autograft or allograft [9]. Takao et al. [27] described an open technique to perform an anatomic reconstruction using a gracilis tendon graft. They reported a mean improvement of the AOFAS score from 69.4 to 97.0 postoperatively. In a recent systematic review, Vuurberg reported a AOFAS score increase from 53.2 ± 10.6 to 90.2 ± 10.9 postoperatively and a Karlsson/Peterson score increase from 38.5 ± 3.2 to 90.1 ± 7.8 [33]. These results are similar to the findings of this study.

The endoscopic approach may offer some advantages in clinical practice. Patients with CAI often have associated lesions which may result in a poor outcome [4]. In some cases MRI is insufficient to detect those additional

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pathologies while arthroscopy remains the gold standard [3, 24]. For this reason, an endoscopic evaluation has been recommended [8]. The endoscopic technique allows the evaluation and treatment of the intra-articular lesions in combination with the ligament procedure [4]. A second advantage is the assessment of the tissue remnants. The endoscopic approach allows a more reliable assessment of the remaining ligaments which is helpful to choose the optimal surgical technique [7, 14, 26, 29]. A final possible advantage of the endoscopic approach is the reduced soft tissue damage, which may allow a shorter time of recovery. Although a rather slow rehabilitation protocol was used in this study, an accelerated rehabilitation programme can be considered. These advantages are already demonstrated in other surgical techniques but further research is still needed in ankle ligament surgery.

Advantages of the arthroscopic technique are major: current knowledge on ankle ligaments is evolving with the definition of the superior fascicle of ATFL as an intra-articular structure and the finding of arciform fibers connecting ATFL's inferior fascicle and CFL [32]. This has important biomechanical and surgical implications, as an isolated injury to ATFL's superior fascicle will be better treated with an arthroscopic all-inside repair, while a combined injury of ATFL and CFL could be treated with the technique presented in this study.

This study has some limitations. In this study, the patients with intra-articular lesions were excluded as this study was focused on the evaluation of the ligament procedure. On the other hand, especially the patients with associated intra-articular lesions would benefit from this endoscopic approach, as these lesions can be treated simultaneously with the same approach. Another limitation of this study was the fact that the instability was not quantified preoperatively and postoperatively. As the stress radiographs have a low sensitivity, the extra value is limited [30]. For this reason, we combined different scores to assess the functional results. Future research should include randomized controlled trials comparing the outcome of different techniques and different approaches.

The results of this study are useful in day-to-day clinical practice when choosing the surgical procedure in patients with chronic lateral ankle instability. Although this procedure is technically more demanding, it offers some advantages. The endoscopic approach allows superior diagnostic and treatment possibilities of the intra-articular pathology. In addition, the reconstruction allows to obtain a stable ankle joint in more difficult cases e.g. insufficient remaining ligament tissue, generalised hyperlaxity, revision cases.

Conclusion

Endoscopic ligament reconstruction for chronic lateral ankle instability is a safe procedure and produces good clinical results with minimal complications. This technique combines the advantages of anatomic reconstruction and the benefits of an endoscopic approach.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval This study received Ethical approval by the Ethics and Research Committee of Clinique du Sport, Bordeaux-Merignac, France, (N° 09.2017.13).

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Arthroscopic-Assisted Versus All-Arthroscopic Ankle Stabilization Technique

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Abstract

Background: Both the percutaneous technique with arthroscopic assistance, also known as arthroscopic Broström (AB), and the arthroscopic all-inside ligament repair (AI) are widely used to treat chronic lateral ankle instability. The aim of this study was to compare the clinical outcomes of these 2 arthroscopic stabilizing techniques.
Methods: Thirty-nine consecutive patients were arthroscopically treated for chronic ankle instability by 2 different surgeons. The AB group comprised 20 patients with a mean age of 30.2 (range, 18-42) years and a mean follow-up of 19.6 (range, 12-28) months. The AI group comprised 19 patients with a mean age of 30.9 (range, 18-46) years and mean follow-up of 20.7 (range, 13-32) months. Functional outcomes using the American Orthopaedic Foot & Ankle Society (AOFAS) hindfoot score and visual analog pain scale (VAS) were assessed pre- and postoperatively. Range of motion (ROM) and complications were recorded.
Results: In both groups the AOFAS and VAS scores significantly improved compared with preoperative values ($P < .001$) with no difference ($P > .1$) between groups. In the AB group the mean AOFAS score improved from 67 (range, 44-87) to 92 (range, 76-100) and the mean VAS score from 6.4 (range, 3-10) to 1.2 (range, 0-3). In the AI group the mean AOFAS score changed from 60 (range, 32-87) to 93 (range, 76-100) and the mean VAS score from 6.1 (range, 4-10) to 0.8 (range, 0-3). At the final follow-up 8 complications (40%) were recorded in the AB group. In the AI group 1 complication (5.3%) was observed ($P < .05$).
Conclusion: Both the AB and AI techniques are suitable surgical options to treat chronic ankle instability providing excellent clinical results. However, the AB had a higher overall complication rate than the AI group, particularly involving a painful restriction of ankle plantarflexion and neuritis of the superficial peroneal nerve.
Level of Evidence: Level III, retrospective comparative study.

Keywords: ankle arthroscopy, ankle instability, ligament repair, arthroscopic Broström, all-inside repair, comparative study

Introduction

Ankle sprains are one of the most common orthopedic injuries, with the lateral ligament complex being involved in 85% of cases.[14,16] Ankle sprains can lead to instability in 10% to 40% of patients, and some of them will require surgical intervention to restore ankle stability. [6,13]

In the past, anatomical open lateral ligament repair as originally described by Broström was considered the gold standard procedure to surgically treat ankle stability.[5] However, the potential for addressing both the instability and any intra-articular associated pathology arthroscopically has deemed ankle arthroscopy as better positioned to be the technique of choice when treating ankle instability.

Hawkins[19] described the first arthroscopic ankle stabilization technique in 1987, although subsequent complaints arose due to the prominent staple used in that technique. Since then, the technical aspects of ankle arthroscopy and

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instruments have significantly evolved, providing much better results in the treatment of ankle instability.

As has been the case in open surgery, a number of arthroscopic techniques have been proposed to restore ankle stability. These can be broadly classified into arthroscopic-assisted and all-arthroscopic techniques. Arthroscopic-assisted techniques combine arthroscopic procedures with a percutaneous[1] or mini-open approach,[19] whereas the all-arthroscopic techniques[32] involve a fully arthroscopic procedure. All-arthroscopic techniques can be further subdivided into ligament repair and ligament reconstruction or ligamentoplasty. The emergence of publications reporting excellent clinical results has helped to popularize both arthroscopic-assisted and all-arthroscopic ligament repairs.[8,23,25,32]

The percutaneous technique with arthroscopic assistance has also been termed arthroscopic Broström (AB). The procedure entails arthroscopic insertion of anchors into the fibula and a percutaneous step to stitch the lateral ligament and the inferior extensor retinaculum (IER). The technique yields excellent clinical results despite a high rate of reported complications (5.3%-29%) due to neurological entrapment or prominent implants.[8,18,22] The all-arthroscopic ligament repair technique, popularized as the arthroscopic all-inside ligament repair (AI), is an anatomical repair of the lateral ligaments under direct arthroscopic visualization with the use of anchors.[32,33] Excellent clinical results have been reported with a low rate of complications, mostly minor ones.[17,27,32]

The purpose of this study was to compare the clinical outcomes of 2 arthroscopic stabilizing techniques used for chronic lateral ankle instability: the percutaneous technique with arthroscopic assistance and the all-arthroscopic ligament repair.

Methods

From February 2016 to June 2018, 39 consecutive patients were arthroscopically treated for chronic ankle instability, after being assessed due to limitations in their daily activities. Surgeries were performed by 2 surgeons trained in foot and ankle arthroscopy, each with more than 3 years of experience and more than 30 cases performed of the described techniques.

Patients were included in 2 groups: the first one underwent the percutaneous technique with arthroscopic assistance (AB), and the second the arthroscopic all-inside ligament repair (AI). Each technique was always performed by the same surgeon, without crossing over. The AB group comprised 20 patients (8 males and 12 females) with a mean age of 30.2 (range, 18-42) years. The right ankle was affected in 13 cases. The mean follow-up was 19.6 (range, 12-28) months. The AI group comprised 19 patients (9 males and 10 females) with a mean age of 30.9 (range, 18-46) years. The right ankle was affected in 9 cases. The mean follow-up was 20.7 (range, 13-32) months.

Inclusion criteria included chronic ankle instability with a minimum duration of symptoms of 6 months. Clinical findings consisted of anterolateral pain, recurrent ankle sprains, or a feeling of the ankle giving way along with a positive anterior drawer test. All patients underwent a 3- to 6-month course of nonoperative treatment (anti-inflammatory therapy, rest, and physiotherapy) without improving.

Patients with previous foot and ankle surgery, malalignment, or end-stage tibiotalar joint osteoarthritis were excluded. Exclusion criteria consisted of the presence of a talar osteochondral lesion, peroneal tendon pathology, or deltoid ligament tear. Cases of generalized ligamentous laxity and neuromuscular diseases were also discarded from the study. The observation of a calcaneofibular ligament (CFL) tear in addition to the anterior talofibular ligament (ATFL) tear was not an exclusion criterion.

Full weightbearing radiographs and magnetic resonance imaging (MRI) were obtained in all cases to obtain a complete imaging study. No stress radiographs were requested.

Functional outcomes using the American Orthopaedic Foot & Ankle Society (AOFAS) hindfoot score and visual analog pain scale (VAS) were assessed preoperatively and at the latest follow-up (minimum of 1 year after the procedure) by a third surgeon not involved in the surgeries. Preoperative and latest follow-up ankle anterior drawer test scores, range of motion (ROM), and complications were recorded. At the latest follow-up, the anterior drawer test score and ROM were compared with the healthy contralateral side. Ankle ROM was measured by a goniometer and a postoperative deficit >10 degrees with discomfort or pain was classified as a minor complication.

The study was approved by the ethics committee of our institution.

Surgical Technique

The instruments required for the arthroscopic procedure included a 4.0-mm 30-degree scope, 3.5-mm arthroscopic motorized shaver, and burr plus standard arthroscopic instruments. Patients were positioned supine under spinal anesthesia with a thigh tourniquet. Cutaneous landmarks over the anterior aspect of the ankle were highlighted.

An ankle dorsiflexion arthroscopic and no-distraction technique was performed that allowed access to the lateral gutter.[9,11] Standard anteromedial and anterolateral portals were established. The anteromedial portal was mainly used as a visualization portal for the arthroscope, whereas instruments were introduced through the anterolateral portal. A full arthroscopic examination was performed, and when present, scar tissue or synovitis was debrided before proceeding to the stabilizing technique.

Percutaneous Technique With Arthroscopic Assistance

The footprint of the remaining ligament on the fibula was debrided with an arthroscopic shaver to create a rough area that would promote healing.

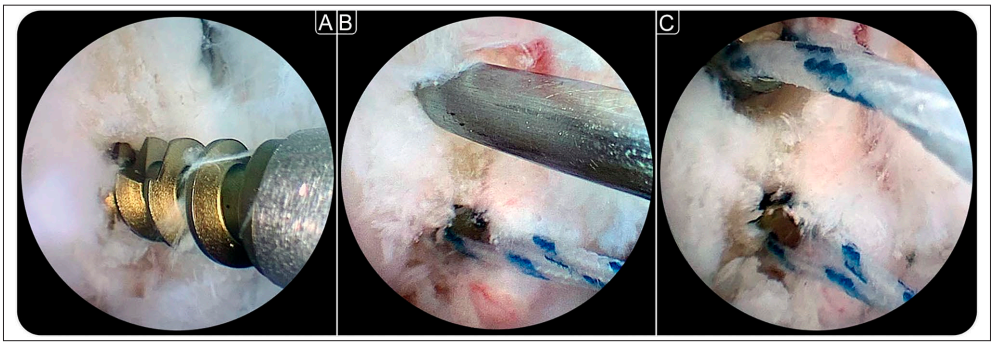


Figure 1. Arthroscopic-assisted placement of 2 suture anchors in the lateral malleolus during arthroscopic Broström. Anchors are placed at approximately 0.5 cm from each other.

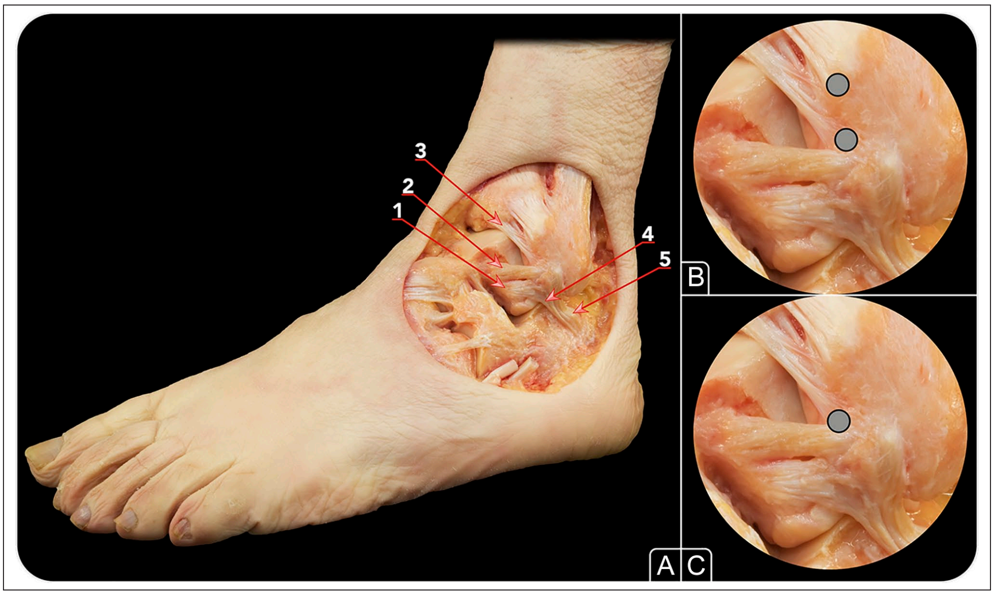


Figure 2. Anterolateral view of an anatomical dissection depicting the (A) anatomy of the lateral ankle ligaments and the position of the anchors for the (B) arthroscopic Broström and (C) all-inside technique. 1, anterior talofibular ligament's (ATFL's) inferior fascicle; 2, ATFL's superior fascicle; 3, distal fascicle of anterior tibiofibular ligament; 4, fibers of the lateral fibulotalocalcaneal ligament complex; 5, calcaneofibular ligament.

Two bone anchors (3.5 × 10–mm CorkScrew; Arthrex, Naples, FL) were introduced through the anterolateral portal and placed 1 and 1.5 cm proximal to the tip of the fibula (Figures 1 and 2).[31] Sutures were pulled out from the anterolateral portal. Next, with the ankle in neutral position, sutures coming from the distal anchor were passed inside out with the use of a suture passer (SutureLasso; Arthrex). The suture passer loaded with one of the sutures was directed first proximally to the peroneal tendons, at about 1.5 cm distal to the apex of the fibula; then a second suture was passed 1 cm proximal to the first suture. Next, sutures from the second anchor were passed with the suture passer at about 1 cm medial to the last suture, and the same with the other suture at 1 cm medial from it (Figure 3). Sutures were intended to

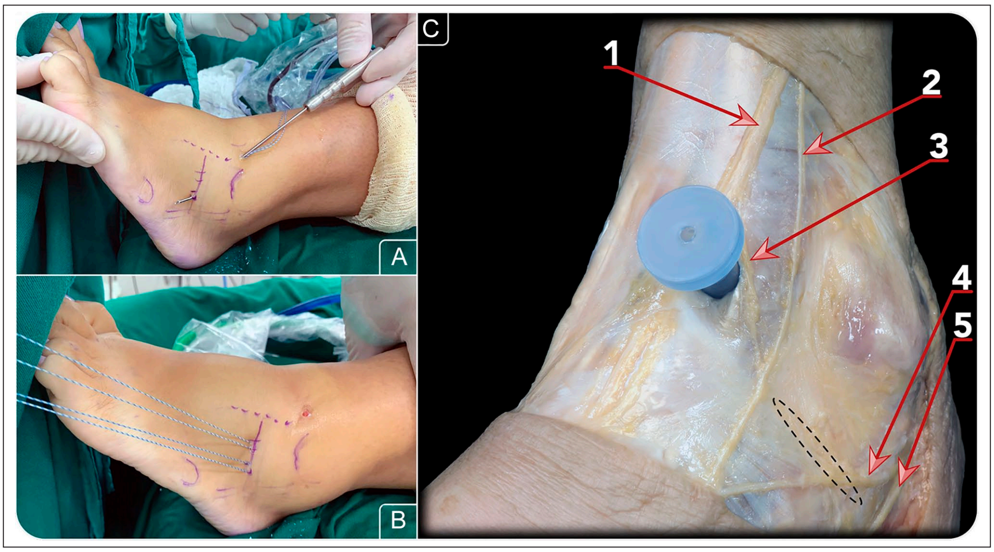


Figure 3. (A,B) Percutaneous suture passing and (C) anatomy of relevant nerves in the arthroscopic Broström. (C) A cannula has been inserted through the anterolateral portal. 1, medial dorsal cutaneous nerve (branch of superficial peroneal nerve); 2, intermediate dorsal cutaneous nerve (branch of superficial peroneal nerve); 3, communicating branch; 4, communicating branch; 5, sural nerve. The dotted area represents the location of the suture.

penetrate the IER while avoiding the superficial peroneal nerve. Two small incisions were made between sutures in order to subcutaneously retrieve them. Next, with the ankle in neutral dorsiflexion and slight eversion, a sliding knot was made with the sutures in every anchor. The stitch was aimed to grasp the ligament structures, the capsule joint, and the IER. Finally, sutures were cut and the incisions closed. A removable walking booth was applied.

Arthroscopic All-Inside Ligament Repair

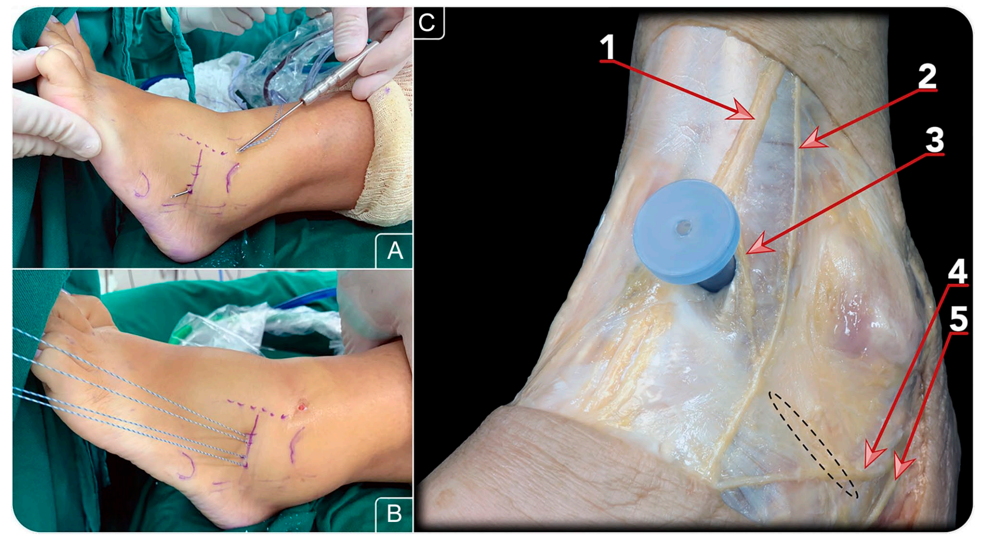
In addition to the standard portals, an accessory anterolateral portal was located about 1 to 1.5 cm proximal to the fibular tip and just anterior to it. The fibular ligament footprint was debrided with an arthroscopic shaver to facilitate the ligament healing. A suture passer (Microsuture lasso 70 degrees curved; Arthrex) was introduced through the anterolateral portal to grasp the ATFL remnant from lateral to medial. Next, the nitinol loop was inserted into the ankle joint and pulled out through the accessory portal. The nitinol was then replaced by a doubled high-resistance suture (Fiberwire No. 0; Arthrex). The limbs of the suture located in the accessory portal were passed through the anterolateral portal. Next, one limb of the sutures was passed through the loop suture, creating a lasso loop. By pulling both suture limbs, the lasso loop was introduced into the joint and the ATFL remnant was grasped. To reattach the ATFL onto its native insertion, a bone tunnel for the knotless anchor was drilled just distal to the fibular attachment of the anterior tibiofibular ligament distal fascicle (Figure 2C). Next, the knotless anchor (Pushlock 2.9 × 15.5 mm; Arthrex) was loaded with sutures and introduced into the fibular tunnel by impaction while the ankle was held in dorsiflexion and eversion (Figure 4). Finally, sutures were cut with arthroscopic scissors and the incisions were closed. A removable walking boot was applied.

Postoperative Protocol

The same postoperative protocol was utilized in both groups. The removable walking boot was kept on at all times for the first 3 to 4 weeks. Partial weightbearing as tolerated with the aid of crutches was recommended from the day following surgery. Formal physiotherapy was initiated after the walking boot was removed. Progressive strengthening and exercises to increase ROM of the ankle were advised. Return to noncontact sports (eg, swimming and cycling) was allowed 2 months postoperatively, and return to any sports without restrictions was allowed 3 months postoperatively depending on muscle conditioning.

Statistical Analysis

Statistical analysis was performed using SPSS 23 (IBM Corp, Armonk, NY). Descriptive results were presented as median, mean, and range. Several tests were used to



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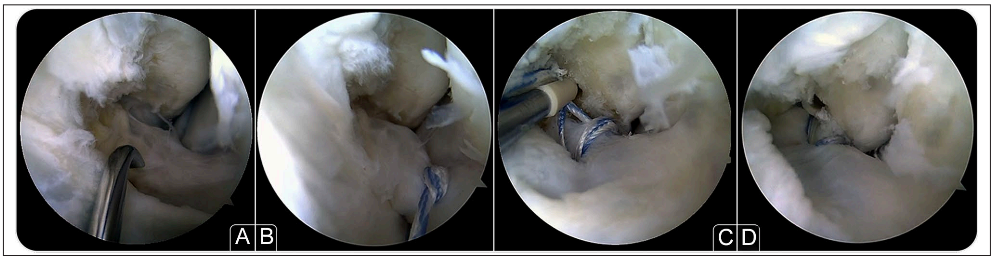

Figure 4. Arthroscopic all-inside anterior talofibular ligament (ATFL) repair. With the help of a (A) suture passer the ATFL is grasped with a (B) high-resistance suture. With a (C) knotless anchor the ligament is reattached onto its (D) native footprint.

Table 1. Characteristics of Arthroscopic Broström and All-Inside Ligament Repair Groups.

	Arthroscopic Broström group	All-inside repair group	*P* value
No. of patients	20	19	
Sex (male/female)	8/12	9/10	
Side (right/left)	13/7	9/10	
Mean age, y (range)	30.2 (18-42)	30.9 (18-46)	<.001
Mean follow-up, mo (range)	19.6 (12-28)	20.7 (13-32)	<.001

evaluate the difference between both surgical techniques. For qualitative variables, Pearson's chi-square and Fisher statistical test were used with continuity correction when necessary. For quantitative variables, the Mann-Whitney *U* test for independent samples was used, since the null hypothesis of data normality by the Kolmogorov-Smirnov test was rejected. Pre- and postoperative VAS and AOFAS results were also evaluated with the Wilcoxon signed-rank tests. *P* values <.05 were considered statistically significant.

Results

The 2 groups were homogenous, and no significant difference was noted in mean age and follow-up (Table 1).

In both groups the AOFAS and VAS scores significantly improved compared with preoperative values ($P < .001$) (Table 2): in the AB group the mean AOFAS score improved from 67 (range, 44-87) to 92 (range, 76-100) and the mean VAS score from 6.4 (range, 3-10) to 1.2 (range, 0-3); in the AI group the mean AOFAS score changed from 60 (range, 32-87) to 93 (range, 76-100) and the mean VAS score from 6.1 (range, 4-10) to 0.8 (range, 0-3). With regard to the AOFAS and VAS improvement, there was no difference ($P > .1$) between groups.

At the final follow-up, 8 complications (40%) were recorded in the AB group (Table 3). Four patients (20%) presented a deficit in ankle plantarflexion >10 degrees compared with the contralateral side, complaining of mild discomfort or pain when plantarflexing the ankle, and it was considered a minor complication. A transient neuritis of the superficial peroneal nerve was experienced in 3 patients (15%). In 1 case (5%) the prominent suture knots required anchor removal 4 months after surgery. Regarding the AI group, only 1 complication (5.3%) involving painful ankle plantarflexion deficit >10 degrees was observed and was considered a minor complication. No cases of neuritis, anchor prominence, or other complications were noted. The differences in complication rates between groups were statistically significant ($P < .05$).

At the latest follow-up, all patients reported subjective improvement in their ankle stability. On clinical examination, the anterior drawer test and the talar tilt test were negative in all patients. To date, no patients required ligament revision surgery. All patients returned to daily and recreational activities without limitations. One patient in the AB group had an ankle sprain after returning to sport activities that was treated conservatively.

Discussion

The most important contribution of this study is that both AB and AI demonstrated similarly excellent clinical results according to AOFAS and VAS scores. However, AB had a higher potential risk of complications.

Arthroscopic techniques to treat ankle instability have significantly evolved in the recent years. While attracting interest from foot and ankle surgeons both the AB and the AI have gained further popularity. They present with the advantage of a minimally invasive approach and the added benefit to arthroscopically treat any concomitant intra-articular pathology besides that of ankle instability. Intra-articular pathology is frequently observed in association with ankle instability, and its treatment at the time of surgery is essential for an optimal result.[3,20,21,29] We believe the potential for addressing both the instability and any associated pathology places ankle arthroscopy as the technique of choice in the presence of ankle instability.[3,7,15,20,21]

Table 2. Clinical Outcomes of Arthroscopic Broström and All-Inside Ligament Repair Groups.

	Scale	Preoperative (range)	Postoperative (range)	*P* value
Arthroscopic Broström group	VAS	6.4 (3-10)	1.2 (0-3)	<.001
	AOFAS	67 (44-87)	92 (76-100)	<.001
All-inside repair group	VAS	6.1 (4-10)	0.8 (0-3)	<.001
	AOFAS	60 (32-87)	93 (76-100)	<.001

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society; VAS, visual analog pain scale.

Table 3. Complications of Arthroscopic Broström and All-Inside Ligament Repair Groups.

Complication	Arthroscopic Broström group (n = 20) (%)	All-inside repair group (n = 19) (%)	*P* value
ROM limitation	4 (20)	1 (5.3)	
Neuritis of SPN	3 (15)	0	
Prominence of suture	1 (5)	0	
Total complications	8 (40)	1 (5.3)	.012

Abbreviations: ROM, range of motion; SPN, superficial peroneal nerve.

Previous studies on AB and AI demonstrated excellent clinical results and a low rate of recurrence of instability of the ankle.[2,8,18,25,27,32] These findings were confirmed in the current study with a statistically significant improvement in clinical scores (AOFAS and VAS) ($P < .001$). When the 2 techniques were compared, no differences were observed in clinical results ($P > .1$). At the latest follow-up, no recurrence of instability was reported in any group.

The main difference observed in the literature between both techniques is in complication rates. Higher complication rates have been reported in the AB technique (5.3%-29%).[18] The 2 most frequently reported complications are neuritis of the superficial peroneal nerve and pain or discomfort due to a prominent anchor or suture knot.[18] This reported higher rate of complications in the AB technique was also confirmed in the current study (40%). Efforts were made to describe a "risk-free" zone for the AB technique,[2] although it is our opinion that nerve complications can be explained due to the percutaneous passage of the suture along the anterolateral aspect of the ankle. In addition, the affected superficial peroneal nerve is known to have multiple anatomical variants plus a mobile path that varies depending on ankle dorsiflexion.[12,28] Anatomical variations in the nerve distribution pose higher risk of injury by the subcutaneous suture passing.[28] Moreover, the nerve moves approximately 2.4 mm laterally when the ankle is dorsiflexed when compared with a plantarflexed and inverted position.[23] In contrast to the AB, the AI is a fully arthroscopic procedure in which the ligament is grasped intra-articularly under direct arthroscopic vision, obviating any risk of subcutaneous nerve entrapment.[17]

As for the postoperative stiffness, it is accepted that a mild deficit in ROM is expected as a consequence of the surgery itself that tightens the stabilizing structures. However, a ROM deficit >10 degrees may compromise the functional outcome and participation in sports activities.[30] In the current study, 4 of 20 (20%) patients from the AB group reported a painful ROM deficit >10 degrees, while in the AI group it was observed in only 1 of 19 (5%) patients. This difference could be explained due to the anatomical elements and tissues grasped with each technique. During the AI procedure, the ATFL and occasionally the CFL remnant are addressed in what is considered an anatomical repair of the ligaments.[34] In contrast, the AB is not strictly an anatomic ligament repair, as the sutures grasp the ligament, the capsule, the IER, and/or the sural fascia while tightening these up. In the authors' opinion, by holding these anatomical structures a secondary effect may ensue, creating ROM deficit and possibly scarring in some patients.

The fact that AB is designed to include the IER to the ligament repair is a matter of controversy known from its open Broström counterpart.[4,10] The augmentation using the IER requires the presence of the superolateral IER band, only present in 25% of cases.[10] In addition, an anatomical study observed that the superolateral IER band is a thin and fragile band that may not add significant mechanical contribution to the ligament repair.[10] This could explain why incorporation of the IER in the traditional Broström procedure showed any mechanical advantage when compared with just a ligament repair without the IER.[4] It is likely that during the percutaneous AB step what is actually tightened is not only the IER but also subcutaneous fatty tissue that brings no real stability to the construct.

In the present study both surgeons had more than 3 years of experience and had performed more than 30 cases of the techniques described. However, it is worth mentioning after the publication of a recent study demonstrating the reproducibility of AI[17] that it is still a demanding technique that requires a

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As for the postoperative stiffness, it is accepted that a mild deficit in ROM is expected as a consequence of the surgery itself that tightens the stabilizing structures. However, a ROM deficit >10 degrees may compromise the functional outcome and participation in sports activities.[30] In the current study, 4 of 20 (20%) patients from the AB group reported a painful ROM deficit >10 degrees, while in the AI group it was observed in only 1 of 19 (5%) patients. This difference could be explained due to the anatomical elements and tissues grasped with each technique. During the AI procedure, the ATFL and occasionally the CFL remnant are addressed in what is considered an anatomical repair of the ligaments.[34] In contrast, the AB is not strictly an anatomic ligament repair, as the sutures grasp the ligament, the capsule, the IER, and/or the sural fascia while tightening these up. In the authors' opinion, by holding these anatomical structures a secondary effect may ensue, creating ROM deficit and possibly scarring in some patients.

The fact that AB is designed to include the IER to the ligament repair is a matter of controversy known from its open Broström counterpart.[4,10] The augmentation using the IER requires the presence of the superolateral IER band, only present in 25% of cases.[10] In addition, an anatomical study observed that the superolateral IER band is a thin and fragile band that may not add significant mechanical contribution to the ligament repair.[10] This could explain why incorporation of the IER in the traditional Broström procedure showed any mechanical advantage when compared with just a ligament repair without the IER.[4] It is likely that during the percutaneous AB step what is actually tightened is not only the IER but also subcutaneous fatty tissue that brings no real stability to the construct.

In the present study both surgeons had more than 3 years of experience and had performed more than 30 cases of the techniques described. However, it is worth mentioning after the publication of a recent study demonstrating the reproducibility of AI[17] that it is still a demanding technique that requires a higher level of expertise in arthroscopy than the AB. The arthroscopic step in the AB is minimal and only aimed at placing anchors onto the fibula. However, the AI procedure is fully performed under direct arthroscopic control. As such, AI is not ideally suitable for the novice ankle arthroscopist. The progress through the learning curve of the surgeon can have implications in the results of the AI technique.

The present study was limited by the fact that a small number of patients were included in each group with no randomization process. Data were collected from 2 different patient cohorts and operating surgeons performing 1 technique each. This may incur a risk of design bias, as may the retrospective nature of the study. However, patients were included consecutively in both cohorts, and surgical indications were the same between the groups. A larger case series with a prospective randomized allocation in groups would certainly improve the validity of the study. Despite the fact that goniometry is commonly used in the clinical setting to measure ankle ROM, the literature suggests that it may not be an accurate measuring method; thus, its use could be considered a limitation.[24] Nevertheless, the same method was used for both groups and the deficit of ankle plantarflexion was also a complaint of the patient. The use of an inclinometer or an automatic device for measurement of ankle ROM could improve the reliability of the measurement and the validity of the study.[35]

Another limitation is that the AOFAS score used is not a validated outcome scale to evaluate ankle instability,[26] and consequently, some clinical aspects may have been overlooked. A specific clinical score to assess ankle instability would have increased the validity of the study.

Conclusion

In conclusion, both the AB and the AI techniques were suitable surgical options to treat chronic ankle instability providing excellent clinical results. However, a higher rate of overall complications was observed in the AB group, particularly involving a painful restriction of ankle plantarflexion and neuritis of the superficial peroneal nerve.

Declaration of Conflicting Interests

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ANKLE

High body mass index is not a contraindication for an arthroscopic ligament repair with biological augmentation in case of chronic ankle instability

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Abstract

Purpose Obesity remains frequently mentioned as a contraindication for lateral ankle ligament repair. The aim of the study was to compare the clinical results of an arthroscopic lateral ligament repair with biological augmentation between patients with a body mass index (BMI) of more than 30 and less than 30.

Methods Sixty-nine patients with an isolated lateral ankle instability were treated with an arthroscopic anterior talofibular ligament (ATFL) repair with biological augmentation using the inferior extensor retinaculum (IER). Patients were divided into two groups according to their BMI: ≥ 30 (Group A; $n=26$) and < 30 (Group B; $n=43$). Patients were pre-and post-operatively evaluated, with a minimum of 2 years follow-up, and using the Karlsson Score. Characteristics of the patients, complications, ankle instability symptoms recurrence, and satisfaction score were recorded.

Results In group A, the median Karlsson Score increased from 43.5 (Range 22–72) to 85 (Range 37–100) at follow-up. Complications were observed in seven patients (27%). Nineteen patients (73%) reported that they were "very satisfied". One patient (4%) described persistent ankle instability symptoms. In group B, the median Karlsson Score increased from 65 (Range 42–80) to 95 (Range 50–100) at follow-up. Complications were observed in four patients (9%). Thirty-three patients (77%) reported that they were "very satisfied". Two patients (5%) described persistent ankle instability symptoms. Pre-operative and at last follow-up Karlsson Score, results were significantly different between the two groups. There was no significant statistical difference in favour of satisfaction score, complications and recurrence of ankle instability between the two groups.

Conclusion ATFL repair with biological augmentation using IER gives excellent results for patients with BMI ≥ 30. Compared to patients with BMI < 30, they present a slightly lower preoperative and postoperative Karlsson score, however, with a similar satisfaction rate, but are at higher risk of transient superficial peroneal nerve dysesthesia.

Level of evidence Level III.

Keywords Ankle arthroscopy · Broström · Gould · Obesity · Body mass index · Chronic ankle instability · Lateral ankle ligament repair · Anterior talofibular ligament · Biological augmentation · Inferior retinaculum extensor

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Introduction

Ankle sprains are amongst the most frequent musculoskeletal injuries and can result in chronic ankle instability (CAI) in up to 40% of the cases. [24] CAI leads to pain, and activity restriction, and threatens at the end stage to severe ankle osteoarthritis [3]. Throughout the years, the open Broström procedure has become the gold standard technique for CAI treatment [5].

Arthroscopic repair procedures have gained popularity in the last years [26] due to the possibility of treating concomitant ankle instability and associated lesions simultaneously through the same arthroscopic approaches, with similar outcomes and complication rates to the open procedure [5, 27, 28]. Traditionally, obesity has been considered one of the contraindications for a Broström procedure, and reconstruction has been advocated in these cases [13].

To the best of our knowledge, this is the first clinical study of an arthroscopic lateral ligament repair procedure that evaluates clinical results according to the patient's BMI.

The aim of the study was to evaluate if obesity (Body Mass Index (BMI) ≥ 30) is a risk factor for an arthroscopic ligament repair with biological augmentation (ALR-BA).

The hypothesis of the study is that patients with BMI ≥ 30 have similar post-operative functional outcomes and satisfaction rates to patients with BMI < 30.

Materials and methods

The study was approved by the Ethics and Research Committee of the Clinique du Sport, Bordeaux-Merignac, France (N° 09.2017.12.)

Between January 2015 and August 2020, all patients treated with an ALR-BA for CAI were included in this retrospective study with prospectively collected data. A failed conservative treatment was observed in all patients after a minimum of 6 months.

Exclusion criteria for the study were a history of ankle surgery, ankle fracture, and the presence of associated ankle lesions requiring treatment during the same operative procedure such as osteochondral defect, concomitant bony impingement, deltoid ligament tear, fibular tendons pathology or posterior ankle pathology that required hindfoot endoscopy. In addition, patients who did not have a minimum 2 years follow-up, were also excluded from the study.

Patients were divided into two groups according to their BMI: ≥ 30 (Group A) and < 30 (Group B). From the initial total group, 26 were included in Group A, and 43 were in Group B.

The flow diagram of the study is presented in Fig. 1. Characteristics of both groups (age, sex ratio, BMI, and follow-up) are presented in Table 1. Karlsson score and a satisfaction score were collected by an independent observer pre- and postoperatively at the last follow-up. All surgical complications were recorded.

All arthroscopic procedures were performed by the senior author, a foot and ankle surgeon with experience in ankle arthroscopy and arthroscopic ligament repair. As previously described, the technique includes two steps, an arthroscopic ligament repair (Fig. 2a, b), and biological augmentation with the inferior extensor retinaculum

Table 1 Groups characteristics

	Group A BMI ≥ 30 (*n* = 26)	Group B BMI < 30 (*n* = 43)
Age, years (median, *range*)	31 *(17–59)*	24 *(15–50)*
Males, *n* (%)	8 (31%)	11 (26%)
BMI, kg/m^2 (median, *range*)	33.2 *(30.2–41.4)*	23 *(18–29)*
Follow-up, months (median, *range*)	40 *(24–82)*	29 *(24–43)*

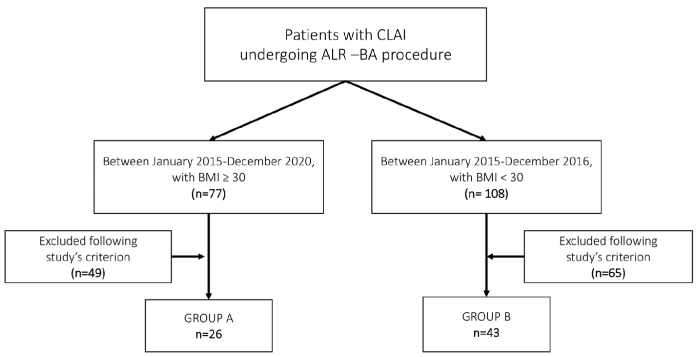

Fig. 1 The flow diagram of the study. *CLAI* Chronic lateral ankle instability, *ALR-BA* Arthroscopic lateral repair with biological augmentation

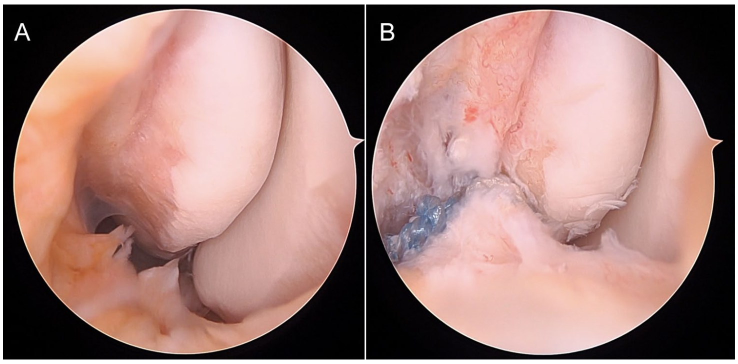

Fig. 2 **a** ATFL proximal rupture. **b** ATFL repair

(IER) (Fig. 3) [6]. First, the ligament is reattached through an arthroscopic procedure. Next, the ligament is augmented with the IER that is endoscopically grasped through a third portal located at mid-distance of the line connecting the lateral malleolus tip and the base of the fifth metatarsal, and 1 cm proximal to this point. Both the ligament repair and its augmentation with IER were performed with the help of an automatic suture passer and two soft anchors, one inserted at the level of the anterior talofibular ligament

(ATFL) footprint and one inserted just proximal to the superior ATFL.

All patients followed the same postoperative protocol. An ankle brace is prescribed for 6 weeks, and physiotherapy with drainage and range of motion is started the day after the surgery. For the first two weeks, a 50% weight-bearing with crutches is permitted with a low-weight molecular heparin as thromboprophylaxis. Full weight-bearing without crutches is started after 2 weeks.

Statistical analysis

EasyMedStat (version 3.20.2) was used to perform all statistical analyses.

Quantitative variables are expressed as median and range. Comparisons within groups were calculated with the Student's T-test for paired quantitative data. Comparisons between the two groups were made with the Mann–Whitney U test for independent quantitative data, and the χ^2 test for qualitative data. A $p < 0.05$ was considered to indicate statistical significance.

Results

In group A, the median Karlsson Score increased significantly from 43.5 (range 22–72) to 85 (range 37–100) at the last follow-up (median difference 34.5, 95% CI 25–45.5, $p = 0.001$). Nineteen patients (73%) reported that they were "very satisfied" with the procedure, 4 (15%) were "satisfied" and 3 (12%) were "non-satisfied".

One patient (4%) described persistent ankle instability symptoms.

Postoperative complications were reported in seven patients (27%). One patient presented a complex regional pain syndrome (CRPS) and two patients had deep venous thrombosis (DVT). Five patients presented neurological complications (18%): two of them presented dysesthesia on

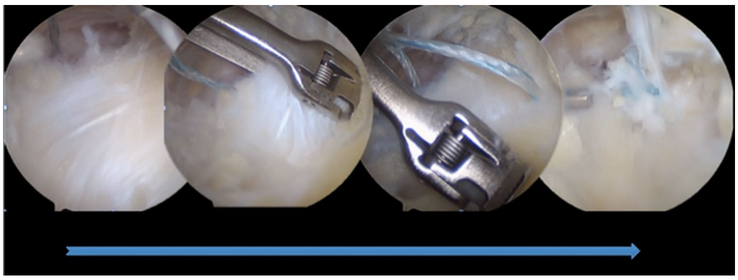

Fig. 3 Biological augmentation with IER

the deep peroneal nerve and three patients presented dysesthesia on the superficial peroneal nerve, which spontaneously resolved. There was no wound healing complication or infection.

At the last follow-up, one patient required revision surgery. Four years after the initial surgery, he suffered a severe ankle sprain playing rugby. With conservative treatment in failure, he benefited from an arthroscopic ankle ligament reconstruction using a gracilis autograft as previously described in the literature [14, 20].

In group B, the median Karlsson Score increased significantly from 65 (range: 42–80) to 95 (range: 50–100) at the last follow-up (median difference: 30, 95% CI 26–31.5, $p = 0.001$). Thirty-three patients (77%) reported that they were "very satisfied" with the procedure, 3 (7%) were "satisfied" and 7 (16%) were "non-satisfied".

Two patients (5%) described persistent ankle instability symptoms. Postoperative complications were reported in four patients (9%). One patient presented a CRPS and one patient had DVT. Two patients presented neurological complications (5%): one with dysesthesia on the superficial peroneal nerve and one with dysesthesia on the deep peroneal nerve, both of which resolved spontaneously. There was no wound healing complication or infection. At the last follow-up, no patient had required revision surgery.

Karlsson Score was significantly different between the two groups preoperatively ($p < 0.001$) with a lower score for patients with a BMI ≥ 30, and at last follow-up ($p = 0.002$) in favour of patients with a BMI < 30.

There was no significant difference in complication, satisfaction score, and recurrence of ankle instability between the two groups.

Discussion

The most important contribution of this study is the excellent clinical outcome of ALR-BA in patients with a BMI ≥ 30 with similar recurrence of ankle instability.

Compared to the open Broström-Gould procedure, arthroscopic treatment has showcased similar outcomes and complication rates [5, 27, 28], validating the technique. Although still no long-term clinical studies for the arthroscopic treatment, the most recent systematic reviews and meta-analyses of comparative studies between the open and arthroscopic treatment even favour the arthroscopic version with a lower rate of complication [2, 22].

In 2017, the ESSKA-AFAS Ankle Instability Group, sent a questionnaire to each expert to survey their surgery indication. Obesity remained controversial with split opinions, as 53.3% of the panel would rather perform a repair than a reconstruction [21].

To the authors' best knowledge, no studies regarding arthroscopic lateral ligament repair in high BMI patients (≥ 30) have been published.

Comparing the results obtained in the current study to the existent literature on arthroscopic ATFL repair with IER augmentation reports a Karlsson Score and a minimum 2 years follow-up [6, 9–11, 16, 29], and two notable differences can be distinguished. First, patients with BMI ≥ 30 have a lower preoperative Karlsson score than reported for patients with BMI < 30. Secondly, patients with BMI ≥ 30 have an excellent but lower postoperative Karlsson score than reported for patients with BMI < 30. These findings are demonstrated in Table 2.

Lee et al. [16], reported similarly lower preoperative and postoperative Karlsson scores in patients with a mean BMI of 29.3. On a cohort of 115 patients and a mean BMI of 23.5, Lopes et al. [18] reported similar satisfaction rates with 81% of the patient satisfied.

The complication rate following arthroscopic lateral ankle ligament repair has been reported to be around 10% [2, 5, 28], with iatrogenic superficial peroneal nerve (SPN) damage being the most reported complication. While primarily minor, we report a higher overall complication rate for patients with BMI ≥ 30 (27%). Although SPN is observed in 57% of patients [17], and specific lectures on portal-related complications have proven useful [19], BMI was found to be the only factor negatively influencing its identification [17], increasing the risk of injury of the SPN.

Regarding the transient deep peroneal nerve dysesthesia, the authors hypothesise that the anesthetic peripheral nerve block is the one responsible for this complication as the standard antero-medial arthroscopic approach has been proven safe. Peripheral nerve block in foot and ankle surgery has been associated with residual neuropathic symptoms [1, 23] up to 24% of patients at 8 months, postoperatively [12].

Regarding DVT, in their meta-analysis, Zhi et al. [28] reported one case for 250 (0.4%) arthroscopically repaired lateral ankle ligaments, which is in line with the overall rate of DVT (0.6%) reported by Huntley et al. [15] on 23,212 patients following foot and ankle surgery. They found that females and high BMI were associated with increased risk for DVT following orthopaedic foot and ankle surgery. Although no BMI information, Cordier et al. [6] reported two cases of DVT on 55 patients (3.6%) following arthroscopic ligament repair with biological augmentation. In the current study, two cases (7.5%) for our high BMI group, affecting women exclusively, raising awareness for this high-risk group even with low-weight molecular heparin given as a thromboprophylaxis.

Better targeting the limits of indications for arthroscopic ligament repair with biological augmentation is mandatory, as high BMI is mentioned as one indication for arthroscopic anatomical ankle ligament reconstruction [25].

Table 2 Arthroscopic lateral ligament repair with biological augmentation using the IER, with min 2 years follow-up and Karlsson Score

Study	*n*	BMI	Pre-op KS	LFU KS	LFU (months)
Zhou et al. [29]					
AO group	31	24.4	54.6	87.5	29.7
Feng et al. [10]					
Remnant ATFL repair group	49	25.0	66.6	91.1	24
Feng et al. [11]					
1 Anchor group	36	25.1	69.3	85.7	44.0
2 Anchors group	39	24.8	68.8	91.6	43.7
Cordier et al. [6]	55	NR	64	92	29
Lee et al. [16]					
With IER group	45	29.3	46.5	83.7	32.6
Feng et al. [9]					
HMS group	31	21.8	64.1	86.3	24
FES group	37	23	67.4	90.5	24
Guiraud et al					
BMI ≥ 30 group	26	33.2*	43.5*	85*	40*
BMI < 30 group	43	23*	65*	95*	29*

KS Karlsson Score, *LFU* Last Follow-Up, *AO* Arthroscopic, *NR* Non-Reported, *HMS* Horizontal Mattress Suture, *FES* Free-Edge Suture, * Median

In a prospective multicenter study comparing 171 arthroscopic ligament reconstructions versus 115 arthroscopic ligament repairs, Lopes et al. reported an overall complication rate three times higher for the reconstruction group [18]. It seems logical to prioritise ligament repair over reconstruction.

Finally, and according to the results obtained in the current study, obesity should not be considered a contraindication for arthroscopic ligament repair with biological augmentation, and it provides an alternative to ligament reconstruction techniques.

Several limits are present in our study. The use of the IER as an augmentation remains controversial and is refuted by some authors due to its limited effect on ankle stability [4] or due to the anatomical variations of the IER that can affect the amount of retinaculum grasped [7, 8]. However, in contrast with a percutaneous technique for augmentation, lateral endoscopy can visualise and grasp a tissue identified as the IER.

Another limitation of this study is the use of a non-specific score to evaluate ankle instability.

Finally, other functional outcomes, such as return to sport, were not evaluated.

More studies are still needed to evaluate arthroscopic lateral ligament repair, with or without augmentation, in patients with BMI ≥ 30 and, ideally, compare it to arthroscopic or open ligament reconstruction.

Conclusion

In conclusion, arthroscopic ligament repair with biological augmentation provides in patients with BMI ≥ 30 excellent clinical and patient's satisfaction results, however, with a higher risk of transient superficial peroneal nerve dysesthesia.

Author contributions All authors fulfil the criteria according to the ICMJE Guidelines.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare they have no conflict of interest.

Ethical approval The study was approved by the Ethics and Research Committee of Clinique du Sport, Bordeaux-Merignac, France (N° 09.2017.12.).

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Original article

Five-year clinical follow-up of arthroscopically treated chronic ankle instability

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ABSTRACT

Introduction: Arthroscopic treatment of lateral ankle instability is a recent innovation. In 2014, a prospective study was initiated by the French Society of Arthroscopy demonstrating the feasibility, morbidity and short-term results of arthroscopic treatment of ankle instability.
Hypothesis: The functional results of arthroscopic treatment of chronic ankle instability found after one year were maintained in the medium term.
Material and methods: The prospective follow-up of the patients included in the initial cohort was continued. The Karlsson and AOFAS scores, as well as patient satisfaction, were assessed. The causes of failure underwent univariate and multivariate analyzes. The results of 172 patients were included (40.2% ligament repairs; 59.7% ligament reconstructions). The average follow-up was 5 years. The average satisfaction was 8.6/10, the average Karlsson score was 85 points and the average AOFAS score was 87.5 points. The reoperation rate was 6.4% of patients. The failures were related to an absence of sports practice, a high BMI and female gender. A high BMI and the intense sports practice were associated to ligament repair failure. The absence of sports practice and the intraoperative presence of the anterior talofibular ligament were associated to ligament reconstruction failure.
Discussion: Arthroscopic treatment of ankle instability confers high satisfaction in the medium term, as well as long-lasting results with a low reoperation rate. A more detailed evaluation of the failure criteria could help guide the choice of treatment between ligament reconstruction or repair.
Level of evidence: II.

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1. Introduction

Arthroscopic treatment of ankle instability has been developing for several years. The advantages of arthroscopy include a thorough joint assessment, allowing the treatment of lesions associated with ligament injuries and achieving the most anatomical treatment possible [1–3]. A distinction is usually made between two

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Table 1
Failure criteria of arthroscopic treatment of chronic ankle instability.

Failures	Criteria retained
Instability	Satisfaction < 8 + Karlsson instability score < 20
Pain	Satisfaction < 8 + Karlsson pain score < 15 and AOFAS < 30
Stiffness	Satisfaction < 8 + Karlsson stiffness score = 0
Overall	1 or more associated causes

types of arthroscopic treatment: ligament repairs [4] and anatomical ligament reconstructions [5].

Anterior talofibular ligament (ATFL) repairs potentially associated with repair of the calcaneofibular ligament (CFL) and reinforcement of the extensor retinaculum are derivatives of the technique described by Broström and modified by Gould [6]. Ligament reconstructions use a graft to replace the ATFL and CFL when repair is no longer possible.

In 2014, the French Society of Arthroscopy endorsed a prospective multicenter study, which assessed the short-term morbidity and efficacy of these arthroscopic treatments. The results were published in 2017 [7] and demonstrated that arthroscopic techniques had excellent short-term efficacy with high satisfaction rates, as well as lower morbidity compared to conventional open surgery. Longer-term evaluations of arthroscopic ligament repair or reconstruction techniques has never been performed.

The aim of this study is to present the long-term follow-up of the 2014 cohort and to identify factors linked to failure of arthroscopic treatment of chronic ankle instability. The hypothesis was that the functional results of arthroscopic treatment of chronic ankle instability found at one year persisted at five years.

2. Material and methods

Inclusion, patient follow-up and the statistical analysis of this study were based on STROBE recommendations [8]. Two hundred and eighty-six patients were included between January 30, 2014 and April 30, 2017. The initial cohort has been described in the aforementioned article from 2017 [7]. All surgeons who took part in the study were asked to recontact the patients they had included. The evaluation criteria sought were satisfaction rated from 0 (not satisfied at all) to 10 (perfectly satisfied), new surgery on the ankle, type and level of sport practiced and occupation. The Karlsson [9] and AOFAS [10] scores were measured. Failure of surgical treatment was defined by a failure related to the recurrence of instability (defined by a satisfaction below 8 and a response other than "No/My ankle twists 1 to 2 times per year during activities" in the Karlsson score) or failure related to pain (satisfaction below 8 and a response other than "no pain or occasional pain" in the Karlsson or AOFAS score) or failure related to stiffness (reported satisfaction below 8 and a "marked/severe stiffness" response in the Karlsson score) or the combination of several factors (Table 1).

Continuous variables were described by their average, standard deviation and range of maximum and minimum values. The Mann–Whitney U-test or the Student's t-test were used to compare quantitative data and the Chi^2 test or Fischer's exact test for qualitative data. p-values < 0.05 were considered significant. A univariate analysis was used to identify potential risk factors for overall failure, failure related to instability and failure related to pain, as chosen from literature data or failure trends from the 2017 study. A multivariate logistic regression model was constructed to identify independent risk factors for failure (overall, instability-related, pain-related). Statistical analysis was performed using EasyMedStat software (version 3.17; http://www.easymedstat.com/).

3. Results

The initial cohort included 286 patients (115 ligament repairs or 40.2% and 171 ligament reconstructions or 59.7%); 172 (60.1%) could be included and assessed. The average follow-up was 60.5 months ± 7.9 months (49.6–85.7). Ligament repairs were of 56 patients or 48.6% of the initial cohort and reconstructions were of 116 patients or 67.8% of the initial cohort. Patient demographics are reported in Table 2.

3.1. Comparison with the original group

There was no significant difference between the initial group and the patients followed up at 5 years, neither on the demographic data (age, sex, BMI, sports level, accident at work or hyperlaxity), nor on the type of lesions identified preoperatively, nor on the type of intervention, nor on the preoperative value of the Karlsson and AOFAS scores. A higher proportion of patients in the cohort had already described failure in 2017 (22.1% vs. 19%; $p = 0.17$).

3.2. Satisfaction

The average patient satisfaction score was 8.6 out of 10 (CI [8.3; 8.9]) with no difference between the two groups (repair 8.9 – CI: [8.48; 9.31]; reconstruction 8.5 – CI: [8.11; 8.93]). By defining patient satisfaction by a score equal to or greater than 8/10, 82% of patients were satisfied, with no difference between the 2 groups (repair 86%; reconstruction 80%).

3.3. Reoperation

A proportion of 6.4% of patients underwent reoperation with no difference between the two groups (repair 6.9%; reconstruction 5.4%). There were 4 hardware removals (knot repair or fibular endobutton), surgical cure of chronic hamstring tendon insertion tendinopathy (following removal of the Gracilis tendon) and two unhealed osteochondral lesions. Two ligament repairs benefited from reconstruction. Finally, three patients underwent iterative ligament reconstruction.

3.4. Sports activity

Resumption of regular sports activity occurred in 71.5% of patients with no significant difference between the two groups (73.2% in the repair group, 70.7% in the reconstruction group). The level of sport was continued at the same stage as before the injury in 85% of cases; 87% in case of repair, 83.7% in case of reconstruction with no significant difference between the groups.

3.5. Professional work

Eight patients had to change their occupation since the initial intervention. In the repair group, 1 patient had to change their role. In the reconstruction group, there were 6 changes of occupation, including 3 for an occupation equivalent in terms of physical labor, 2 for a position with less physical labor and 1 patient in the reconstruction group was deemed to have a long-term disability, thus ending his professional career.

3.6. Functional scores

The average AOFAS score was 87.5 points (CI: [84.88; 89.93]), 85.0 points (CI: [80.96; 88.97]) in the repair group and 88.6 points (CI: [85.31; 91.84]) in the reconstruction group. A significant drop of 7 points ($p < 0.001$) was found between the intermediate evaluation

Table 2
Baseline patient demographics. Sport level according to IKDC score: 1 sports with jumps, pivots, abrupt change of direction – 2 intense activities but with less pivoting – 3 straight line activities without jumps or pivots – 4 sedentary activities. Associated lesions identified during exploratory arthroscopy.

Demographic data	Total (n = 172)	Repairs (n = 56)	Reconstructions (n = 116)	p-value
Age (years)	34.4	29.3	36.9	**< 0.001**
Gender f/m (%)	44.2/55.8	60.7/39.3	36.2/63.8	**0.004**
BMI	25.2	23.4	26	**< 0.001**
Hyperlaxity (%)	13.95	17	12.1	0.35
Work accident (%)	14.5	12.5	15.5	0.65
Sport (%)				
None	28.5	26.7	29.3	> 0.99
Leisure	48.4	51.1	47.7	
Competitive	21.7	22.2	21.5	
Professional	1.2	0	1.7	
Level of sport (IKDC – %)				
1	24.6	34.5	19.6	0.18
2	9.6	29.1	30.4	
3	35.9	29.1	39.3	
4	29.9	7.3	10.7	
Osteochondral lesions of the talus (%)	14.2	13	14.8	0.82
Presence of ATFL (%)	54.1	100	31.9	**0.001**
Anteromedial impingement (%)	44.8	46.4	44.0	0.90
Anterolateral impingement (%)	50.6	44.6	53.5	0.35
Chondral lesions (%)	29.7	35.7	26.7	0.30
Pathological syndesmosis (%)	1.2	1.8	0.9	0.55

f: female; m: male; ATFL: anterior talofibular ligament. Bold type indicates a statistically significant difference.

and the last follow-up for the repair group. A small non-significant increase was found in the reconstruction group.

The average Karlsson score was 85 points (CI: [82.22; 88.04]), 82.2 points (CI: [77.35; 87.01]) in the repair group and 86.5 points (CI: [82.84; 90.26]) in the reconstruction group. A significant drop of 7.5 points ($p < 0.002$) was found between the previously published assessment and the last follow-up for the repair group. A small non-significant increase was found in the reconstruction group.

3.7. Failure

The overall failure rate was 23.8% with no significant difference between reconstructions (22.4%) and repairs (26.8%). Instability was a more common cause of failure in the ligament repair group, but persistent pain was the main cause of failure (18.6%) with no significant difference between the 2 groups. Pain manifested predominantly from participating in sports or being on unstable ground. Finally, 7% of patients (n = 12; 5 repairs, 7 reconstructions) complained of ankle stiffness.

Satisfaction and functional results are listed in Table 3.

The progression of clinical scores and failures between the evaluation at 1 year and at 5 years are reported in Table 4 for ligament repairs and in Table 5 for ligament reconstructions.

3.8. Causes of failures

Univariate analysis of potential factors associated with overall failure showed a significant association with BMI ($p < 0.01$); the female gender ($p = 0.02$), the absence of preoperative sports practice ($p = 0.002$) and the practice of less demanding sports (level 3 and 4 of the IKDC classification). No association was noted between overall failure and age, absent ATFL or the presence of associated joint lesions. Accidents at work were almost twice as numerous in the failure group; 22% compared to 12% but non-significant (OR = 2.02 [0.82; 5.0], $p = 0.13$). These factors are listed in Table 6.

The absence of sports practice ($p = 0.01$), high BMI ($p = 0.01$) and female gender ($p = 0.02$) were statistically significant risk factors for overall failure as identified by multivariate analysis.

A failure subgroup analysis was performed. The female gender was a cause of instability-related failure in univariate and multivariate analyses ($p = 0.028$). High BMI ($p = 0.032$), female gender ($p = 0.022$) and the practice of light sports or a sedentary lifestyle (level 3 and 4 of the IKDC classification) were causes of pain-related failures ($p = 0.036$) in a univariate analysis.

A high BMI ($p = 0.03$ in a multivariate analysis) and the practice of level 1 and 2 sports of the IKDC classification were causes of overall failure for ligament repairs ($p = 0.17$ in univariate analysis). The absence of sports practice ($p = 0.01$ in multivariate analysis) and the intraoperative presence of ATFL ($p = 0.02$ in univariate analysis) were causes of overall failure for ligament reconstructions. These risk factors are listed in Table 7.

4. Discussion

To our knowledge, this series is the largest with the longest follow-up concerning the arthroscopic treatment of chronic ankle instability. We identified a very high satisfaction rate in more than 80% of patients. This study thus corroborates the findings of other studies on the progression of arthroscopy in the arthroscopic treatment of ankle instability [11–14].

This study has certain limitations. Its multicentric design may be the source of certain biases: differences in diagnostic criteria for chronic ankle instability, indications, repair techniques (with or without extensor retinaculum reinforcement, use of different arthroscopic equipment, repair with or without a knot) and different postoperative protocols according to the surgeons. The level of expertise of the surgeons was also variable and certain failures might be due insufficient experience with arthroscopic techniques. Nevertheless, the strict inclusion criteria followed by the investigators and patients ensured that chronic instability due to lateral ligament insufficiency was present preoperatively. The same reconstruction technique was used by all the surgeons.

Table 3
Satisfaction and functional results at 5 years.

	Overall ($n = 172$)	Repairs ($n = 56$)	Reconstructions ($n = 116$)
Satisfaction (/10)	8.6	8.9	8.5
Satisfaction (%)	82	86	80
Reoperations (%)	6.4	6.9	5.4
AOFAS	87.5	85	88.6
Karlsson	85	82.2	86.5
Overall failure (%)	23.8	26.8	22.4
Pain failure (%)	18.6	19.6	18.1
Instability failure (%)	11.1	14.3	9.5
Stiffness failure (%)	7.0	9.0	6.0

Table 4
Progression of ligament repair results.

Results of the repairs ($n = 56$)	At 1 year of follow-up	At 5 years of follow-up	*p*-value
Overall failure (%)	21.4	26.8	0.51
Pain failure (%)	14.3	19.6	0.45
Instability failure (%)	10.7	14.3	0.57
AOFAS	92.4	85.0	**0.001**
Karlsson	89.6	82.2	**0.002**

Bold type indicates a statistically significant difference.

Table 5
Progression of ligament reconstruction results.

Results of the reconstructions ($n = 116$)	At 1 year of follow-up	At 5 years of follow-up	*p*-value
Overall failure (%)	22.4	22.4	> 0.9
Pain failure (%)	15.5	18.1	0.59
Instability failure (%)	11.2	9.5	0.67
AOFAS	88.6	87.4	0.197
Karlsson	85.2	88.6	0.24

Table 6
Association between risk factors and overall failure.

Risk factors	Failure	Success	
Age (median)	33.9	34.4	$p = 0.81$
Gender ratio (M/F)	**0.64**	**1.57**	$\mathbf{p = 0.02}$
BMI (median)	**27.53**	**24.09**	$\mathbf{p < 0.01}$
Work accident (%)	21.95	12.21	$p = 0.13$
Preoperative sports practice (%)	**51.2**	**77.9**	$\mathbf{p = 0.002}$
Sports level (ratio: levels 1 and 2/levels 3 and 4)	**0.65**	**1.52**	$\mathbf{p = 0.035}$
Absence of ATFL (%)	36.59	48.85	$p = 0.23$
Presence of associated joint lesions (%)	29.7	20.4	$p = 0.14$

M: male; F: female; ATFL: anterior talofibular ligament. Bold type indicates a statistically significant difference.

Table 7
Significant risk factors for failure of arthroscopic treatment for chronic ankle instability, in bold the significant risk factors from a multivariate analysis.

Risk factor	Overall failure	Instability failure	Pain failure
Total series	**Lack of sports** **High BMI** **Female gender**	**Female gender**	**Female gender** **IKDC sports levels 3 or 4** Elevated BMI
Repairs	**High BMI** IKDC sports levels 1 and 2		
Reconstructions	**Lack of sports** Presence of the ATFL		

ATFL: anterior talofibular ligament.

The second limitation is the large number of patients lost to follow-up. However, the follow-up group remained comparable to the initial group. In addition, patients with failures in 2017 were over-represented at 5 years, but not significantly.

Finally, additional examinations were not systematically carried out to assess for radiological osteoarthritis, objective laxity, proprioception [15,16] of the ankle or the state of the ligament or ligamentisation of the transplant [17]. These additional examinations would have been an important contribution to understanding the failures or the development of ankle osteoarthritis; a possible cause of the stiffness failures.

The defined failure criteria were intentionally severe to allow causes to be more readily identified. Despite a high failure rate, patient satisfaction remained high and functional scores, despite their limitations, remained at a high level over time. The AOFAS score has not been validated for assessments of chronic ankle instability but remains the most widely used [18,19]. These results are comparable to those of publications on the long-term results of open surgery [20–22], particularly the series of the French Society of Orthopedic Surgery (SOFCOT) [23]. In this study, at an average follow-up of 13 years, the satisfaction rate reached 92% and the Karlsson score 90 points for all surgeries combined (Broström, Duquennoy, Castaing, etc.). There were no Gracilis ligament reconstructions in this study.

A lack of preoperative sports practice was found to be an independent cause of failure of arthroscopic ankle stabilization. This has never been reported in other studies. This could be explained by a deficiency in muscle control and proprioception, which are factors contributing to functional instability [24]. Furthermore, the persistence of a functional deficit of the peroneal muscles 2 years after Bröstrom-type ligament repair [25] may not be compensated for in patients who are more sedentary. Thus, a greater risk of developing chronic instability has also been shown in patients with less dynamic control of certain Star Excursion Balance Test tasks or less physical activity 6 months after the initial sprain [26]. Ligament reconstructions also appear to be indicated more often in patients with greater sporting demands [27–29].

A high body mass index is also associated with a risk of failure. This factor has already been established as a risk for developing chronic ankle instability [30,31] but is also a risk factor in the failure of open ligament repairs [32,33].

Female gender was identified as an independent cause of overall failure but also of instability-related and pain-related failure. This factor was not identified in a meta-analysis published in 2021 [34], which involved 618 patients (402 men and 216 women). It has been demonstrated that the risk of chronic ankle instability is greater in the female population in general [31], particularly due to more marked ligament laxity [35].

No association was found between the risk of failure and the presence of associated lesions discovered during arthroscopy. These usually contribute to poorer results [1,36] but as previously mentioned, strict patient selection prior to surgery meant that they were only operated on for ligament lesions. The presence of an ATFL, although always pathological, is associated with an overall failure of ligament reconstructions. This could reflect inappropriate indications.

Patients who sustained work accidents were almost twice as numerous in the setting of failure without there being a significant correlation. This over-representation has previously been identified in the short-term follow-up but also appeared in the long-term follow-up of the SOFCOT cohort [23] and in a 2009 study [37] which found an AOFAS score of approximately 10 points lower in patients with work accidents and a satisfaction score of 1 point lower out of 5.

This study shows that arthroscopic ligament repairs of the Bröstrom-Gould type seem to provide a high level of satisfaction at 5 years, but less enduring clinical scores, particularly in patients with a high BMI and greater sports activity.

Similarly, ligament reconstructions with Gracilis would also confer a high satisfaction rate, results progressing with follow-up and would be better in patients with a high level of sports activity.

From these data, it would be useful to create and test a predictive score for the success of an intervention, like the ISIS score for shoulder instability [38].

5. Conclusion

Arthroscopic treatment of ankle instability maintains satisfactory functional results at 5 years. Ligament reconstructions appear to have better progression over time when compared to ligament repairs. The risk factors for failure (high BMI, female gender and lack of sports practice) must be considered when choosing between ligament repair and reconstruction.

Disclosure of interest

André Thès, Fabrice Colin, Stéphane Guillo declare that they have no competing interest; Michael Andrieu: consultant and developer for Serf Extremity; Guillaume Cordier, Marc Elkaim: Arthrex Consultants; Francois Molinier: Stryker Consultant; Jonathan Benoist: Novastep and Orthonov Consultant; Olivier Boniface: Novastep Consultant; Thomas Bauer: President of the Board of the French Society of Arthroscopy, Arthrex Consultant; Ronny Lopes: Board member of the French Society of Arthroscopy, Arthrex consultant, Consultant and developer for Serf Extremity, Orthopedic Implant Service and Orthonnov.

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Contribution from the authors

André Thès: editing.

Michael Andrieu, Guillaume Cordier, François Molinier, Jonathan Benoist, Fabrice Colin, Marc Elkaïm, Olivier Boniface, Stéphane Guillo, Thomas Bauer: inclusion.

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Review article

Role of surgery in the management of lesions of the medial collateral ligament of the ankle

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ABSTRACT

Medial ankle instability is likely underestimated. Three types of medial collateral ligament (MCL) lesion exist: isolated lesions, in case of valgus sprain in external rotation; lesions associated with chronic lateral instability, in case of rotational instability; and lesions associated with medial insufficiency and valgus flat-foot. Diagnostic confirmation and treatment of MCL lesions, isolated or associated with chronic lateral instability, by ligament suture is at present largely arthroscopic. Chronic MCL lesions with valgus flat-foot are probably irreversible: ligament reconstruction is unreliable, and bone surgery (osteotomy, fusion) is required.

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1. Introduction

Medial ankle instability is often thought to be rare, but is likely underestimated, being often overlooked, difficult to diagnose and little described in the literature.

There is no doubt as to the importance of the medial ligamentous plane in ankle stability and function; complete medial collateral ligament (MCL) tear is well-established in Weber B ankle fracture. However, diagnostic and therapeutic management of acute and chronic MCL lesions in case of medial sprain or chronic instability is less clear and is subject to controversy.

Apart from MCL lesions associated with ankle fracture, 3 main types are encountered:

- isolated lesions, in case of valgus sprain in external rotation, are relatively rare, in 5-7% of ankle sprains [1,2];
- lesions associated with chronic lateral instability, inducing rotational instability: the MCL is involved in more than 80% of chronic lateral collateral ligament injuries, due to abnormally elevated anterior drawer in talar internal rotation [3,4];
- and lesions associated with medial insufficiency, as in valgus flat-foot: the MCL and more particularly the spring ligament is subject to abnormal strain and is liable to be injured in case of posterior tibial tendon failure or abnormal hindfoot valgus [5].

Precise knowledge of MCL anatomy is obviously a prerequisite for the understanding and description of these lesions. After providing some anatomic reminders, we shall describe the 3 main types of lesion and the corresponding diagnostic approaches, and attempt to specify the respective treatments.

1.1. Anatomy

The MCL (also known as the deltoid ligament) comprises 2 bundles: superficial and deep. Some authors consider the spring ligament to be part of the MCL, due to its attachments and involvement in medial ankle stability [6].

The superficial bundle comprises 4 ligaments, all with proximal origin in the medial malleolus (Fig. 1): the tibionavicular tibio-spring, tibiocalcaneal and posterior tibiotalar ligaments. The tibio-spring and tibiocalcaneal are constant and the other 2 inconstant.

The deep bundle comprises 2 ligaments (Fig. 1): anterior and posterior tibiotalar ligaments. The posterior tibiotalar ligament is constant, thick and resistant; the anterior tibiotalar ligament is inconstant [7].

The MCL stabilizes the ankles under eversion, valgus and rotational stress [6]. The deep bundle is an important stabilizer in valgus, limiting lateral translation and abduction of the talus and eversion of the ankle. It is rarely injured but, when it is, talar

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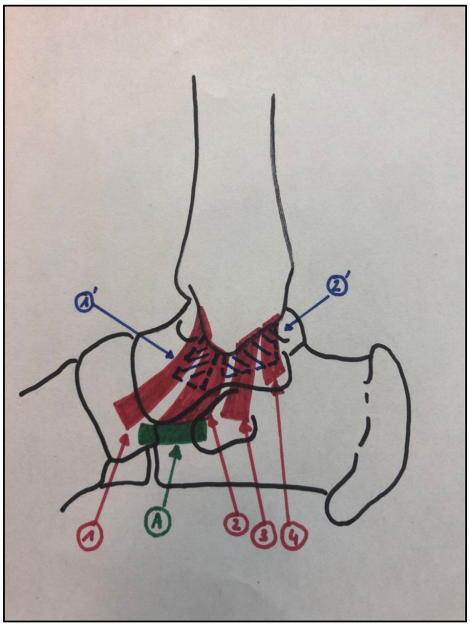

Fig. 1. Medial collateral ligament anatomy (drawing by O. Barbier): Superficial bundle, comprising tibio-navicular ligament (1), tibio-spring ligament (2), tibio-calcaneal ligament (3) and posterior tibio-talar ligament (4). Deep bundle, comprising anterior (1′) and posterior (2′) tibio-talar ligaments. A: Spring ligament.

translation increases from the normal value of 2 mm to 3.7 mm [8]. The superficial bundle limits external rotation and valgus stress in the foot and hindfoot, but seems to be less important than the deep bundle for stabilization in valgus. It is often injured in lateral malleolar fractures; it is also subject to particular stress and injury in case of chronic lateral instability (83% rate of medial lateral collateral ligament lesion in case of lateral collateral ligament lesion) [7,9,10]. Ziai et al. showed that co-involvement of the lateral collateral ligament and the deep MCL bundle, and the tibio-calcaneal ligament in particular, significantly increased lateral and rotational instability, increasing talar internal rotation. In case of lateral collateral ligament lesion, the tibiocalcaneal ligament becomes an important secondary stabilizer in inversion [11].

1.2. Isolated MCL lesion

Isolated MCL lesions occur in valgus external rotation sprain. Interview seeks to determine the mechanism, which is not the same as in lateral sprain in inversion. Patients complain mainly of medial pain. In the acute phase, examination finds hematoma around the medial malleolus with pain on MCL palpation. Ankle pain precludes ligament testing. X-ray rules out fracture. Ultrasound confirms diagnosis of severe MCL sprain and screens for associated lesions. First-line treatment is non-operative, with 1 month's strict low boot non-weight-bearing immobilization. Rehabilitation is initiated as soon as possible.

Diagnosis is often much more difficult in chronic cases. Medial pain is often the main presenting symptom; patients do not systematically report instability. The mechanism of the initial sprain or valgus instability episodes again needs to be determined, suggesting medial ligament lesion. Clinical examination finds pain on MCL palpation and screens for medial ligament laxity as compared to the contralateral side. Complete clinical examination of the ankle reveals signs of any associated lesions or for differential diagnosis. Complementary examinations complete the work-up. X-ray screens for signs of proximal ligament avulsion in the form of ligament ossifications, and can rule out anteromedial bone impingement, which is a differential diagnosis in medial pain. X-ray also specifies foot morphotype and hindfoot axis. Valgus flat-foot is a risk factor for medial ligament lesions. Ligament assessment is based on MRI and ultrasound, which are not always easy to interpret, especially when a medial ligament lesion is found without further detail. However, they do rule out associated lateral ligament lesions or tibiofibular syndesmosis. Contrast-enhanced CT- or MRI-arthrography may show contrast medium passage between the proximal ligament enthesis and the bone insertion, revealing bone avulsion. In chronic cases, the bone insertion area is, however, usually filled by fibrosis.

Diagnosis of isolated chronic MCL instability is thus radiological and clinical. When medical treatment fails, arthroscopic treatment is the first-line attitude.

Progress in ankle arthroscopy has improved both diagnosis and treatment of medial ligament lesions. As a first step, it provides ligament assessment, confirming the lesion and surgical indication (Figs. 2 and 3). Knowledge of arthroscopic anatomy enables the medial ligament plane to be isolated for repair. Anterior arthroscopy easily visualizes the deep anterior part of the MCL. However, the superficial and deep bundles cannot be separated under arthroscopy; taken together, they constitute the “medial ligament complex”.

The patient is positioned supine with a tourniquet at the root of the thigh; anesthesia is usually locoregional. The classic ankle anterior arthroscopic approaches are used. The first step is lesion assessment. Exploration of the medial groove assesses the anterior insertion of the deep MCL bundle; this may require careful resection of fatty tissue adhering to the articular side of the ligament. In the second step, the arthroscope is introduced in the anterolateral portal and the palpator in the anteromedial portal. Exploration thus locates the distal anterior part of the medial malleolus, with no ligament insertion, confirming proximal avulsion of the MCL: the palpator introduced under the malleolus can pass over the medial side. Using a shaver, the scar tissue between the malleolus and the ligament is resected and the malleolar insertion is freshened. The shaver is used as a stick, to painstakingly isolate the medial side of the MCL (Fig. 4). An accessory medial portal is located by needle and created to insert an anchor at the distal part of the malleolus (Fig. 5). The sutures are then retrieved in the anteromedial portal and passed into the proximal MCL lateral-to-medially; 2 anchors can be used. The ligament reinsertion knot is on the medial side of the MCL, to avoid joint impingement (Fig. 6). Postoperative care includes 6 weeks' ankle brace immobilization (day and night for the first 4 weeks), with 40% body-weight non-weight-bearing for 30 days. Rehabilitation is initiated immediately.

This procedure can also be performed in severe acute tibiofibular sprain with associated severe proximal MCL lesion.

1.3. MCL lesion with rotational instability

In rotational instability of the ankle, lateral ligament laxity is sometimes associated with an anterior MCL lesion. Chronic functional failure of the anterior talofibular ligament increases talar anterior translation and internal rotation, inducing anterior proximal MCL avulsion. In lateral ligament instability, clinical examination screens for medial pain, which may have various origins. The proximal lesion of the anterior MCL is one, and is not to be confused with impingement due to malleolar osteophytosis. An anterior malleolar osteophyte can mimic anterior MCL avulsion.

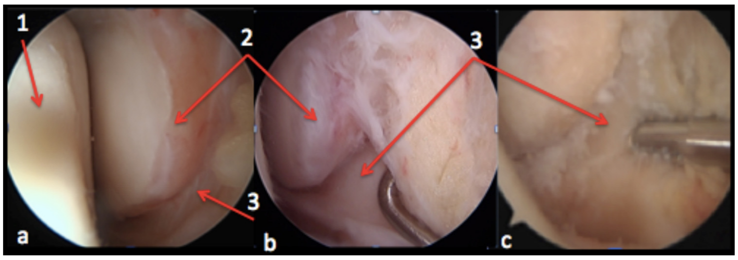

Fig. 2. Normal arthroscopic view of anterior MCL. a. Visualization on inspection. b. Testing by palpator. c. After resection anterior malleolar osteophyte. 1. Talus; 2. Medial malleolus; 3. MCL.

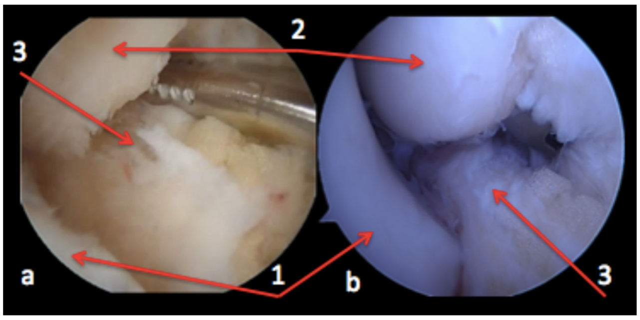

Fig. 3. Pathologic arthroscopic view of anterior MCL. a. Open-book lesion. b. Complete proximal lesion. 1. Talus; 2. Medial malleolus; 3. MCL.

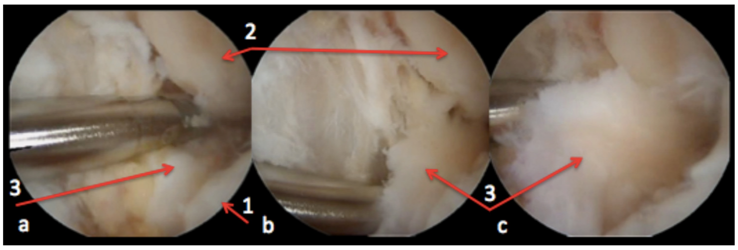

Fig. 4. MCL dissection. a. Resection of fibrosis adjacent to avulsion and freshening of bone insertion. b. Dissection of medial MCL. c. Reducibility testing. 1. Talus; 2. Medial malleolus; 3. MCL

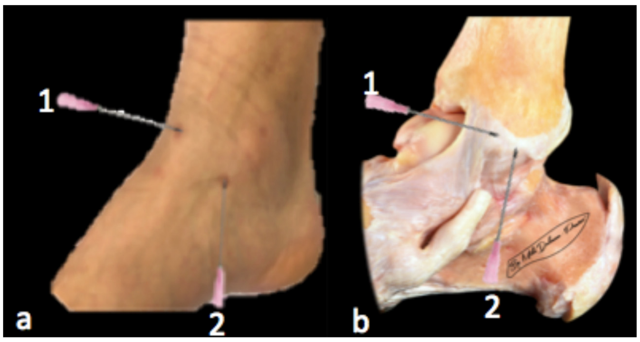

Fig. 5. Portal positioning. a. External view of portal positioning. b. Anatomic view of portal trajectories. 1. Classic anteromedial portal for anchor insertion in open-book repair. 2. Accessory medial portal for anchor insertion in distal and medial malleolus for repair of complete MCL avulsion.

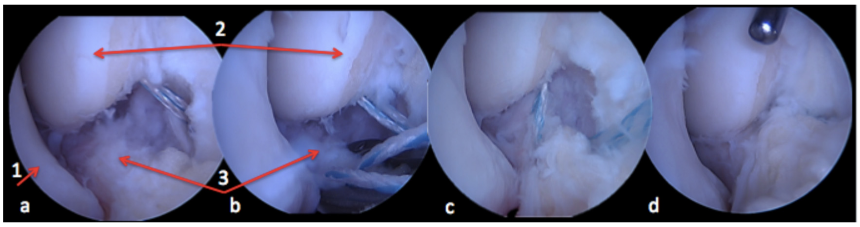

Fig. 6. MCL suture. a. Anchor insertion via accessory medial portal. b. Ligament suture by suture passer after bringing sutures into anteromedial portal. c. Visualization of the 2 sutures passed medial-to-laterally. d. Final result (knot on medial side of ligament). 1. Talus; 2. Medial malleolus; 3. MCL

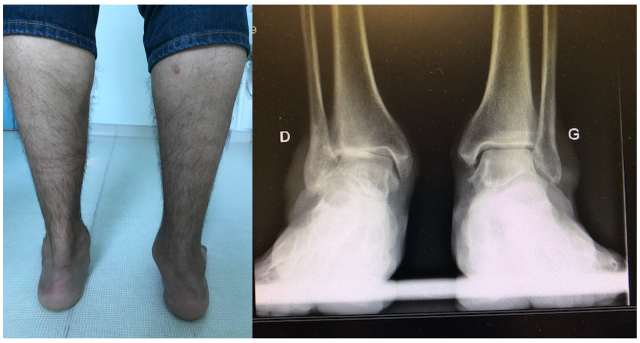

Fig. 7. Patient with right valgus hindfoot due to chronic MCL and posterior tibial lesion (A). Radiography confirms intra-articular valgus (B).

Knowledge of arthroscopic anatomy is thus essential, so as not to over-indicate repair. Normal anatomy needs to be known: there are no ligament insertions at the apex or anterior side of the medial malleolus.

During systematic exploration of the medial groove during arthroscopic lateral ligament reconstruction, the palpator screens for ligament detachment from the bone on the anterior and medial side of the malleolus: i.e., the "open book" lesion described by Vega [12]; this can be repaired arthroscopically, the malleolar osteophytes having already been resected in the search for the lesion.

The portals are inverted, the anteromedial portal being instrumental. Like for isolated MCL lesions, the ligament insertion area on the medial malleolus is shaved. The medial side of the anterior MCL is isolated. An anchor is inserted via the anteromedial portal to the avulsion area or a few millimeters above, depending on the type of anchor, to achieve sufficient ligament tension, and the two sutures are passed in the anterior part of the MCL lateral-to-medially. The knot enables reinsertion, and again is on the medial side of the ligament to avoid joint impingement. Postoperative care is as in lateral ligament reconstruction.

1.4. MCL lesion with medial insufficiency

Associated chronic medial insufficiency and valgus flat-foot may have two different etiopathogeneses:

- usually idiopathic valgus flat-foot decompensating with secondary medial capsule-ligament insufficiency due to excess stress;
- or, conversely, longstanding medial capsule-ligament trauma inducing secondary valgus flat-foot.

The association of valgus flat-foot and MCL lesion corresponds to Myerson's grade 4 [13].

The main presenting symptom in longstanding medial capsule-ligament insufficiency is medial pain, without instability as such, and a sensation of the ankle "giving way".

Positive diagnosis is based on clinical examination finding flat-foot with hindfoot valgus and pronation [8]. Medial pain may be associated along the course of the posterior tibial tendon, spring ligament and MCL. Clinical medial laxity may be found. Initial imaging on AP and lateral weight-bearing X-ray finds loss of talar centering and intra-articular valgus (Fig. 7).

Work-up screens for posterior tibial tendinopathy with pain along the tendon course exacerbated by opposed inversion starting from eversion or, in case of tear, a sudden sharp pain. Imaging findings of uncovered talar head, increased talo-calcaneal divergence and/or Djian and Meary-Tomeno angle closure suggest primary osseous valgus flat-foot. Meary cerclage hindfoot view differentiates hindfoot valgus as of either intra-articular or osseous origin.

Severity assessment screens for calcaneal tendon retraction, associated hallux valgus and posterior tibial tendon lesion. Hindfoot osseous valgus reducibility is assessed on the single heel-rise test, which, in case of posterior tibial tendon involvement, shows no automatic hindfoot varus when standing on tip-toes. Radiologic work-up is completed by valgus/varus stress views and MRI or CT-arthrography, screening for intra-articular valgus reducibility, spring ligament and posterior tibial tendon involvement or valgizing osteoarthritis.

This work-up distinguishes supple IV A grade 4 valgus flat-foot or rigid IV B in case of osteoarthritis [14].

First-line treatment is medical, with orthoses or orthopedic insoles.

If this fails, various conservative surgical procedures have been described: medial ligament reconstruction associated to

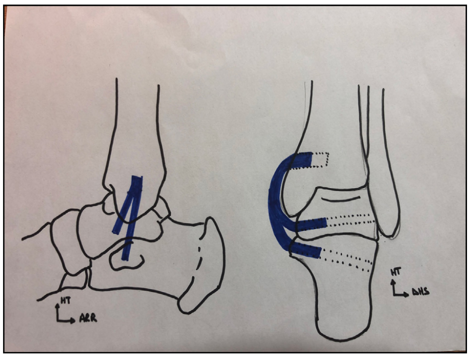

Fig. 8. Myerson MCL Y plasty by gracilis.

soft-tissue procedures (posterior tibial reinforcement, posterior tibial tendon combing, spring ligament suture, etc.) and bone procedures (Evans or Myerson calcaneal osteotomy, supramalleolar osteotomy, arthrorisis screw). There are no indications for isolated MCL suture, which is insufficient in chronic cases as the ligament is poorly vascularized, loses tension and heals poorly. Suture on MCL anchors is thus only effective in the acute phase. Various ligament reconstruction techniques have been described, using the peroneus longus, flexor hallucis longus, posterior tibial tendon, calcaneal tendon or allograft. The main two use the calcaneal tendon following Deland, reconstructing only the deep capsule-ligament plane, or hamstrings following Myerson, reconstructing the deep and superficial MCL bundles [15–17] (Fig. 8). More recently, an alternative to repair or reconstruction was described, with suture reconstruction augmented by artificial ligament without osteotomy [18].

Non-conservative surgery such as fusion or total ankle replacement are to be considered in advanced stages.

Concerning indications, in Myerson grade IV, in case of reducible supple talocrural deformity (Myerson IV A), treatment focuses on the flat-foot with associated MCL reconstruction. In stiff flat-foot with fixed intra-articular deformity (Myerson IV B), pan-talar (talocrural plus subtalar) fusion is performed. Hindfoot reconstruction involves treating all associated midfoot and lateral collateral ligament lesions if necessary, and treatment of the valgus flat-foot in case of progressive valgus deformity plus calcaneal lengthening osteotomy.

2. Conclusion

Treatment of chronic medial instability of the ankle may in some cases be arthroscopic, with the advantages reported in lateral instability: reduced iatrogenesis, and treatment of associated lesions. In rare complex cases of instability with medial insufficiency, conservative surgery provides unreliable or disappointing results; this pathology is probably irreversible, with little role for MCL reconstruction as opposed to fusion.

Disclosure of interest

The authors declare that they have no competing interest.

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None.

Authors' contributions

Olivier Barbier: article writing and re-editing.
Guillaume Cordier: article writing and re-editing.
Fabrice Colin: article writing and re-editing.

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MRI Assessment of Tendon Graft After Lateral Ankle Ligament Reconstruction

Does Ligamentization Exist?

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and Benjamin Dallaudiere,[§††] MD, PhD
Investigation performed at Clinique du Sport, Vivalto Santé, Bordeaux-Merignac, France

Background: No description exists in the literature about the normal evolution of tendon graft after a lateral ankle ligament (LAL) reconstruction.

Purpose: To assess the magnetic resonance imaging (MRI) characteristics and the evolution of the tendon graft during different moments in the follow-up after an endoscopic reconstruction of the LAL.

Study Design: Cohort study; Level of evidence, 3.

Methods: This prospective study included 37 consecutive patients who underwent an endoscopic reconstruction of the LAL with an autograft using the gracilis tendon to treat chronic ankle instability (CAI) resistant to nonoperative treatment (CAI group) and 16 patients without ankle instability (control group). All patients in the CAI group underwent a postoperative assessment at 6, 12, and 24 months using the Karlsson score and MRI examination. Only patients with good and excellent results were included in the study. Graft assessment consisted of qualitative measurements and quantitative evaluations of the reconstructed anterior talofibular ligament (RATFL) and reconstructed calcaneofibular ligament (RCFL), including signal-to-noise quotient (SNQ) and contrast-to-noise quotient (CNQ) measurements in proton density–fat suppressed (PD-FS) and T1-weighted sequences. The analysis of variance test was used to compare the SNQ and the CNQ at different time points for each sequence.

Results: The MRI signal at 6 months was increased compared with that of the control group. Next, a significant signal decrease from 6 to 24 months was noted on PD-FS and T1-weighted images. SNQ measurements on PD-FS weighted images for both the RATFL and the RCFL demonstrated a significantly higher signal ($P < .01$ and $P = .01$, respectively) at 6 months compared with that of the control group. Subsequently, the signal decreased from 6 to 24 months. Similarly, CNQ measurements on PD-FS weighted images for both the RATFL and the RCFL demonstrated a significantly higher signal ($P < .01$ and $P < .01$, respectively) at 6 months compared with that of the control group. Subsequently, the signal decreased from 6 to 24 months.

Conclusion: The present study demonstrated an evolution of the MRI characteristics, suggesting a process of graft maturation toward ligamentization. This is important for clinical practice, as it suggests an evolution in graft properties and supports the possibility of creating a viable ligament.

Keywords: lateral ankle ligament; chronic ankle instability; ligamentization; ligament reconstruction; magnetic resonance imaging; signal-to-noise quotient; tendon graft healing

Chronic ankle instability (CAI) is a common complication after an ankle sprain.[14] Surgical treatment is considered in case of remaining symptoms despite adequate nonsurgical treatment.[28] Anatomic repair and reconstruction are the 2 preferred surgical techniques.[32,36] In recent years, arthroscopic anatomic repair techniques have been increasingly published.[6,34] Although anatomic ligament repair is still the most commonly performed technique, some relative contraindications exist.[7] In those cases, a reconstruction of the lateral ankle ligaments (LAL) should be considered. This involves reconstructing the anterior talofibular ligament (ATFL) and the calcaneofibular ligament (CFL). Recently, an endoscopic technique for ligamentous reconstruction has been developed.[12] The validity of this technique has been confirmed by anatomic[27] and clinical studies.[7,13,25] Although ankle ligament reconstruction using tendon graft has already proved its ability to restore functional properties over time, there is no literature about the normal evolution of tendon graft. It is unknown whether this reconstructed ligament undergoes a maturation process resulting in native ligament

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properties.[19] In anterior cruciate ligament (ACL) reconstruction (ACLR), the postoperative magnetic resonance imaging (MRI) aspect of the tendon graft showed an evolution according to its state of maturation.[15,33] Ligamentization research for reconstructed ACLs showed an evolution of MRI signals comparable with histological changes.[38] The T1-weighted sequence is used to assess the morphological aspect, while the proton density–fat suppressed (PD-FS) sequence is used to assess the tissue's inflammatory level and healing stage. Therefore, in ankle ligament reconstruction, the normal evolution of the MRI aspects of tendon graft may be very useful in assessing the process of graft maturation. This information may be useful to guide the rehabilitation process and return to sports, such as after ACLR in the knee.[2,23,26] These data are also useful for developing MRI criteria that can be used as a reference to assess postoperative imaging after LAL endoscopic reconstruction.

This study aimed to describe the MRI aspects and the evolution of tendon graft after an endoscopically reconstructed ATFL (RATFL) and CFL (RCFL). A group of patients was examined in terms of the short-, mid-, and long-term MRI features and clinical outcomes. This study hypothesized that a postoperative MRI analysis of tendon graft after an LAL reconstruction (LALR) would allow the assessment of graft remodeling and demonstrate ligamentization signs.

METHODS

This study included 37 patients who underwent an endoscopic reconstruction of the LAL. All patients operated in our institution between September 2016 and June 2018 were tested for eligibility. This single-center cross-sectional study was approved by the ethics and research committee of Clinique du Sport, Bordeaux-Merignac, France (No. 09.2017.13), and patients gave informed consent.

The inclusion criteria were persistent reports of ankle instability despite a nonsurgical treatment for ≥6 months. The exclusion criteria were earlier ankle surgery or ankle fractures and additional procedures modifying the postoperative protocol (calcaneal osteotomy for hindfoot varus, gastrocnemius lengthening). The diagnosis of mechanical ankle instability was confirmed via clinical tests, including positive anterior drawer and talar tilt. Diagnosis of ATFL and CFL ruptures was confirmed via ultrasound. All patients were operated on by the same surgeon (G.C.), an experienced foot and ankle surgeon. The surgical procedure involved ligament reconstruction of the ATFL and the CFL using a gracilis tendon autograft. Fixation was provided by a tenodesis screw in the talus, an interference screw in the calcaneus, and an Endobutton (Tight rope ACL RT; Arthrex). in the fibular tunnel.[27] Postoperatively, an ankle brace was indicated for 4 weeks, night and day, and gradually removed over 15 days. Partial weightbearing was permitted. Physical therapy was begun immediately, with a protocol allowing full weightbearing at 2 weeks and nonweightbearing sports at 6 weeks postoperatively (swimming or cycling). Running was introduced progressively from 3 months. The return to competition took place around 5 months.

All included patients underwent a postoperative clinical assessment, including the Karlsson score at 6, 12, and 24 months, by an orthopedic surgeon (J.O.). At the same times, an MRI was performed. As the study focused on the normal evolution of the reconstructed ligaments, only patients with good or excellent clinical scores were included (Karlsson >80). The MRI aspects of the reconstructed ligaments in the study group were compared with the normal ligaments of a control group of 16 patients without a history of instability reports, sprains, or ankle surgery.

MRI Evaluation Protocol

MRI examinations were performed using a 1.5 tesla MRI scanner Optima GEM450 (GE Healthcare) comprising 3 conventional axial, sagittal, and coronal views in PD-FS and T1-weighted sequences (Table 1).

Imaging data were collected once for the control group and 3 times (at 6, 12, and 24 months postoperatively) for the CAI group. MRI images were assessed in consensus by a musculoskeletal radiologist and an independent foot and ankle surgeon (S.B. and J.O.). All measurements were performed in the central part of the ligaments (Figure 1).

The normal ATFL and CFL were assessed in the control group. The RATFL and RCFL were evaluated in the CAI group.

For qualitative analysis, the general impression of the graft signal was given as a "low," "intermediate," or "high" signal.

For quantitative analysis, regions of interest (ROIs) of 6 pixels were placed in the ATFL, CFL, fat, muscle, and talar bone, as well as in the void on axial images at 6, 12, and ≥24 months. For both axial T1 and PD-FS sequences, the

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TABLE 1
Summary of MRI Sequence Parameters[a]

	TR, ms	TE, ms	Nex	FOV, cm	Thickness, mm	Spacing, mm	Slices, n	Duration
Axial T1	3.130	minimum	3	17	3.5	1	20	1 min 08 s
Axial PD-FS	3.083	45	3	17	3.5	1	20	1 min 57 s
Sagittal PD-FS	2.500	45	2	16	3.5	0.5	17	2 min 35 s
Coronal PD-FS	3.344	45	4	17	3.5	0.5	22	2 min 47 s

[a]FOV, field of view; MRI, magnetic resonance imaging; Nex, number of excitations; PD-FS, proton density–fat suppressed; TE, time to echo; TR, repetition time.

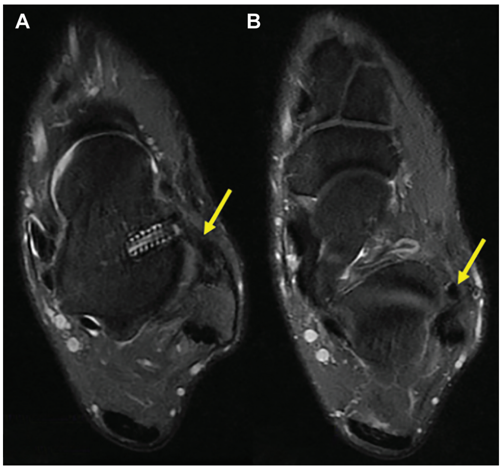

Figure 1. Area of reconstructed anterior talofibular ligament signal measurements (A) and area of reconstructed calcaneofibular ligament signal measurements (B) are indicated by yellow arrows.

signal-to-noise quotient (SNQ) and the contrast-to-noise quotient (CNQ) of the different limbs were evaluated. The SNQ was determined by dividing the mean pixel value over the ROI by the standard deviation of the noise. The Gaussian noise standard deviation was calculated as the standard deviation of the signal measured in a background ROI on the magnitude image divided by 0.695. This value was used to correct the Rayleigh distribution of noise for a 4-element phased-array coil, as shown by Constantinides et al.[5] The CNQ was also determined by subtracting the SNQ of the 2 closer neighboring ROIs (ATFL/fat, CFL/fat).

Statistical Analysis

Statistical analysis was performed using R Software (R Core Team). Categorical data are expressed as fractions (percentages). SNQ and CNQ data were normally distributed. Means were calculated and used for comparison between groups. Therefore, we used an analysis of variance test to compare SNQ and CNQ at different times for each sequence. $P < .05$ was considered significant.

RESULTS

A total of 37 patients were initially enrolled in the CAI group (Table 2). Also, SNQ and CNQ data are presented in Tables 3 and 4, respectively.

MRI assessments were conducted at 6, 12, and 24 months on 36, 30, and 20 patients, respectively (Figure 2). Sixteen patients were also included in the control group.

Image Analysis of Normal and Reconstructed Ligaments

Qualitative Assessment. The normal ATFL and CFL from the control group showed a thin band structure and a low signal in all sequences (Figure 3). The RATFL and RCFL showed a thicker linear band structure than did the normal anatomic ATFL and CFL.

All signal measurements of reconstructed ligaments were compared with those of the control group. The control group demonstrated a low signal for both ligaments in all sequences.

The signal of the RATFL and RCFL was high at 6 months and decreased between 6 months and 24 months postoperatively on PD-FS (Figures 4 and 5, respectively) and T1-weighted images (Figures 6 and 7, respectively).

The qualitative results of the CAI are summarized in Figure 8.

Quantitative Assessment. SNQ and CNQ measurements of RATFL and RCFL were compared with those of the control group corresponding to the qualitative visual analysis assessment.

Analysis of SNQ. Normal ATFL and CFL have SNQ measurements of 16.9 ± 3.4 and 17.8 ± 6.8 in PD-FS, respectively, and 8.2 ± 2 and 11.3 ± 2.9 in T1-weighted images, respectively. All SNQ measurements in the CAI group are summarized in Figure 9.

On PD-FS images, SNQ measurements for RATFL and RCFL demonstrated a significantly higher signal ($P < .01$ and $P = .01$, respectively) at 6 months compared with that of the control group. The SNQ for RATFL decreased significantly between 6 to 24 months postoperatively ($P < .0001$). The SNQ for the RCFL also decreased significantly between 6 and 12 months ($P = .04$) and between 6 and 24 months ($P < .0001$).

TABLE 2
Patient Characteristics of the CAI and Control Groups[a]

Variable	All Patients (N = 37)	6 mo (n = 33)	12 mo (n = 29)	24 mo (n = 20)	Control Group (n = 16)
Age, mean (SD), y	43 (6.7)	43 (6.9)	42 (5.7)	44.5 (5.3)	38.5 (18)
Sex, n (%)					
Male	23 (62.2)	21 (63.6)	17 (58.6)	14 (70)	10 (62.5)
Female	14 (37.8)	12 (36.4)	12 (41.4)	6 (30)	6 (37.5)
Side, n (%)					
Right	24 (64.9)	21 (63.6)	18 (62)	14 (70)	6 (37.5)
Left	13 (35.1)	12 (36.4)	11 (38)	6 (30)	10 (62.5)
Karlsson, mean (SD)	91.5 (8.7)	91.5 (8.7)	90.7 (6.8)	98.2 (3.4)	100 (0)

[a]CAI, chronic ankle instability.

TABLE 3
Data of Signal-to-Noise Quotient[a]

Ligament	MRI	Control Group	6 mo	12 mo	24 mo
ATFL	PD-FS	9 ± 2.7	32.4 ± 7.5	24.1 ± 5.9	22.3 ± 10.8
	T1	8.2 ± 2	38.5 ± 5.9	36.7 ± 4.4	35 ± 8.7
CFL	PD-FS	12.2 ± 5.5	20.1 ± 4.6	17.4 ± 5.2	17 ± 8
	T1	11.3 ± 2.9	33.3 ± 5.5	32.6 ± 5.5	29.7 ± 8.6

[a]Data are presented as mean ± SD. ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; MRI, magnetic resonance imaging; PD-FS, proton density–fat suppressed.

TABLE 4
Data of Contrast-to-Noise Quotient[a]

Ligament	MRI	Control Group	6 mo	12 mo	24 mo
ATFL	PD-FS	30.1 ± 10	8.2 ± 8.2	–4.7 ± 11.3	–8.4 ± 7.8
	T1	173.1 ± 46.9	–92 ± 26.7	–104.5 ± 22	–118.1 ± 39.8
CFL	PD-FS	26.8 ± 8.2	–4 ± 6.8	–11.3 ± 10.5	–13.6 ± 7.8
	T1	169.8 ± 47.2	–99.4 ± 26.8	–110.5 ± 22.7	–126.5 ± 40.2

[a]Data are presented as mean ± SD. ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; MRI, magnetic resonance imaging; PD-FS, proton density–fat suppressed.

No significant SNQ variation was found on T1-weighted images.

Analysis of the CNQ. CNQ measurements on PD-FS were −15.9 ± 11.8 and −15.1 ± 8.3, respectively, for the normal ATFL and CFL and 173 ± 46.9 and 169.8 ± 47.2, respectively, for T1-weighted images. All CNQ measurements in the CAI group are summarized in Figure 10.

On PD-FS images, CNQ measurements at 6 months for both the RATFL and the RCFL confirmed a significantly higher signal than that of the control group ($P < .01$ and $P < .01$, respectively). The CNQ for the RATFL decreased significantly from 6 to 24 months ($P = .0001$). The CNQ for the RCFL significantly decreased from 6 to 24 months ($P = .02$).

On T1-weighted images, CNQ measurements for the RATFL and the RCFL demonstrated a significantly higher signal ($P < .01$ and $P < .01$, respectively) at 6 months compared with that of the control group. The CNQ for the RATFL decreased from 6 to 24 months ($P = .03$). The CNQ for the RCFL decreased from 6 to 24 months ($P = .04$).

DISCUSSION

The present prospective study assessed the MRI characteristics of a tendon graft in a cohort of patients with good clinical outcomes. It demonstrated an evolution of the MRI aspects of the tendon graft after an ATFL and CFL reconstruction. Compared with that of the control group, the MRI images showed a high occurrence of high signal at 6 months and a signal decrease from 6 to 24 months. This evolution suggests a process of graft maturation.

The native ATFL and CFL, as well as the normal semitendinosus and normal gracilis tendons (used for grafts), have a low MRI signal in all sequences as described in the literature.[41]

Earlier research assessed the MRI aspects of the ATFL after ligament repair. The repaired ATFL was described as a linear band structure with a low signal and a low SNQ on MRI assessment.[39] Liu et al[24] demonstrated that the ATFL in CAI ankles had a higher SNQ than that of the control

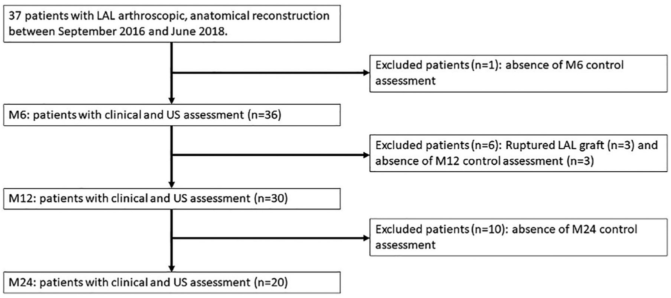

Figure 2. Flowchart of patient inclusion. LAL, lateral ankle ligament; M, month; US, ultrasound.

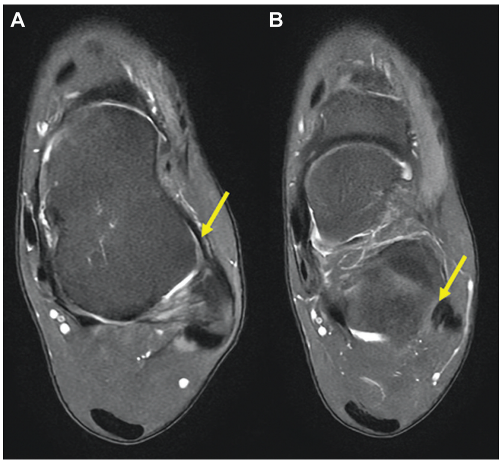

Figure 3. Area of normal reconstructed anterior talofibular ligament signal measurements in the control group (A) and normal calcaneofibular ligament signal measurments in the control group (B) are indicated by yellow arrows.

group; after surgical repair, the mean SNQ value of the ATFL decreased, indicating that the repaired ATFL became tight postoperatively. To date, no earlier research has assessed the MRI characteristics after LALR.

In knee surgery, gracilis and semitendinosus tendon grafts are commonly used for ACLR. Several published studies have focused on graft maturation of the reconstructed ACL. In addition to MRI studies, histologic studies have been used to assess the process of graft remodeling after ACLR in animals and humans.[1,4] Three phases are distinguished—(1) an early healing phase with central graft necrosis (0 to 6 months); (2) a proliferative phase with revascularization and remodeling (3-12 months); and (3) a maturation or ligamentization phase (9-48 months).[16,33] The literature has demonstrated that the tendon graft transforms into an ACL-like ligament for ACLR without completely restoring biological properties.[17,31]

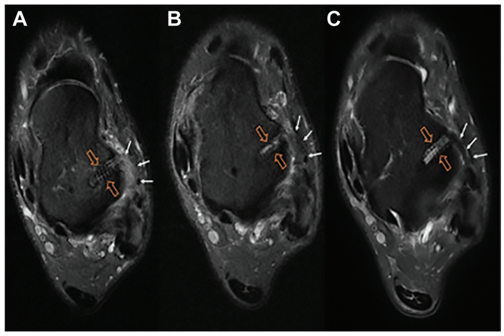

Figure 4. Proton density–fat suppressed weighted sequence with axial ankle view at (A) 6, (B) 12, and (C) 24 months after anatomic lateral ankle ligament reconstruction showing the morphological/signal magnetic resonance imaging evolution of the ATFL graft—ATFL graft (white arrows) and talar tunnel (large open arrows). ATFL, anterior talofibular ligament.

The tendon graft maturation has also been demonstrated on MRI scans.[38] Howell et al[15] proposed a classification depending on the signal intensity of the graft (low, intermediate, or high) to evaluate its maturation. A low signal of the graft similar to the native posterior cruciate ligament is considered a sign of graft maturation.[16] A high signal was correlated with hypervascular tissue and corresponded with inferior biomechanical properties.[11,30] The SNQ method, measured using an ROI tool, is currently the reference to evaluate graft maturation.[10,20,21,29,35] A correlation has been described between histologic modifications of the ACL graft and SNQ in an animal study.[37] High SNQ corresponds to poorer graft maturity.[40] In a systematic review, Van Groningen et al[33] found an initial signal increase in the SNQ until 6 months, followed by a signal decrease. It

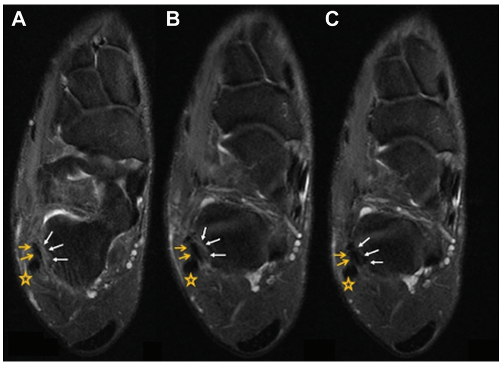

Figure 5. Proton density–fat suppressed weighted sequence with fat-suppressed axial ankle view at (A) 6 months, (B) 12 months, and (C) 24 months after anatomic lateral ankle ligament reconstruction showing the morphological/signal magnetic resonance imaging evolution of the CFL graft—the CFL graft (white arrows), the peroneus brevis tendon (thick arrows), and the peroneus longus tendon (stars). CFL, calcaneofibular ligament.

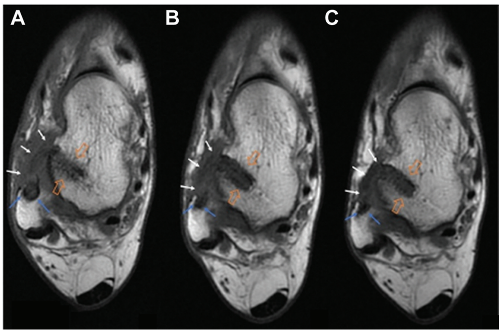

Figure 6. T1-weighted axial view of the ankle at (A) 6 months, (B) 12 months, and (C) 24 months after anatomic lateral ankle ligament reconstruction showing the morphological/signal magnetic resonance imaging evolution of the ATFL graft—the ATFL graft (white arrows), the talar tunnel (large arrows), and the fibular tunnel (gray arrows). ATFL, anterior talofibular ligament.

is commonly accepted that the ACL graft shows a low signal on all sequences immediately postoperatively and after 2 years.[38] However, it has also been demonstrated that a moderate, nonliquid PD-FS hypersignal is present between 3 and 12 months.[18,35] The initial increase of the SNQ in the postoperative period until approximately 6 months corresponds to increased water content and vascularity related to a process of synovialization, which could be seen from 3 months onward.[33]

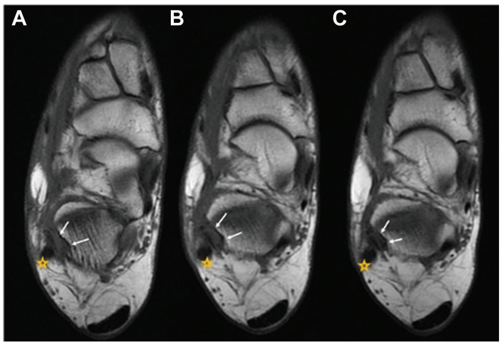

Figure 7. T1-weighted axial view of the ankle at (A) 6 months, (B) 12 months, and (C) 24 months after anatomic lateral ankle ligament reconstruction showing the morphological/signal magnetic resonance imaging evolution of the CFL graft—the CFL graft (white arrows) and the peroneus longus tendon (stars). CFL, calcaneofibular ligament.

Measurement of the different MRI characteristics has been commonly used after ACLR to assess graft maturation.[33] The surgical technique of LALR shows several similarities with that of ACLR. A tendon graft is used in both surgical techniques. During LALR, the tibiotalar joint capsule is partially removed, resulting in tendon grafts becoming in an intra–articular like area. The synovial liquid is beneficial to support the graft pending revascularization. By analogy, it seems reasonable to find similar results about the remodeling of the autograft after LALR.

In the present study, the qualitative view and the SNQ/CNQ of the RATFL and the RCFL demonstrated a high signal at 6 months, and then the signal decreased significantly over 24 months. This process of graft maturation in the ankle is similar to what has been reported for the tendon grafts used for ACL surgery.

The process of graft maturation toward ligamentization is essential for clinical practice. LALR offers the advantage of providing biological tissue at the normal anatomic location of the concerned ligaments. The arguments for ligamentization of the tendon graft confirm the possibility of recreating the LAL.

The current findings are also helpful in postoperative radiographical assessment. Therefore, understanding the normal evolution of the graft tissue is of high importance. The MRI findings of our study can be utilized as a reference for radiologists in particular to determine what a well-functioning LAL graft should look like.

Concerning the schedule of the postoperative rehabilitation, even if the primary stability is excellent, it seems logical to have a progressive loading of the LAL to respect the remodeling of the graft. Although studies concerning ACLR do not demonstrate a correlation between graft maturity and the clinical results,[3,21] understanding periods when the graft is most fragile allows for the modification of

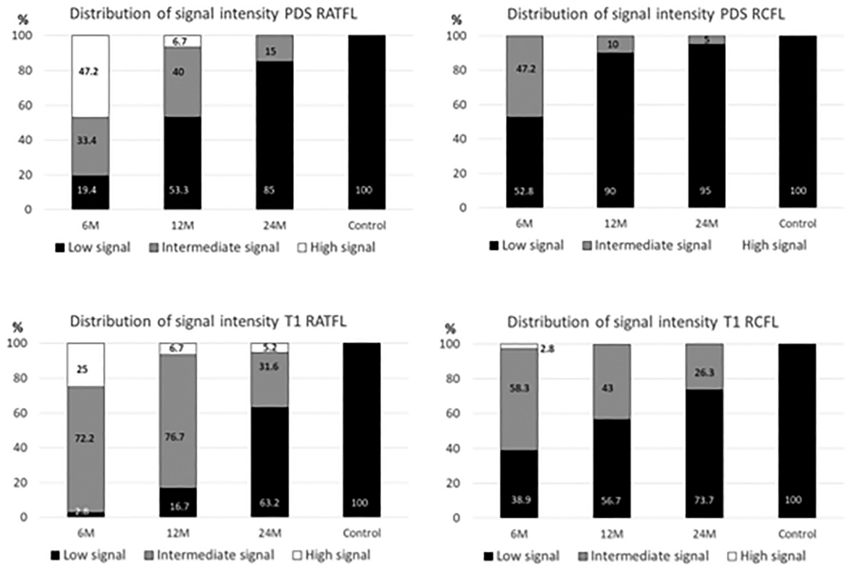

Figure 8. Main qualitative results of visual analysis of the graft from PD-FS and T1 images during the 6 to 24 months of follow-up in the chronic ankle instability group. PD-FS, proton density–fat suppressed; RATFL, reconstructed anterior talofibular ligament; RCFL, reconstructed calcaneofibular ligament.

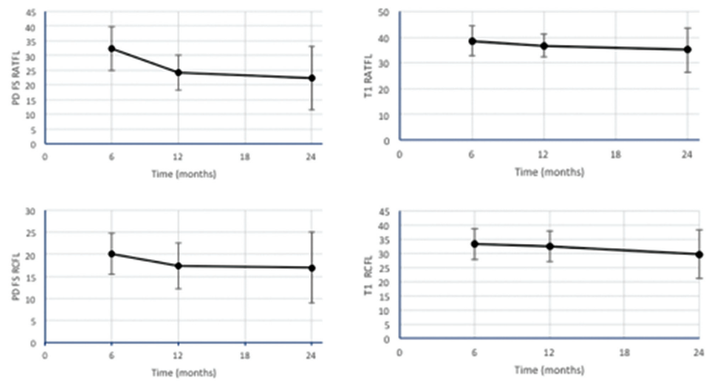

Figure 9. The signal-to-noise quotient of the graft in the chronic ankle instability group was determined using the PD-FS and T1 images. Measurements were performed at 6, 12, and 24 months. PD-FS, proton density–fat suppressed; RATFL, reconstructed anterior talofibular ligament; RCFL, reconstructed calcaneofibular ligament.

rehabilitation exercises. For the same reasons, to prevent reinjury, athletes cannot be allowed to return to the field before the final stage of graft maturation. The literature on animal studies demonstrated that lower graft signal intensity is correlated with higher strength and superior biomechanical properties of the reconstructed ligament.[2,9,37] A similar correlation has been shown after ATFL repair open repair. A lower signal intensity in the ATFL based on preoperative MRI scans is associated with a better clinical outcome—particularly a higher rate of return to sport.[22]

Our results should be interpreted with the following limitations. First, no MRI analysis of the RATFL and

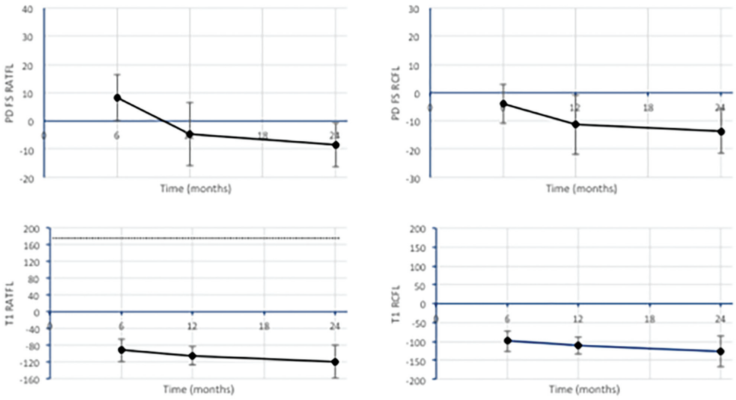

Figure 10. The contrast-to-noise quotient of the graft in the chronic ankle instability group calculated from the PD-FS and T1 images. Measurements were performed at 6, 12, and 24 months. PD-FS, proton density–fat suppressed; RATFL, reconstructed anterior talofibular ligament; RCFL, reconstructed calcaneofibular ligament.

RCFL grafts was performed in the immediate postoperative period. This may complicate the interpretation of the evolution in the first 6 months. However, the qualitative and quantitative measurements of the native ATFL and CFL in the control group correspond with the literature.[8] Second, 17 patients were lost to follow-up between 6 and 24 months follow-ups. However, all patients had good to excellent results during the last MRI. Finally, this study assessed the MRI appearance of intact, well-functioning autografts. This should be taken into account when interpreting the results of this study. The data presented can be compared with future studies assessing allografts or abnormal conditions.

CONCLUSION

This study demonstrated an evolution of the MRI characteristics of the tendon graft after an ATFL and CFL reconstruction. Compared with that of the control group, the MRI scans showed a high signal at 6 months and a signal decrease from 6 to 24 months. A similar evolution was demonstrated by the SNQ and CNQ measurements. The findings of this study suggest a process of graft maturation similar to the graft in ACLR. When SNQ analysis is used as an indirect measure of graft maturation, MRI is the only method available for assessment. MRI scans could be a clinically significant, relevant, and easy-to-obtain assessment of graft maturity when assessing the outcomes of reconstructed LAL and readiness for return to work and sport.

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13. Discussion

The arthroscopic repair of ATFL was firstly introduced in the 90s by Hawkins (87) and Ferkel (88). The use of ankle arthroscopy in the management of lateral instability then developed in the 2000s. Reconstruction using tendon grafts of the lateral ankle ligament under arthroscopy began in the 2010s. Since then, numerous studies have analyzed the results of arthroscopic techniques. Since 2019, the start of our thesis work, the number of publications comparing the results of open and arthroscopic surgical techniques for chronic lateral ankle instability has increased exponentially. This growth demonstrates the need for this work to help establish a therapeutic strategy. In 2013, aware that there were no recommendations on surgical indications for the management of lateral ankle instability, Guillo and the ankle Instability group published an expert consensus article on the indications and place of arthroscopy in the surgical management of ankle instability (89). This work confirms a similar evolution in ankle ligament surgery to that already seen for knee and shoulder joints, namely the gradual transition from non-anatomical open surgery to anatomical surgery under arthroscopy. Indeed, an anatomical technique is recommended because non-anatomical procedures, even if they stabilize the ankle, can lead to excessive joint stress, limit joint amplitude and result in arthropathy. Also, the use of a tendon from the peroneal muscles, which are dynamic lateral stabilizers of the ankle, does not make sense from a biomechanical point of view. These techniques should therefore no longer be used (90). The arthroscopic technique is also gradually and naturally becoming the norm: The high incidence rate of associated lesions with ligament injuries in ankle instability has led to an increase in the use of arthroscopy during ligament surgery. Many surgeons begin the surgical procedure with ankle arthroscopy to treat these associated lesions and then perform in a second part of the procedure, the open ligament surgery. Progressively, surgeons have used arthroscopy to perform ligament repair as well with an all-inside procedure. Firstly, to clean the lateral tibio-talar groove and to visualize ATFL lesion, then to position the anchors, thus performing arthroscopically-assisted open surgery techniques. Finally, the technique was further improved, allowing the ligaments to be sutured and, if necessary, biological reinforcement of the retinaculum to be performed under endoscopy. At the same time, the technique of anatomical reconstruction using a tendon graft has been developed under arthroscopy, and now makes it possible to carry out revision surgery if the repair treatment fails. As well as treating injuries to the lateral ligament, arthroscopy can also be used to treat associated injuries, in particular injuries to the medial ligament. For many years, arthroscopic examination has revealed injuries to the deep plane of the medial ligament. An understanding of the pathophysiology of rotatory instability has made it possible to explain these injuries. The arthroscopic technique makes it possible to treat them during the same operation by repairing the ligament, as described in our thesis article: **“Role of surgery in the management of lesions of the medial collateral ligament of the ankle”.**

The first objective of our thesis was to study the results of a cohort of patient treated by arthroscopic repair with retinaculum augmentation (Broström-Gould arthroscopic). Our study: **"Arthroscopic ankle lateral ligament repair with biological augmentation gives excellent results in case of chronic ankle instability"** provides information on the medium-term results of this arthroscopic technique. The post-operative scores of our cohort of 55 patients with a 2-year follow-up showed an increase in the AOFAS score from 74 to 90. The Karlsson score improved from 65 to 95. We conclude that arthroscopic all-inside ATFL repair with biological augmentation using the IER is a viable option for surgical treatment of chronic ankle instability. The analysis revealed no major complications, but 1 revision at 23 months post-operatively. This technique has the advantage of its mini- mally invasive approach and the potential to treat concomi- tant ankle intra-articular pathology in the same procedure.

To validate the results of our series, we felt it necessary to compare them with other publications on arthroscopic repair. If we analyze our study with published results for the same arthroscopic Broström-Gould technique, we find similar results, as in Yang's study (91).

To conclude, we then studied the results of the open surgery Broström Gould series. Analysis of the literature now provides medium- and long-term results for the techniques. The open surgical repair technique of the Broström Gould type is currently the worldwide standard for the treatment of chronic ankle instability (92). Guelfi, analyzed 13 studies reporting the results of open Broström Gould between 1972 and 2015 (93). The mean follow-up was 73.4 months, with a minimum of 2 years. The mean postoperative AOFAS score was 90.34. The complication rate was 8%: skin complications 2%, neurological lesions 1.8%, lateral pain 1.8%. The satisfaction rate was 91% at final follow-up. Buerer (92) reported a return to sport activities after 4.7 months (range 2-12 months) and Schmidt (94) a return-to-work activities after a mean of 38.5 day. The literature shows a reduction in the VAS score reported in 5 studies, involving 165 patients, from 5.89 to 1.53 (95-98). So et al described in a systematic review of the published data a revision rate of 1.2% at a mean follow-up of 8.4 years (99). BG leads to returns to their pre-injury activity levels for high-demand athletes (100-102). If we compare the results of our study with those of open surgery, the postoperative AOFAS score is equivalent, with a lower complication rate for the arthroscopic technique. We thus find postoperative results at least equivalent to open techniques in agreement with numerous publications; In 2016, in a review of the literature, Guelfi compared open and arthroscopic ligament repair techniques and conclude that Arthroscopic repair technique now produces results that are at least equal to those of traditional open techniques (103-107). Traditional open and arthroscopic Broström–Gould repair for CAI in high-demand patients (Tegner activity level> or =6, minimum follow-up of 2 years; AOFAS and Karlsson) had comparable radiological and clinical outcomes (108). Arthroscopic BG yielded favorable results, comparable to those of open BG, according to measures of biomechanical activity and clinical outcomes (109-111). Attia reported that arthroscopic Broström was superior to open Broström-Gould surgery in post- operative AOFAS scores, VAS pain scores, and time to return to weightbearing. The operative time, complication rate, talar tilt, and anterior drawer tests were excellent and statistically comparable (112).

The second objective of the thesis was to evaluate the result of the endoscopic lateral ligament reconstruction. If ligament repair is contraindicated, the technique of ligament reconstruction using a tendon graft may be used. Our study: **"Endoscopic anatomic ligament reconstruction is a reliable option to treat chronic lateral ankle instability"** published the results of a cohort of 53 patients. After an average follow-up of 31.5 ± 6.9 months, all patients reported significant improvement compared to their preoperative status. The preoperative AOFAS score improved from 76.4 ± 15 to 94.7 ± 11.7 postoperatively ($p = 0.0001$). The preoperative Karlsson-Peterson score increased from 73.0 ± 16.0 to 93.7 ± 10.6 postoperatively ($p = 0.0001$). The VAS score improved from 1.9 ± 2.5 to 0.8 ± 1.7 ($p < 0.001$). Two patients had complaints of recurrent instability. We conclude that Endoscopic ligament reconstruction for chronic lateral ankle instability is a safe procedure and produces good clinical results with minimal complications. This technique combines the advantages of anatomic reconstruction and the benefits of an endoscopic approach.

There are few series in the literature concerning the results of endoscopic ligament reconstruction. In his series of 34 patients at 48.7 months, Guillo found an improvement in the AOFAS score from 60.3+/-11.9 to 94.3+/-6.2 and in the Karlsson score from 49.0 +/-10.9 to 87.2+/-10.1. These results are similar to our series. This technique, initially performed in open surgery, has also been published by differents authors. In a review of the literature in 2020, Lu analyzed 12 articles. He found 85% good and excellent results. This meta-analysis included autograft and allograft reconstructions. In another meta-analysis, Brambilla compared the results of autograft and allograft surgery and found no significant difference. Wang reports the results of a series of 19 patients at 30 months; AOFAS improved from 64.00+/-18.43 to 90.32+/-5.17 and Karlsson score improved from 50.84+/-16.73 to 90.89+/-5.08 (p<0.01). For Jung, who also uses open reconstruction with a gracilis tendon, the postoperative results of a series of 27 patients at 19 months' follow-up show an improvement in the AOFAS score from 63 (41-84) to 91 (81-100) and in the Karlsson score from 55 (32-77) to 8 (59-100). To our knowledge, there are no studies comparing the results of open and endoscopic reconstruction techniques. However, we can conclude that the arthroscopic technique provides results that are at least equivalent to the open techniques.

The third objective was to compare the results of our series to the literature. We made it in the previous paragraph of the chapter but we have to precise considering the indications. Although it seems to be accepted that the use of arthroscopy is advantageous, the choice of surgical technique remains poorly codified. Surgeons decide on the indication for an operating technique on the basis of the patient, the clinical examination and the data from complementary imaging examinations. However, the surgeon's habits have a major influence on this decision. Arthroscopy requires a considerable learning curve, and an untrained surgeon will not be able to perform this technique, even if its advantages are proven, without specific training. This notion explains the slow progression from open techniques to purely arthroscopic techniques. The proliferation of techniques and their constant evolution also make it difficult to create a decision tree. Arthroscopic ligament repair is a reliable and reproducible surgical procedure. It is therefore the surgery of first choice in cases of ATFL rupture; if there is an associated CFL lesion, the results are also excellent. This possibility of acting on the CFL by suturing the ATFL has been confirmed by our biomechanical study: "Connecting fibers between ATFL's inferior fascicle and CFL transmit tension between both ligaments"(5). The fibers connecting the ATFL and the CFL act to hold the CFL in place by reinserting the ATFL. If the injury to the CFL is a rupture, rather than distension healing, Vega has shown that it is possible to repair the ligament by reinserting each ligament with an anchor (113). In his series of 22 patients at 35 months' follow-up, the AOFAS score increased from 65 (52-85) to 97 (85/100). No recurrence of instability was reported. The technique of ligament repair under arthroscopy therefore makes it possible to treat the majority of cases of lateral ankle instability. However, if we look at the evolution of open surgery over the years, it has evolved towards the addition of a biological augmentation to the repair (reinforcement by the retinaculum plasty described by Gould) to compensate for the failures of isolated repairs. A number of biomechanical factors therefore need to be taken into account when deciding on a surgical technique. To date, the debate is not anymore arthroscopy or open surgery but which technique must be indicated. A criticism of ligament repairs was that their results were unreliable over time; Guelfi (114) showed that the 5-year results were excellent and comparable between the open and arthroscopic techniques. The complications were minimal in both study groups with no significant differences in AOFAS and FAAM-SS scores. However, arthroscopic repair showed significantly better results on the Foot Functional Index. Arthroscopic surgery has produced superior results regarding cosmesis and the benefit of the diagnosis and treatment of intra-articular pathologies associated with chronic ankle instability. We can conclude that the arthroscopic technique provides results that are at least equivalent to the open techniques. Thès, in the article of the thesis **"Five-year clinical follow-up of arthroscopically treated chronic ankle instability"**, reported that arthroscopic BG provide a high satisfaction score at five years similarly to patients treated by endoscopic ligament reconstruction with a low reoperation rate (6,4%). The choice of technique must also take into account the learning curve and the complication rate. Lopes (115) described 3 times more complications with the ligament reconstruction compare to the repair.

If we go back to the 2017 expert consensus published by Michels (116), ligament repair is indicated as the first line of treatment, but certain indications are discussed (Figure 12).

Searching for consensus in the approach to patients with chronic lateral ankle instability: ask the expert

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Table 4 Associated aspects

	Repair	Reconstruction
Obesity	16 (53.3%)	14 (46.7%)
Ossicle size >1 cm	16 (53.3%)	14 (46.7%)
High-level sports	25 (83.3%)	5 (16.7%)
Generalized hyperlaxity	12 (40.0%)	18 (60. 0%)
Positive stress radiographs	27 (90.0%)	3 (10.0%)
MRI finding of CFL injury	24 (80.0%)	6 (20.0%)
Poor ligament quality during surgery	9 (30.0%)	21 (70.0%)
Suspicion of subtalar instability	16 (53.3%)	14 (46.7%)

Fig. 12: Factors affecting the choice of technique. Reproduced from Michels (116).

With the same idea, the French Arthroscopy Society has proposed an arthroscopic classification of ATFL lesions which, depending on the stage, determines whether ligament repair or reconstruction is required (117). This decision tree is the subject of debate, as many surgeons carry out systematic repairs. Furthermore, this article only considers injuries to the ATFL. In order to confirm the role of arthroscopic techniques in instability, we feel it is essential to consider the indication of repair or reconstruction techniques.

If we take the issue of patient obesity, our study "**<u>High body mass index is not a contraindication for an arthroscopic ligament repair with biological augmentation in case of chronic ankle instability"</u>** showed that ATFL repair with biological augmentation using IER gives excellent results for patients with BMI ≥ 30. Compared to patients with BMI < 30, they present a slightly lower preoperative and postoperative Karlsson score, however, with a similar satisfaction rate, but are at higher risk of transient superficial peroneal nerve dysesthesia. This is the 1st study in the literature to compare post-operative results in obese patients at more than 2 years' follow-up of ligament repair with Gould-type reinforcement under arthroscopy.

There is also a debate about post-traumatic lateral sub-malleolar ossifications; for a long time, the size of more than 1cm has been accepted as a quasi-dogma for limiting repair techniques. However, the conclusions reached in the literature are contradictory. In open surgery, the BG technique has been shown to give equivalent results in patients with and without sublateral malleolar ossification. The size of the ossification did not affect the indication for repair. There was no osteosynthesis but systematic removal even if the ossification was voluminous. Mancuso et al (118), Ahn and Lee (119), and Hasegawa et al. (120) also recommended ossicle resection and lateral ligament repair. However, Kim et al. (121) reported poor improvement in anteroposterior stability in the large ossicle group after ossicle resection and MBP. They found that the resection of a large ossicle could result in an unrepairable gap between ligament remnant tissue, leading to poor anteroposterior stability. The most logical surgical option is therefore to decide peroperatively if the ligament repair is feasible; if this is not possible, the surgeon must be able to modify the indication and perform ligament reconstruction using a tendon graft.

Concerning generalized ligamentous laxity (GLL), it's well known that is an independent predictor of poor outcomes after a Broström-Gould procedure (122). Long time ago, Karlsson et al. (123) reported that Broström-Gould repair produced unsatisfactory results with patients with GLL. Messer et al (124). also found that patients with GLL had significantly lower satisfaction scores. Xu and Lee (125) suggested that additional augmentation or ligament reconstruction should be per- formed as a primary operation for patients with high Beighton scores (≥7 points). A more recent study reported that BG may be successful in patients with chronic ankle instability and generalized laxity. More recently (126), Tang (127) confirmed que the generalized ligamentous laxity GLL according to Beighton scores may not be a contraindication to the Broström-Gould operation being used to treat CLAI. However, some augmentation operations may be combined with the classic Broström-Gould operation, especially for those patients with preoperative Beighton scores > or =7. There is still debate as to whether biological augmentation by retinaculum autoplasty is sufficient. The question then arises as to whether a tendon graft reconstruction should be performed as the 1st option. However, the question of tissue quality remains the same: if an autograft is used, will the mechanical quality of the graft be satisfactory? An allograft or artificial ligament augmentation should therefore be used?

About MRI findings of CFL injury, in 2015, White published the results of a series of 42 athletes treated with Broström-Gould for chronic lateral instability. 30 patients had ruptured LTFA and LCF. The 2-year review found no recurrence. We therefore believe that there is no systematic indication for ligament reconstruction using a tendon graft.

If we focus on high-demand patient, Krips et al. compared anatomical versus non-anatomical repair for lateral instability in high-demand athletes and found that anatomical repair resulted in significantly less restricted ankle range of motion (ROM) in dorsiflexion (3 vs 15 patients) and more athletes returned to their previous activity levels compared with the tenodesis group. The 2-year review found no recurrence. Goru reported in a recent literature analysis that BG procedure using a suture anchor was observed to provide satisfactory clinical outcomes in high-demand athletes with lateral ligament Instability. We therefore believe that ligament repair should be the first line of surgical treatment. There is no systematic indication for ligament reconstruction using a tendon graft.

Imaging is currently not reliable enough to predict whether the biological quality of the residual ligament will be sufficient to ensure mechanical strength in the medium and long term. As a reminder, if the residual ligament is not sufficient (in qualitative terms, presence of fibrosis or calcifications, or in quantitative terms, stump too short to be reinserted), the surgeon must use a ligament reconstruction technique. However, Park's study of open surgery suggests that the modified Broström operation for patients with chronic ankle instability gives good results, regardless of the presence or absence of ATFL remnant. Feng described no statistically significant differences in postoperative outcomes between ATFL remnant repair and non-repair for the management of CLAI using the all-inside arthroscopic Broström-Gould procedure. It therefore seems logical to give preference to arthroscopic BG as the 1st line of treatment. The arthroscopic technique also allows intraoperative assessment of ligament residue and will confirm the indication for the technique. Also, the final arthroscopic check of the ligament repair enables the surgical procedure to be modified, if necessary, by changing the technique.

Some surgeons suggest reinforcing the ligament repair not with a biological augmentation, such as the Gould-type plasty, but with an artificial ligament. This technique has many limitations. The main problem is adjusting the tension of the artificial ligament. Its composition means that it has no elastic capacity and therefore no "margin for error". It has been suggested that this type of ligament should be tensioned by interposing an instrument (Figure 13), but in our opinion, this leads to totally random adjustment of ligament tension.

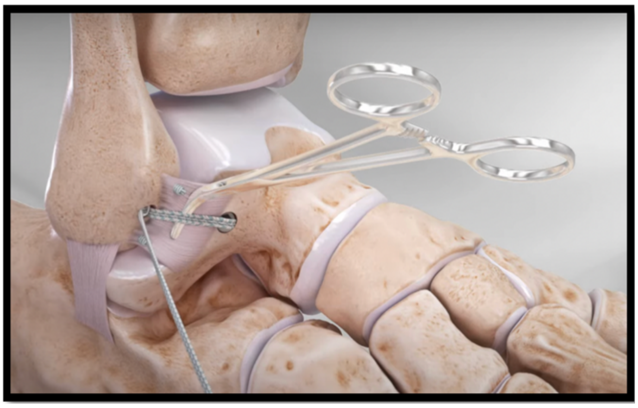

Fig. 13: Schematic view of the tensioning of the synthetic ligament (Picture obtained from Arthrex Mgbh; available at website: https://www.arthrex.com/resources/AN1-000329-en-US/internalbrace-repair-with-dx-knotless-fibertak-anchors?referringteam=foot_and_ankle.).

The 2nd limitation of synthetic ligaments is that they are currently only used for LTFA reinforcement. The advantage would be a faster recovery through a quicker rehabilitation protocol, allowing weight-bearing activities to be resumed in an extremely short space of time. However, the meta-analysis of Lei suggested that there was no clinical superiority for the synthetic ligament operation over the BG operation for patients with chronic ankle instability. Modified Broström With and Without Suture Tape Augmentation: A Systematic Review: Modified Broström with suture tape augmentation for chronic lateral ankle instability can produce good short-term clinical outcomes with few complications, but comparable to the Modified Broström alone.

It would therefore appear that the majority of cases of lateral ankle instability can be treated by ligament repair. Anatomic repair techniques may offer the advantage of reduced recovery times compared to reconstruction procedures. Other advantages include smaller incisions, decreased tissue damage, fewer complications, and earlier weight bearing. Lateral ligament reconstruction using tendon grafts is therefore reserved for revision surgery in cases where ligament repair has failed. In our opinion, there is no longer any reason for this technique to be indicated as first-line treatment in cases of high BMI, constitutional ligament hyperlaxity with Beighton <7, lateral sub-malleolar ossification greater than 1 cm in size, or professional or sporting activities at risk of hypersensitivity of the ankles. It should be one of the techniques practiced by ankle surgeons, who will be able to modify their technique intraoperatively if a repair fails. One argument put forward by surgeons in favour of reconstruction using tendon grafts is the theoretical possibility of ligamentisation of the tendon graft, which would reproduce the anatomy of the ankle... We therefore carried out the study **"MRI Assessment of Tendon Graft After Lateral Ankle Ligament Reconstruction: Does Ligamentization Exist?"** which is effectively in favour of a ligamentization phenomenon. However, it is important to bear in mind the conclusions of the study by the French Arthroscopy Society, which found 3 times more complications with reconstructions. The comorbidity associated with grafting must also be taken into account.

Limitations of the study:

Lateral ankle instability also involves the tibiotalar joint. There is an associated injury to the subtalar joint in approximately 25% of cases, and in particular to the cervical ligament. However, the diagnosis of subtalar instability has not yet been made reliable, either clinically or by imaging. As a result, the incidence rate remains highly variable, ranging from 10 to 80% depending on the study. In these cases, a repair Theoretically, isolated ATFL surgery cannot treat these injuries. In this context, it is legitimate to consider a technique that stabilises the subtalar joint in cases of associated laxity. There is still considerable debate about the mechanical role of Gould plasty in stabilising the subtalar joint. Furthermore, it is common to think that the subtalar joint can be stabilised by means of ligament reconstruction associated with the LCF; this idea is incorrect; depending on the damage to the subtalar ligaments, it is sometimes necessary to carry out additional reconstruction of the subtalar ligaments, particularly the cervical ligament; Michels, who wrote his PhD thesis on the subject of subtalar instability, carries out intraoperative testing in cases of suspected associated subtalar instability in order to decide on the surgical indication for subtalar ligamentoplasty.

The 2nd limitation concerns the surgical technique of biological augmentation of the Gould type. To date, lateral ligament repair has been performed preferentially in isolation, as was the initial technique. As we have said, with regard to repairs, our work compares an arthroscopic technique with the reference open technique. The thesis technique is therefore optimal for comparison with open techniques, but does not exactly represent the most common arthroscopic technique. The conclusions of the literature on the mechanical quality of this biological reinforcement are contradictory. The value of Gould-type reinforcement has been demonstrated in open surgery; studies will be required to validate the fact that it is not necessary to perform this augmentation as a matter of course during arthroscopic ligament repairs. It should be borne in mind that arthroscopic repair is a capsulo-ligament reattachment procedure and not an isolated ligament repair procedure. This impact on the capsule may lead to similarities with open Broström-Gould. It should also be borne in mind that this procedure adds an additional technical element that is not fully mastered and therefore may not be performed by all surgeons. It is therefore possible that certain indications for arthroscopic repair are limited by surgeons who do not perform biologic augmentation and who prefer to turn to a reconstructive procedure. This would explain the "broad" indications for ligament reconstruction and their reduction with the increase in the use of arthroscopy in the management of instability.

14. Conclusion:

1. The study of a cohort of patients treated by arthroscopic repair with retinaculum augmentation (Broström-Gould arthroscopic) demonstrated that postoperative results were at least equivalent to open techniques.
2. Similarly, the postoperative results of a cohort of patients treated with an endoscopic lateral ligament reconstruction confirmed results at least equivalent to open techniques.
3. These conclusions are supported by studies published in the literature. This review also validated the indication of ligament repair as the 1st-line surgical procedure in case of chronic ankle instability and clarified the arthroscopic treatment strategy.

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