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Modified classifications and surgical decision-making process for chronic anterior talofibular ligament injuries based on the correlation of imaging studies and arthroscopic findings

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Abstract

Purpose Surgical treatment of chronic ankle instability (CAI) typically includes ligament repair or reconstruction. Using preoperative ultrasonography or magnetic resonance imaging (MRI) to choose an appropriate arthroscopic procedure is still difficult. The aim of this study was to evaluate the correlation of imaging studies with arthroscopic findings and support the arthroscopic surgical decision-making process.

Methods One hundred twelve patients with chronic anterior talofibular ligament (ATFL) injuries were treated using the arthroscopic surgical decision-making process from November 2018 to August 2020. Preoperative imaging assessments using dynamic ultrasonography, MRI, and combined methods were applied to categorize the ATFL remnants into three quality grades ("good," "fair," and "poor"). Arthroscopic findings were classified into 6 major types (7 subtypes) and used to select an appropriate surgical procedure. Correlations between imaging studies, arthroscopic findings, and surgical methods were evaluated. Diagnostic parameters, clinical outcomes, and complications were also assessed.

Results There was a significant interobserver agreement in the evaluation of dynamic ultrasonography (0.954, $P < 0.001$), MRI (0.958, $P < 0.001$), and arthroscopy diagnosis (0.978, $P < 0.001$). There was a significant correlation between the modified imaging classifications, arthroscopic diagnostic types, and surgical procedures. The mean follow-up period was 33.58 ± 8.85 months. Significant improvements were documented in postoperative ankle functions when assessed with Karlson-Peterson scores and Cumberland Ankle Instability Tool scores. The risk of complications is also very low.

Conclusion The modified classifications and surgical decision-making process based on dynamic ultrasonography, MRI, and arthroscopic findings, as proposed in this study, might help in selecting an appropriate arthroscopic surgical procedure for chronic ATFL injuries.

Keywords Anterior talofibular ligament · Chronic ankle instability · Arthroscopy · Broström · Broström-Gould · Ankle ligament reconstruction · Surgical decision-making

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Introduction

Arthroscopy has become a popular, minimally invasive, and reliable tool in treating chronic ATFL injuries when conservative treatment fails [1–3]. Arthroscopic treatment for chronic ATFL injuries incudes ligaments repair with or without augmentation (Broström or Broström-Gould) and anatomic reconstruction using a tendon graft [4–6]. Preoperative evaluation of ATFL injuries usually includes magnetic resonance imaging (MRI) and dynamic ultrasonography [7–10]. Few articles regarding these imaging techniques and expert's consensus have been published to help guide the surgical decision-making [11, 12]. Although many classifications are available in literature, further investigation is needed to accurately diagnose chronic ATFL injuries with MRI and dynamic ultrasonography [13–15]. Actually, imaging findings do not always correlate with arthroscopic findings, and the preoperative plan may need to be changed during surgery [12, 16].

MRI can be used to measure the ATFL thickness and identify different ligament signal intensities, and thus provide high sensitivity images for detecting ATFL injuries [17–20]. Concomitant osteochondral lesions, loose bodies, syndesmotic injuries, and fibular tendon abnormalities can also be found with MRI [2, 18]. However, MRI does not provide dynamic images [21–23]. Sometimes, scan angle and artifacts can be mistaken for ligament injuries [24]. Recently, dynamic ultrasonography is useful for evaluating the quality and continuity of ligaments [8–10]. Compared with MRI, ultrasonography provides the advantages of dynamic imaging [13]. The main limitation of ultrasonography is its highly dependent on equipment and the operator's experience [13, 25, 26].

The purpose of this study was to evaluate the correlations of chronic ATFL injuries classified based on dynamic ultrasonography, MRI, and the combination of both methods, with the arthroscopic findings, which was considered the reference standard for an accurate diagnosis of ATFL lesions [27]. A modified classification based on arthroscopic findings was also developed to support appropriate surgical strategies. We have hypothesized that following this modified classification and individualized surgical decision-making process will yield satisfactory results.

Materials and methods

Patients with chronic ATFL injuries were treated according to our modified classifications and surgical decision-making process at our hospital from November 2018 to August 2020. Inclusion criteria were (1) recurrent ankle sprain for more than 12 months; (2) positive or suspicious signs of ankle instability on physical examinations; (3) no response to a minimum of 3 months of conservative treatment; and (4) the chronic ATFL injury was identified by MRI and dynamic ultrasonography. Exclusion criteria were (1) a ligament injury combined with an acute fibular fracture, previous ankle surgery, or any foot and ankle malalignment; (2) generalized ligamentous laxity (Beighton score > 5) [28]; (3) systemic disease, neuromuscular disorders, or an infectious disease; and (4) inconsistant follow-up appointments that were shorter than 24 months. All included patients had undergone weight-bearing plain radiography, dynamic ultrasonography, and MRI before surgery. Additionally, cases with suspected avulsion fracture of the fibula or subfibulare were evaluated with a 3-dimentional CT scan. Diagnoses based on dynamic ultrasonography, MRI, and CT were assessed by two senior radiologists, and arthroscopic views were evaluated by two senior surgeons. If inconsistencies occurred, a third radiologist/surgeon was consulted and the diagnosis was agreed upon by consensus. This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of our hospital (No. 2018-017). The written informed consent has been obtained before surgery.

Modified classifications based on dynamic ultrasonography and MRI images

Dynamic ultrasonography was performed using a Philips EPIQ7 ultrasound system (Philips, Netherlands), equipped with a SL12–5 scanner. Patients were examined in three ankle positions with their knees flexed to 90°: neutral position (plantar flexion 15° without inversion or eversion), anterior drawer stress position, and inversion stress position. MRI was performed using a Signa HDxt 1.5-T MRI system (GE Medical Systems, Waukesha, WI, USA), equipped with an 8-channel receive-only foot and ankle array.

The quality of ATFL remnants assessed by dynamic ultrasonography and MRI was classified into three grades. On dynamic ultrasonography, a clear fibrillar band was considered "good"; a partially clear fibrillar band was considered "fair"; and a fuzzy or absent fibrillar band was considered "poor" (Fig. 1). On MRI, a thickened and disrupted signal intensity at the fibular or talar side was considered "good"; a thin and disrupted signal intensity at the fibular or talar side was considered "fair"; and a disorganized, attenuated, or absent signal intensity was considered "poor" (Fig. 2).
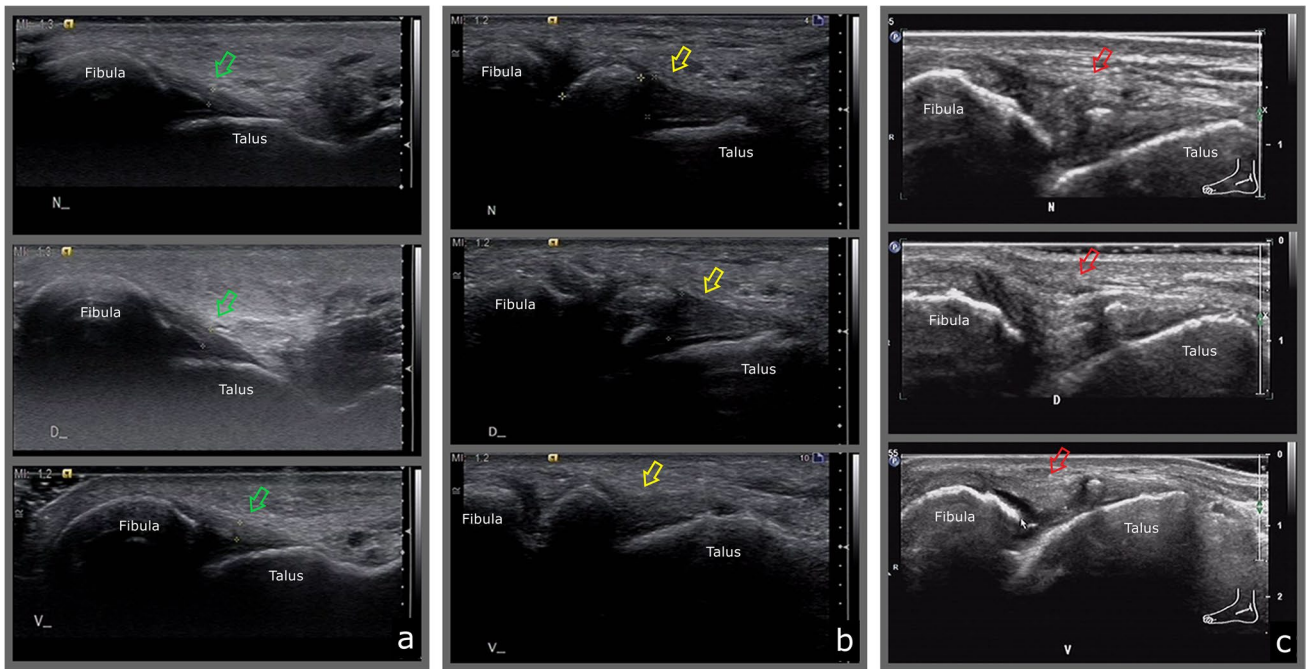
Fig. 1 Representative dynamic ultrasonography images depicting the 3 classifications of chronic ATFL injuries. **a** The "good" grade, a clear fibrillar band (green arrow: ATFL); **b** the "fair" grade, a partially clear fibrillar band (yellow arrow: ATFL); **c** the "poor" grade, a fuzzy or absent fibrillar band (red arrow: unclear ATFL). From top to bottom: N, natural position; D, anterior drawer position; V, varus position
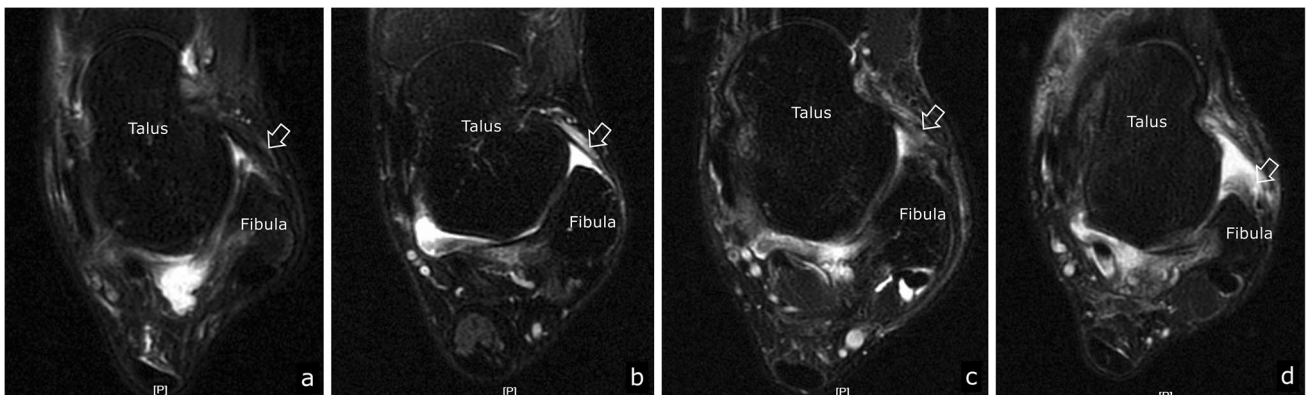

Fig. 2 Representative MRI images depicting the classifications of chronic ATFL injuries. **a** the "good" grade, a thicken and disrupted ligament at the fibular or talar side; **b** the "fair" grade, a thin and disrupted ligament at the fibular or talar side; **c** the "poor" grade, a disorganized structure of the ligament; **d** and another poor grade, an attenuated or absent ligament

Osseous avulsion or os subfibulare assessments on CT scans

CT was performed using a 16-row multi-slice CT scanner (Aquilion, Toshiba Medical Systems, Tokyo, Japan). CT scanning and 3D reconstruction of the lateral gutter were used to evaluate the effective size of the osseous avulsion at the fibular side or the os subfibulare. The effective diameter was defined by the involved width of the bony fragment at the plane of the ligament remnant (the plane connecting the talus obscure tubercle and the fibular obscure tubercle) (Supplementary figure 1).

Modified classifications of arthroscopic findings in chronic ATFL injuries

Based on our arthroscopic evaluation, chronic ATFL injuries were classified into six major diagnostic types (7 subtypes) (Fig. 3), and the types were used to guide the surgical procedures. A type I represented minimal ligament injury,
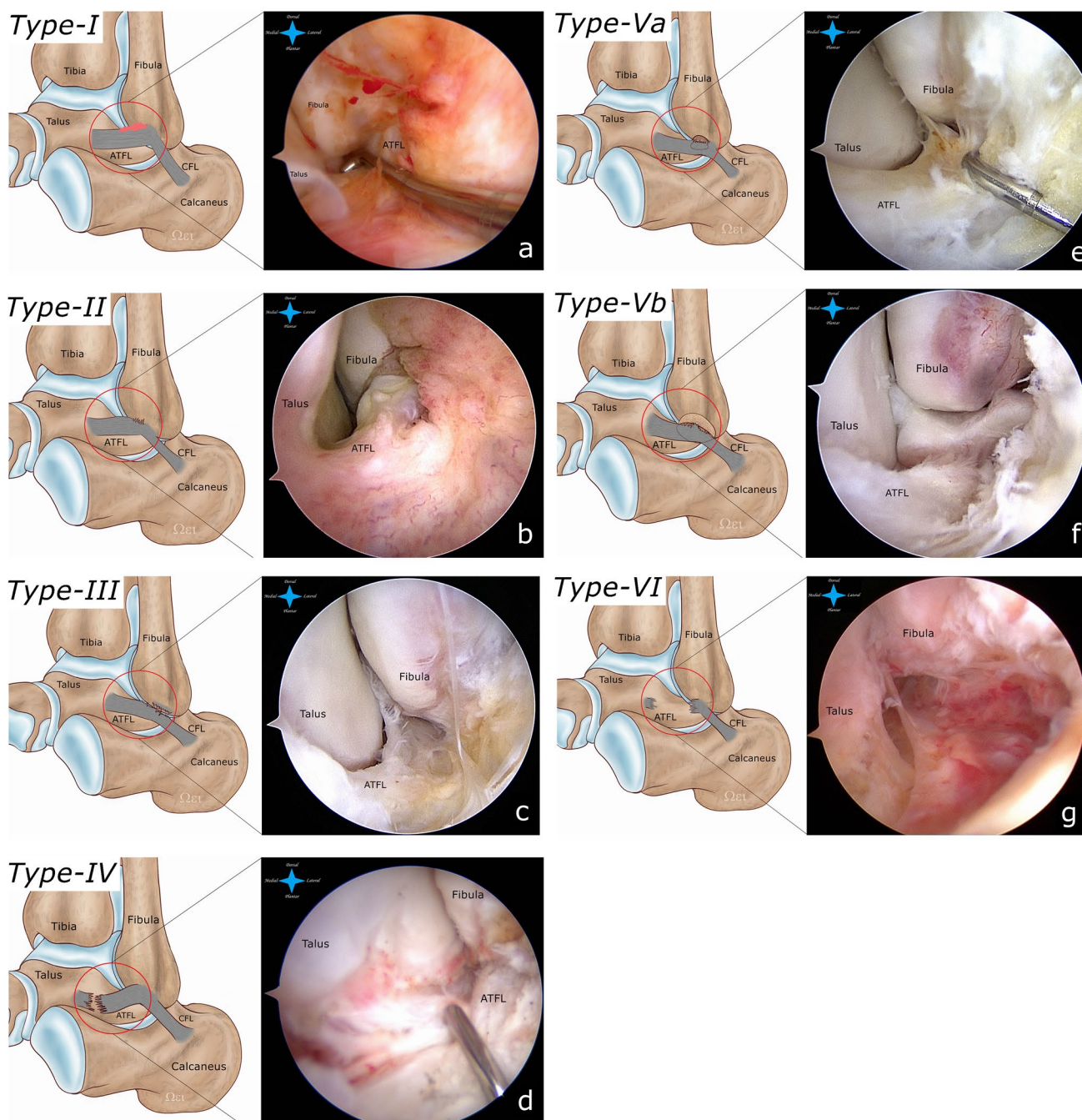
Fig. 3 Representative arthroscopic images depicting the 6 major types (7 subtypes) of chronic ATFL injuries. **a** Type I; elongated ligament. **b** Type II; partial ligament tear at the fibular side. **c:** Type III; complete ligament tear at the fibular side. **d** Type IV; partial or complete ligament tear at the talar side. **e** Type Va; a small osseous avulsion of the fibular side or os subfibulare (effective diameter < 5 mm). **f** Type Vb; a large osseous avulsion of the fibular side or os subfibulare (effective diameter ≥ 5 mm). **g** Type VI; attenuated or absent ligament

with an elongated ligament, and was treated with ligament repair. Types II, III, and IV represented a partial or complete ligament tear at the fibular side, and a ligament tear at the talar side, respectively. A type V consisted of osseous avulsion or os subfibulare and was subclassified into type Va (a small sized bony fragment; effective diameter < 5 mm) and type Vb (a large sized bony fragment; effective diameter ≥ 5 mm). In types II–V, according to the boundary, colour, and elasticity of the fibril under arthroscopic visualization, the quality of the remnant was further graded as "good," "fair," or "poor" quality (Fig. 4). Surgical methods for type II–V injuries included ligament repair with or without
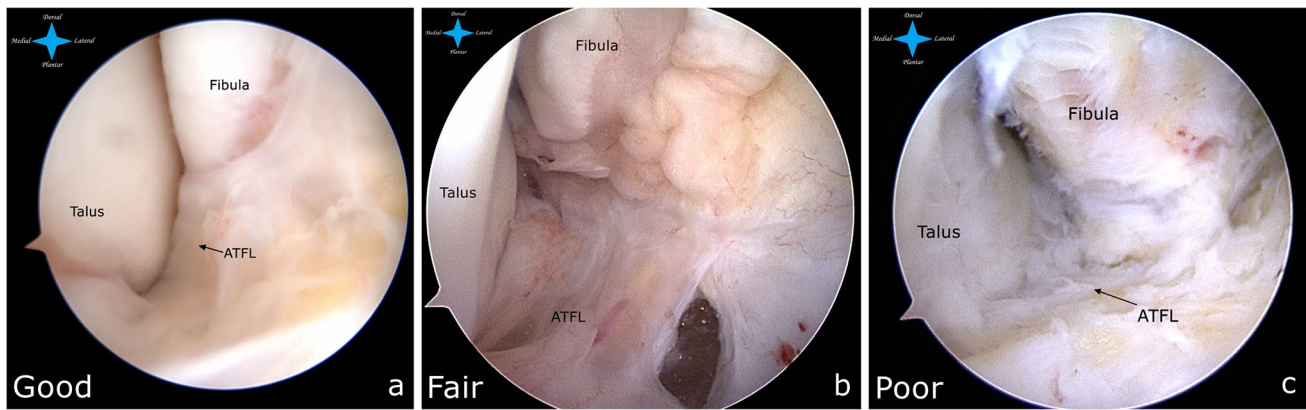
Fig. 4 Representative images of arthroscopic quality grades of the ATFL remnant. **a** Good quality; ligaments are clearly demarcated and well-organized, with only abnormal tension. **b** Fair quality; the liga-ment boundary is discernible, with a partially organized structure. **c** Poor quality; the ligament boundary is blurred, and ligament fibers are disorganized

augmentation and ligament reconstruction, depending on the quality of ligament remnant and patient demand (activity level). Type VI injuries (attenuated or absent ligament) were treated with ligament reconstruction.

Surgical decision-making process

The surgical methods used to treat chronic ATFL injuries included ligament repair (Broström procedure), ligament repair plus inferior extensor retinaculum (IER) augmentation (Broström-Gould), or Broström with inter-brace technique, and ligament reconstruction. Details of these surgical methods have been described previously [3, 29–31]. The overall surgical decision-making process considering the various types of ligament injuries, patients' demand (activity level), and surgical procedures are illustrated in Fig. 5. Karlson-Peterson scores [32] and CAIT scores [33] were used to assess clinical outcomes. The intraoperative and postoperative complications were also recorded.

Statistical analysis

All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous data were presented as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR). Categorical data were presented as frequencies and percentages. Fisher's exact test was used to examine the association between categorical variables. The Kendall-W test was used to assess interobserver agreement. Using arthroscopy as the standard reference, the diagnostic value, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the imaging techniques (dynamic ultrasound, MRI, and both combined) were evaluated. One-way ANOVA was used to compare preoperative Karlson-Peterson scores and

Cumberland Ankle Instability Tool (CAIT) scores between the 6 major arthroscopic types. The Wilcoxon test was used to compare the preoperative and postoperative Karlson-Peterson scores and CAIT scores. For all tests, a value of $P < 0.05$ was considered statistically significant.

Results

Patients' characteristics

A total of 139 patients who received these surgical strategies from November 2018 to August 2020 were evaluated. After excluding 27 patients with insufficient follow-up data, 112 patients (112 ankles) were included. The mean follow-up period was 33.58 ± 8.85 months (range, 24–54 months). The median patient age at the time of injury was 33 years (IQR27–39), with a range of 18 to 50 years. The majority of the patients was male (74.1%). The injury side was evenly distributed between the left and right ankles (Table 1) [34].

Interobserver agreement of image assessment methods

The results of Kendall-W tests showed that there was significant interobserver agreement in the evaluation of dynamic ultrasonography (Kendall-W = 0.954, $P < 0.001$), MRI (Kendall-W = 0.958, $P < 0.001$), and arthroscopy diagnosis (Kendall-W = 0.978, $P < 0.001$). However, there was no significant interobserver agreement in the evaluation of between avulsion fracture and os subfibulare on CT. The interobserver agreement rates of the different preoperative image assessment methods are summarized in Supplementary Table S1.
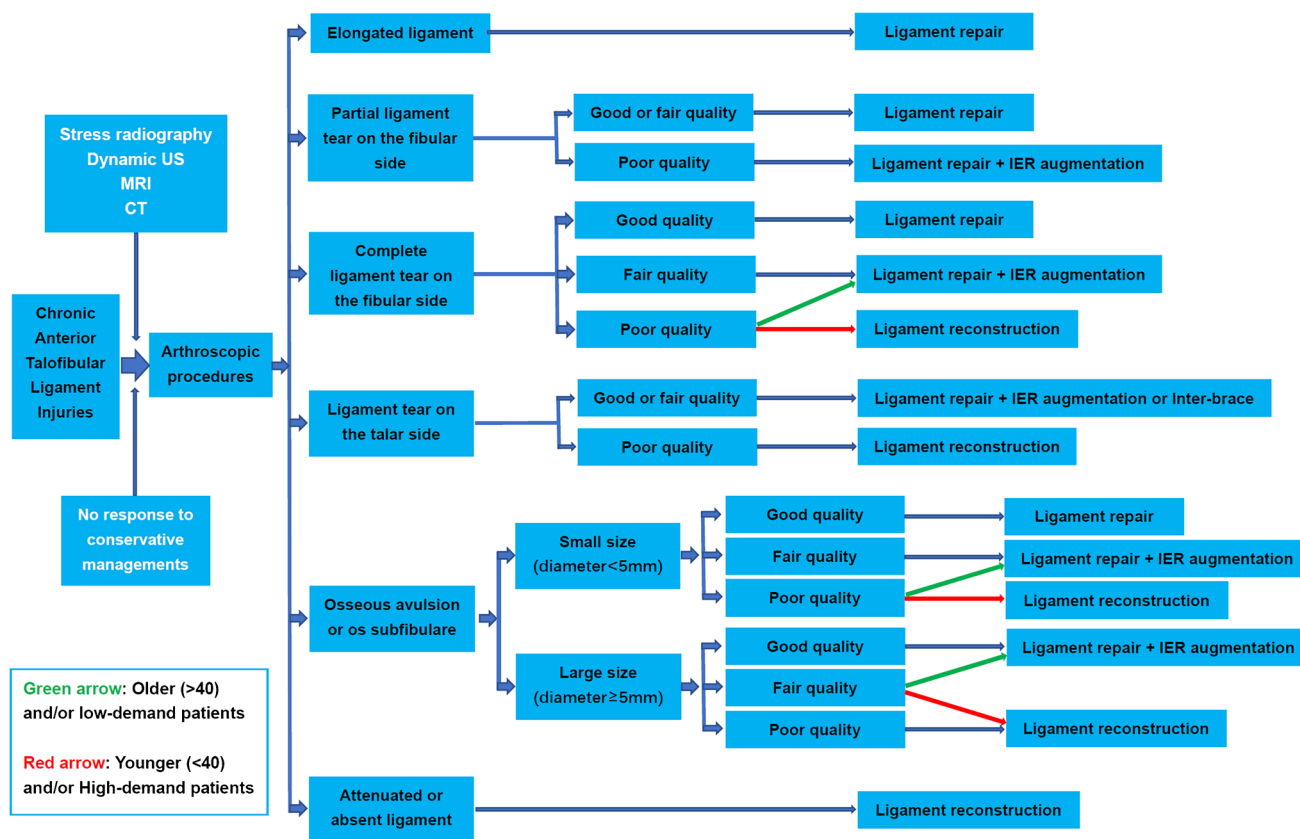
Fig. 5 Surgical decision-making flow diagram illustrating the surgical strategies for chronic ATFL injuries

Table 1 Characteristics of included patients

Variables	Results
Age, median (IQR; range) (years)	33 (27–39; 18–50)
Sex, n (%)	
Male	83 (74.1%)
Female	29 (25.9%)
Injury side, n (%)	
Left	57 (50.9%)
Right	55 (49.1%)
Follow-up, mean (SD) (months)	33.58 (8.85)
Talar tilt angle on stress radiography, n (%) [34]	
Positive (>10°)	34 (30.4%)
Suspicious or negative (≤10°)	78 (69.6%)
Anterior talar translation on stress radiography, n (%) [34]	
Positive (>10 mm)	52 (46.4%)
Suspicious or negative (≤10 mm)	60 (53.6%)

Correlation of imaging classifications with arthroscopic diagnostic types

The correlations of dynamic ultrasonography, MRI, and combined classifications with the six major arthroscopic diagnostic types (7 subtypes) of chronic ATFL injuries are presented in Table 2. The correlation analysis revealed that for all 3 imaging methods, the imaging classifications were significantly correlated with the seven arthroscopic diagnostic subtypes ($P < 0.001$, $P = 0.018$, and $P = 0.005$ for dynamic ultrasonography, MRI, and the combined method, respectively).

Table 2 Correlation of imaging classifications and arthroscopic types of chronic ATFL injury

	Type I (n = 3)	Type II (n = 24)	Type III (n = 27)	Type IV (n = 11)	Type Va (n = 25)	Type Vb (n = 14)	Type VI (n = 8)	Cramer's v values	P value[a]
Dynamic ultrasonography								0.481	**<0.001**
Good (n = 29)	3	11	5	1	6	3	0		
Fair (n = 63)	0	10	20	9	17	6	1		
Poor (n = 20)	0	3	2	1	2	5	7		
MRI								0.323	**0.018**
Good (n = 57)	3	13	11	5	18	5	2		
Fair (n = 23)	0	9	4	1	2	4	3		
Poor (n = 32)	0	2	12	5	5	5	3		
Dynamic ultrasonography and MRI combination								0.370	**0.005**
Good (n = 66)	3	18	11	5	19	8	2		
Fair (n = 39)	0	6	15	5	6	4	3		
Poor (n = 7)	0	0	1	1	0	2	3		

[a]Fisher exact test; statistical significance (bold): $P < 0.05$

For dynamic ultrasonography, 11 "good" cases (37.9%) were arthroscopic type II, while 20 "fair" cases (31.7%) were type III, followed by 17 (27.0%) type Va, and 7 "poor" cases (35.0%) were type VI.

For MRI, 18 "good" cases (31.6%) were arthroscopic type Va, followed by type II (n = 13, 22.8%). MRI "fair" cases were mostly arthroscopic type II (n = 9, 39.1%), and "poor" cases were mostly type III (n = 12, 37.5%). Using the combination of dynamic ultrasonography and MRI, 19 "good" cases (28.8%) were arthroscopic type Va, followed by type II (n = 18, 27.3%). Fifteen "fair" case (38.5%) were type III, and three "poor" cases (42.9%) were type VI.

Correlation of preoperative imaging classifications with surgical procedures

For all three imaging methods, the modified imaging classifications were significantly correlated with the surgical procedures performed ($P < 0.001$, $P = 0.022$, and $P < 0.001$ for dynamic ultrasonography, MRI, and combined imaging, respectively).

For dynamic ultrasonography, most "good" cases (n = 26, 89.7%) received ligament repair, 42 "fair" cases (66.7%) received ligament repair with augmentation, and 11 "poor" cases (55.0%) received ligament reconstruction. For MRI, however, about half of "good" cases (n = 32, 56.1%) received ligament repair, 12 "fair" cases (52.2%) received ligament repair with augmentation; 20 "poor" cases (62.5%) finally received ligament repair with augmentation rather than reconstruction.

For the combined method using dynamic ultrasonography and MRI, 39 "good" cases (59.1%) received ligament repair, 29 "fair" cases (74.4%) received ligament repair with augmentation, and most "poor" cases (n = 5, 71.4%) finally received reconstruction. The correlations of preoperative modified imaging classifications with surgical procedures are shown in Supplementary Table S2.

Diagnostic parameters of the imaging techniques

Using arthroscopy as the reference standard for evaluation the quality of ligament remnant, dynamic ultrasonography had a sensitivity of 95.52% and a specificity of 57.78% (95% confidence interval [CI]: 0.669–0.864); MRI had a sensitivity of 65.67% and a specificity of 75.56% (95% CI: 0.607–0.805), and the combined method had a sensitivity of 61.19% and a specificity of 88.89% (95% CI: 0.659–0.842). The sensitivity, specificity, PPV, NPV, and accuracy of the three imaging methods are presented in Supplementary Table S3. The receiver operating characteristic (ROC) curve analysis is provided in Supplementary Figure 2.

Correlation of arthroscopic diagnostic types with surgical procedures, complications, and preoperative assessments

No significant differences were encountered with preoperative Karlson-Peterson scores and CAIT scores between different ligament injury types (eta = 0.029, $P = 0.790$; eta = 0.046, $P = 0.538$). The modified arthroscopic diagnostic types were significantly correlated with the surgical procedures performed (Cramer's $V = 0.718$, $P < 0.001$). The surgical complications included knot irritation (n = 4), mild keloid formation (n = 3), and superficial peroneal nerve injury (n = 1). Two cases needed to receive a revision surgery due to additional ankle sprains. There were no

significant differences in surgical complications between the arthroscopic diagnostic types (Cramer's $V = 0.077$, $P = 1.000$). The correlations of arthroscopic diagnostic types with surgical procedures, complications, and preoperative assessments of ankle function are shown in Supplementary Table 4 and Table 5.

Clinical outcomes

Preoperative and postoperative Karlson-Peterson scores and CAIT scores were compared to assess the clinical outcomes (Table 3). Both Karlson-Peterson scores and CAIT scores were significantly increased after surgical treatment ($Z = -9.189$, $P < 0.001$; $Z = -9.191$, $P < 0.001$).

Discussion

The main finding of this study is that a preoperative evaluation assessment of the quality of the ATFL remnant using our modified classifications based on the combination of dynamic ultrasonography and MRI was reliable and correlated well with the arthroscopic findings. Dynamic ultrasonography and MRI are important preoperative imaging methods for CAI, and classification of ATFL injuries based on either technique has been described previously [13, 14]. Kemmochi et al. first reported a classification of acute ATFL injuries based on ultrasonographic findings [13]. Acute ATFL injuries were classified into five types of increasing severity from an intact ATFL and fibrillar pattern to an avulsion fracture of the talar insertion or distal lateral malleolus [13]. Morvan et al. examined the reliability of preoperative MRI for surgical decision-making in chronic lateral ankle instability [14]. The authors reported that an avulsion or thickened ligament is reparable, while a thin or absent ATFL on MRI would indicate a poor-quality remnant, and thus require ligament reconstruction with a graft. However, only

a few consensuses have been published regarding preoperative planning for treating chronic ATFL injuries based on these imaging techniques [11, 12]. In the present study, ATFL remnants were simply classified into "good," "fair," or "poor" quality on dynamic ultrasonography, MRI, and the combined methods. On dynamic ultrasonography, slightly different to the classification of Kemmochi et al., we focused on the intactness or clarity of the fibrillar band of the ligament, and only used three types (clear or partially clear or fuzzy fibrillar band) rather than five. On MRI, in contrast to the two types (thin or thicken) of ATFL injuries suggested by Morvan et al., we also used three grades to classify remnant quality: thickened (good) or thin (fair), or disorganization/attenuation/absence (poor). According to Morvan's report, diagnostic performance parameters of preoperative MRI were good: sensitivity: 85.7–87.5%, specificity: 86.7–92.9%. However, our results showed that dynamic ultrasonography is relatively better than MRI for assessing the quality of the ATFL remnant (sensitivity: 95.52%, specificity: 57.78% vs sensitivity: 65.67%, specificity: 75.56%). When we combine the imaging methods, a higer specificity was obtained (88.89%). Actually, the accurate assessment of the remnant quality can be influenced by an avulsion fracture of the fibula, os subfibulare, and severe synovitis on the MRI. In addition, it is worth noting that CT scans still lack significant consistency in distinguishing between avulsion fractures of the fibula and os subfibulare, as well as determining their impact on the ligament remnants.

The secondary finding is that modified arthroscopic classifications might provide more details about the ATFL remnants, thereby guiding the appropriate selection of arthroscopic procedures: ligament repair with or without augmentation, or reconstruction. Arthroscopic evaluation of chronic ATFL injuries is often considered the reference standard because the scar tissue can be easily distinguished from normal tissue, identify capsular adhesions, and confirm the boundary of the ATFL remnant [2, 35]. Yasui and Takao [36] also reported a good correlation between arthroscopic evaluation of an irregular ATFL and its histological characteristics. In the present study, we classified arthroscopic manifestations of chronic ATFL injuries into six major types (7 subtypes) for selecting the appropriate surgical procedure. Correlation analysis of the modified classifications of the imaging findings with arthroscopic diagonostic types showed a significant difference in the distribution of the seven subtypes. In addition, the modified imaging classifications were also significantly associated with different surgical procedures (ligamentous repair with or without augmentation, or ligamentous reconstruction). These results suggest that the modified classifications might provide an increased accuracy when assessing chronic ATFL injuries, as well as planning an appropriate surgical procedure. Furthermore, the Karlson-Peterson scores and CAIT scores were greatly

Table 3 Comparison of Karlson-Peterson and CAIT scores before and after surgery

	Median	Minimum	Maximum	Z value	P value
Karlson-Peterson				$Z = -9.189$	<0.001
Preoperative	61	42	72		
Postoperative	90	78	100		
CAIT scores				$Z = -9.191$	<0.001
Preoperative	50	20	70		
Postoperative	90	70	100		

improved postoperatively, suggesting satisfactory recovery of ankle functions.

Moreover, our modified arthroscopic classifications of chronic ATFL injuries differs slightly from that of Thès et al. [2]. We classified chronic ATFL injuries in a more detailed manner (elongated ligament; partial or complete ligament tear at the fibular side; partial or complete ligament tear at the talar side; small or big size osseous avulsion of the fibular or os subfibulare; attenuated or absent ligament), as compared to the five types used by Thès (normal; distended; avulsion from the fibula; thin; absent with a bald malleolus). Actually, compared with small size osseous avulsion of the fibula or os subfibulare, the surgical method of large size bony fragments at the ATFL remnant is not the same. In these cases, with large size bony fragments was resected, the CFL was usually affected, so, arthroscopic repair is always difficult and local tissue is not sufficient. Similarly, the ATFL avulsion of the fibular side is different from the talar side. Based on our clinical data, the size of the osseous avulsion or os subfibulare and location of the ATFL tear were considered in the modified classifications and surgical decision-making process.

There are some limitations with this study. First, the patient number is relatively low in some subgroups such as only three patients in type I, which results in a partial conclusion. Second, although different imaging classification grades were significantly associated with different arthroscopic types, a strong correlation was still not obtained, and there was a slightly high false positive rate. Third, some diagnostic procedures might not have been performed strictly while following the same protocol. Finally, our assessments were based on the ATFL remnant, not on the CFL, more assessments about the CFL should be conducted in the future due to the difficulty of arthroscopic evaluation. Still, this study provides some useful information of the surgical decision-making process for chronic ATFL injury treatment.

Conclusion

The modified classifications and surgical decision-making process based on dynamic ultrasonography, MRI, and arthroscopic findings, as proposed in this study might help in selecting an appropriate arthroscopic surgical procedure for chronic ATFL injuries.

Author contribution Jing Han: manuscript preparation and literature research

Shenglong Qian: data collection and follow-up assessment.
Junhong Lian: data collection and follow-up assessment.
Helin Wu: data review and assessment.
Boyu Zheng: data analysis and statistical analysis
Xinchen Wu: data review and assessment.
Feng Xu: manuscript review
Shijun Wei: designed study and manuscript revision
All authors read and approved the final manuscript.

Declarations

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