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ORIGINAL ARTICLE

Diagnostic value of intraoperative tap test for acute deltoid ligament injury

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Abstract

Purpose Deltoid ligament injuries appear with isolated or even no displacement of the lateral malleolus fracture which could easily lead to misdiagnosis, which frequently brings about ankle medial instability and talus shift that eventually lead to the occurrence of ankle osteoarthritis. This study is aimed to investigate the value of the tap test for assessing the integrity of the deltoid ligament intraoperatively.

Methods Ninety-two patients with malleolar fractures and possible acute deltoid ligament injury treated in our hospital from March 2013 to May 2016 were enrolled in this prospective study. The gravity stress test and tap test were performed preoperatively by three physicians independently before and after fixation of the fibula. The sensitivity, specificity, positive and negative predictive values, and false-positive and false-negative rates of both tests were determined based on medial malleolus exploration for the integrity of the deltoid ligament. The inter-observer consistency was also analyzed.

Results Forty seven (51.1%) versus fifty two (56.5%) of the 92 patients tested positive for deltoid ligament injury according to the preoperative gravity stress test or the subsequent tap test. Forty-eight cases (52.2%) were confirmed during surgery. The sensitivity of gravity stress test was lower than that of tap test (95.8% vs 100%), and specificity of gravity stress test was the same as tap test (97.7% vs 97.7%). Between gravity stress test and tap test, the positive and negative predictive values were 97.9% vs 92.3% and 95.6% vs 100%, and the false-positive and false-negative rates were 2.3% vs 9.09% and 4.2% vs 0%, respectively. Between the two tests results, the percentage of inter-observer agreement was > 90% (kappa coefficient > 0.80).

Conclusion The tap test has the advantages of high sensitivity, simple operation, and less radiation exposure, suggesting that it is of high diagnostic value for assessing the integrity of the acute deltoid ligament.

Keywords Deltoid ligament · Stress test · Diagnosis

Background

Ankle sprain often leads to ankle ligament injury and about 5% of such injuries are deltoid ligament injuries [1]. The classic symptoms of deltoid ligament injury include ankle medial ecchymosis, tenderness, and swelling, with typical X-ray manifestations of medial malleolus space widening and talus shift. However, some deltoid ligament injuries appear with isolated or even no displacement of the lateral malleolus fracture, only a small amount of petechia, and mild tenderness, which could easily lead to misdiagnosis. Therefore, the actual incidence of deltoid ligament injury may be higher than reported [2, 3]. The misdiagnosis of the deltoid ligament injury often brings about ankle medial instability and talus shift which eventually lead to the occurrence of ankle osteoarthritis. Schuberth et al. found that about 1/3 of patients with isolated distal fibular fractures

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had deltoid ligament damage through ankle arthroscopy [4]. Michelson et al. proposed that a stress test should be performed to evaluate the integrity of the deltoid ligament in cases of an isolated fibular fracture [5]. The common stress tests are the external rotation stress test and gravity stress test. The gravity stress test, designed by Michelson et al., is considered the gold standard in the diagnosis of deltoid ligament injury [6, 7], because of its high specificity, sensitivity, and reproducibility. However, the application of gravity stress test in the clinic is limited, due to the requirement of a special posture. Without anesthesia, it is difficult for the patients to maintain the posture due to pain. If patients are unable to cooperate, even the normal placement of the surgical position could be affected. Researchers have suggested that magnetic resonance imaging (MRI) and color Doppler ultrasound examination have high sensitivity and specificity for identifying damage to the deltoid ligament [8–12]. However, these two examination techniques are highly dependent on the expertise of radiologists and ultrasonographers and are subject to the resolution and accuracy of the device, and still they may not provide evidence of indications for surgery. Thus, the search for an easily operable and reproducible test that can provide evidence for surgical exploration to diagnose deltoid ligament rupture is of high clinical significance.

In recent years, Rajagopalan et al. described the application of the tap test to evaluate the stability of ankle syndesmosis [13]. In our initial experience, when the deltoid ligament was intact, the diastasis of tibiofibular syndesmosis and the widening of the medial clear space caused by the tap test were much smaller than those when the deltoid ligament was ruptured. We, therefore, assumed that the tap test has the ability to predict the integrity of the deltoid ligament. To validate the diagnostic value of the tap test for acute deltoid ligament injury, we collected a case series of 92 patients with suspected deltoid ligament injury at the trauma center from March 2013 to May 2016. Both the tap test and gravity stress test were conducted to evaluate the sensitivity and specificity of the tap test in the diagnosis of acute deltoid ligament injury to compare the consistency of the tap test with that of the gravity stress test and to evaluate the advantages and disadvantages of the tap test.

Materials and methods

Patient characteristics

The inclusion criteria were: (1) distal fibular fracture with or without medial clear space widening; (2) preoperative X-ray Lauge-Hansen classification of supination-external rotation (SER) rotation, pronation-abduction (PA), or pronation-external rotation (PER) type; and (3) ankle medial subcutaneous ecchymosis or tenderness. The exclusion criteria were: (1) multiple ipsilateral fractures; (2) open fractures; (3) previous ankle injury and deformity; (4) pathological fracture; (5) age < 16 years; and (6) medial malleolus fracture.

Ninety-two consecutive patients with suspected deltoid ligament injury were treated at the trauma center between March 2013 and May 2016 and were included in the study. Patients were given drug treatment and instructed to elevate the limb preoperatively to reduce swelling. Three-dimensional computed tomography (CT) examination was performed to identify the type of fracture. The Lauge-Hansen classification was based on the evaluation of X-ray films by two senior surgeons. According to the Lauge-Hansen classification, 42 cases were SER, 43 cases were PER, and 7 cases were PA type. According to the AO/OTA classification, all PER and PA cases were type C. In 42 SER cases, there were 32 cases of type B and 10 cases of type C. All patients signed an informed consent form and the study was approved by the Medical Ethics Committee of Shanghai General Hospital.

Intraoperative procedures

All internal fixation procedures were performed by a group of three senior surgeons. The tap test and gravity stress test also were conducted on each patient by the three doctors separately. Positive or negative results were determined when two out of three doctors reached consensus. Open reduction and internal fixation (ORIF) was applied to treat the fibula and the posterior ankle fractures, and then the tap test was performed by the surgeons individually with the same criteria to assess deltoid ligament injury. Finally, deltoid ligament exploration was performed for all cases.

Gravity stress test

The patient was placed in supine position to observe the medial clear space under C-arm fluoroscopy from the mortise view of the ankle. As shown in Fig. 1c, a sandbag was placed under the contralateral hip of the patient in the supine position, with the hip and knee in external rotation and flexion and a bracket under the proximal side of the ankle. The C-arm was placed at the mortise view of the ankle with the tibia stabilized at approximately 10° of internal rotation. A positive finding on the gravity stress test was defined as a medial clear space of > 4 mm that was also > 2 mm greater than the superior joint space. When the deltoid ligament was ruptured, the medial clear space was significantly widened (Fig. 1d).

Fig. 1 Case 1, male, 42 years old, Lauge-Hansen supination-external rotation. **a** X-ray image from the anteroposterior view suggested ankle fracture, with normal medial malleolus space and slightly swollen soft tissue shadow; **b** lateral view on ankle radiograph; **c** preoperative gravity stress test; **d** C-arm fluoroscopic X-ray indicated medial malleolus space widening and slight talus shift and tilt, suggesting deltoid ligament injury, and the gravity stress test outcome was positive

Tap test

The patient was placed in supine position under general anesthesia or spinal anesthesia. An incision was made at the posterolateral side of the fibula and then the lateral malleolus was reduced and internally fixed. If the posterior malleolar fragment was large enough to allow placement of screws, internal fixation was applied. The one-third tubular plate was applied to fix the larger bone fragment, and a 4.0-mm cannulated compression screw was used for the smaller bone fragment (such as Wolkmman tubercle avulsion fracture). As shown in Fig. 2d, after the reduction and fixation of the fibula and the posterior malleolar fractures, at the level of the tibiofibular syndesmosis, through the binding holes of the plate, a drill hole was made in the fibula until the tap reached the second layer of cortex using the drill bit at a 15 ~ 20-degree coronal angle where it was stopped to keep the lateral tibial cortex intact. Then, a 3.5-mm tap was inserted from the screw hole and stopped when the second layer of cortex was ruptured (the tap was through the fibula; Fig. 2a). The width of the medial clear space and the degree of talar shift were observed under the C-arm. Then, the tap was screwed in until resistance was felt again and progressed for another three rotations before radiographic observation (Fig. 2b). The before and after talus shift and widening of the medial clear space were compared. A positive finding was defined as an increase in the medial clear space of > 2 mm.

Medial deltoid ligament exploration

After completion of the stress test, a 5-cm curved incision was made from the medial malleolus forward and below, and the deep fascia and retinaculum were dissected. The great saphenous vein and accompanied saphenous nerve were protected, and the medial malleolus was exposed. The conditions of superficial and deep deltoid ligaments were observed and recorded. If the tibionavicular, tibiocalcaneal, and other superficial ligaments were not completely ruptured, the incision was made along the longitudinal direction of the ligament fibers to observe the integrity of the deep tibiotalar ligaments. After fixation of the fibula, the deep ligament may be difficult to expose due to narrowing of the medial malleolus space. Plantar flexion, external rotation of the ankle, and traction of the forefoot can be helpful, as shown in Fig. 2e.

Statistical analysis

All data were analyzed by a member of the study group using the statistical software SPSS 16.0 (SPSS, Chicago, IL, USA). The sensitivity, specificity, positive predictive

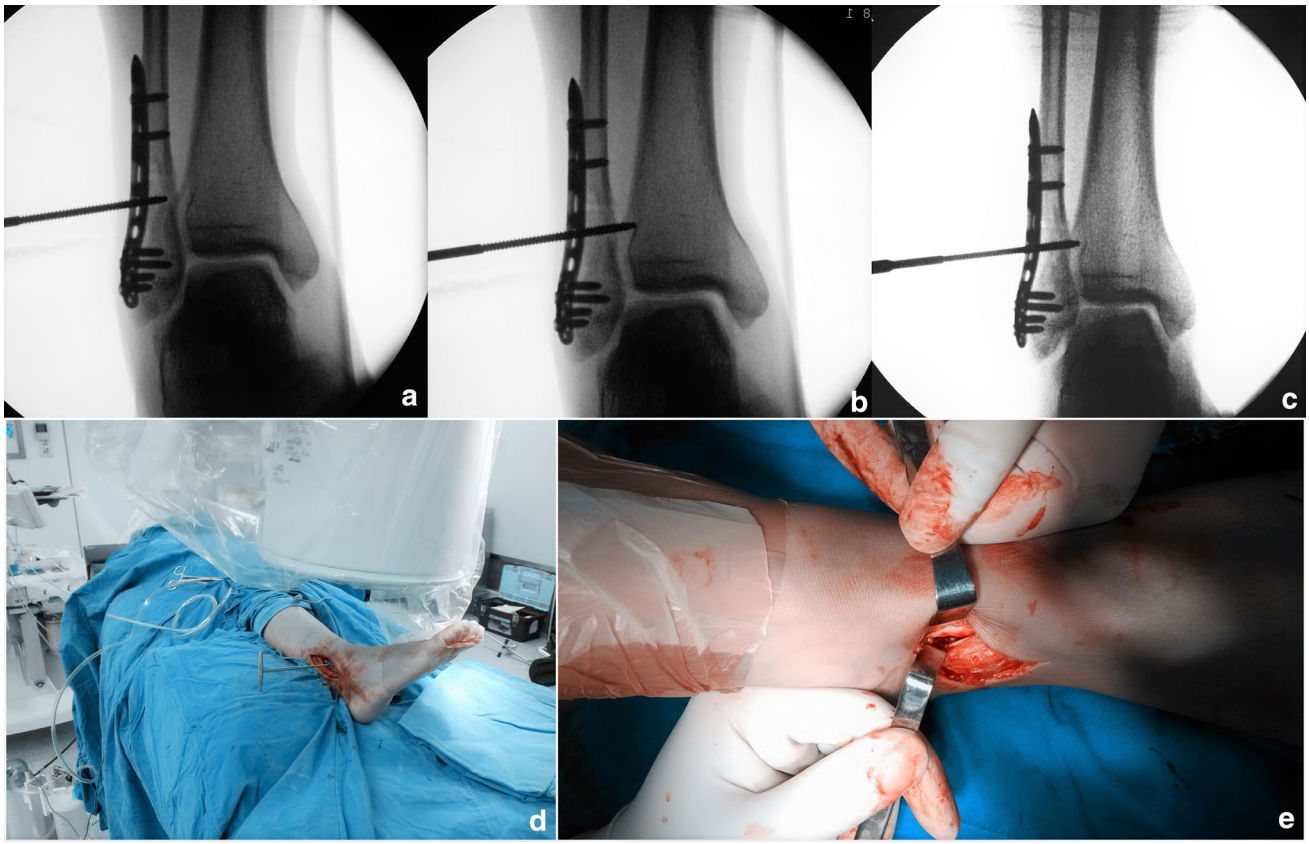

Fig. 2 Case 1: follow-up. **a** Intraoperative ankle anteroposterior view by C-arm fluoroscopy showed when tap was through the first layer of the fibula cortex, there was no widening of the inferior tibiofibular joint syndesmosis and medial malleolus space; **b** after the tap reached the second layer of the fibular cortex and was twisted another three times, the medial malleolus space was significantly widened, suggesting a positive outcome on the tap test; **c** tap test after repair of the inside deltoid ligament, suggesting normal medial malleolus space; **d** exterior view of tap test; **e** medial deltoid ligament exploration suggesting superficial deltoid ligament rupture and deep layer ligament tear from the tibia side

value, negative predictive value, false-positive rate, and false-negative rate of each diagnostic test were evaluated. The exploration results were used as the gold standard for the tap test and gravity stress test. The kappa coefficient was used to determine the agreement between the observers for the two stress tests. The analysis of kappa coefficients was based on the criteria proposed by Fleiss and Landis [14, 15]. Kappa < 0.40 represents inconsistency between observers, 0.40 < kappa < 0.75 represents better agreement between observers, and 0.75 < kappa < 1 represents excellent agreement between the observers. According to the Landis and Koch standard, a kappa coefficient between 0.01 and 0.2 represents slight agreement between the observers, kappa between 0.21 and 0.40 indicates fair agreement, kappa between 0.41 and 0.60 indicates moderate agreement, kappa between 0.61 and 0.80 indicates substantial agreement, and kappa > 0.80 reflects almost perfect agreement. $P < 0.05$ was considered statistically significant.

Results

The clinical data of the 92 consecutive patients with suspected deltoid ligament injury are presented in Table 1. The mean age of the patients was 39.4 years (range 19–64 years), and the study population included 58 males and 34 females. Among them, 69 patients had medial subcutaneous ecchymosis and 85 had medial tenderness.

The results of the preoperative gravity stress test were positive for 47 (51.1%) of the 92 patients and negative for 45 (48.9%) patients. Fibular fractures were fixed in all cases, and 42 of the 92 patients had a fixed ankle fracture. The results of the tap test were positive for 52 patients (56.5%) and negative for the other 40 patients (43.5%) with no significant widening in the medial joint space (Fig. 2b).

In this study, observations on surgical exploration were used as the gold standard for diagnosis of deltoid ligament

Table 1 Clinical characteristics of 92 patients

Age (years)	Gender	AO classification	Lauge-Hansen classification	Medical ecchymosis	Medial tenderness
Average (39.4)	Males (58)	Type B (32)	SER (42)	Positive (69)	Positive (85)
Range (19–64)	Females (34)	Type C (59)	PER (42)	Negative (23)	Negative (7)
			PA (7)		

injury. Different degrees of deltoid ligament injury were observed in 48 (52.2%) of the 92 patients. There were 5 cases of superficial ligament layer injury, 18 cases of deep ligament layer injury, and 25 cases of complete ligament complex injury. The sensitivity and specificity of the tap test were 100% and 90.9%, respectively, and the positive and negative predictive values were 92.3% and 100%, respectively. The false-positive and false-negative rates were 9.09% and 0%, respectively. By comparison, the sensitivity of the gravity stress test was 95.8%, and the specificity was 97.7%. The positive and negative predictive values were 97.9% and 95.6%, respectively, and the false-positive and false-negative rates were 2.3% and 4.2%, respectively (Table 2).

The inter-observer consistency rates for the gravity stress test and tap test were 96.7%, 96.7%, and 95.6% between the three observers, and the corresponding kappa coefficients were 0.934, 0.933, and 0.912, respectively. By comparison, the inter-observer consistency rates for the corresponding gravity test were 97.8%, 98.9%, and 96.7%, and the kappa coefficients were 0.957, 0.978, and 0.935, respectively (Table 3). The consistency between the tap test and the gravity test was > 90% between the different observers, and the kappa coefficient among all observers was > 0.80, suggesting excellent consistency and high reliability according to the standards proposed by Fleiss and Landis [14, 15].

Discussion

In this study, we compared the efficiency of the tap test to that of the gravity stress test for the diagnosis of deltoid ligament injury. Although both tests exhibited good inter-observer consistency and high reliability, the tap test had a higher sensitivity and lower false-negative rate. However, its specificity was slightly lower than that of the gravity test, which led to a certain degree of false-positive results. Both the sensitivity and specificity of the gravity stress test were high, consistent with the results reported by Michelson et al. [5].

Whether deltoid ligament rupture requires repair is still a controversial topic [16]. Many studies have reported that deltoid ligament injury can be treated conservatively [3, 17]. However, in more recent studies, surgeons tended to repair the deltoid ligament [18–21]. The advantages include early stabilization, early onset of functional exercise and, in some cases, avoidance of syndesmotic screws, thus, avoiding the problems of ruptured screws and implant removal. However, questions such as what are the indications for ligament repair in patients with deltoid ligament injury and whether all deltoid ligament injuries require repair remain unanswered. Michelson et al. proposed that surgery should be performed in patients with positive gravity stress test results, because the test is very specific and sensitive [5, 7]. However, in misdiagnosed cases that need to be diagnosed intraoperatively during internal fixation surgery, the gravity stress test could be inconvenient and even conflict with the operative position, making the operation more time consuming and

Table 2 Results of the tap test and gravity stress test in 92 patients

	Results confirmed by surgery		Sensitivity	Specificity	Positive predictive value	Negative predictive value	False-positive rate	False-negative rate
	Positive	Negative						
Tap test								
Positive	48	4		90.9% (40/44)	92.3% (48/52)	100% (40/40)	9.09% (4/44)	0 (0/48)
Negative	0	40						
Gravity stress test								
Positive	46	1	95.8% (46/48)	97.7% (43/44)	97.7% (46/47)	95.6% (43/45)	2.3% (1/44)	4.2% (2/48)
Negative	2	43						

Table 3 Kappa test for inter-observer agreement between the tap test and gravity stress test

	Observer 1	Observer 2		Consistency	Kappa	*t*	*P* value
		Positive	Negative				
Tap test	Positive	50	0	96.7%	0.934	8.98	< 0.001
	Negative	3	39				
Gravity stress test	Positive	45	0	97.8%	0.957	9.18	< 0.001
	Negative	2	45				
	Observer 2	Observer 3		Consistency	Kappa	*t*	*P* value
		Positive	Negative				
Tap test	Positive	51	1	96.7%	0.933	8.96	< 0.001
	Negative	2	38				
Gravity stress test	Positive	47	1	98.9%	0.978	9.39	< 0.001
	Negative	0	44				
	Observer 1	Observer 3		Consistency	Kappa	*t*	*P* value
		Positive	Negative				
Tap test	Positive	50	2	95.6%	0.912	8.74	< 0.001
	Negative	2	38				
Gravity stress test	Positive	45	0	96.7%	0.935	8.99	< 0.001
	Negative	3	44				

laborious. Therefore, it is of great clinical significance to find a simple and easy intraoperative method for the diagnosis of deltoid ligament injury.

The tap test was first proposed by Rajagopalan et al. for the diagnosis of inferior tibiofibular syndesmosis [13]. The principles are as follows: after a drill hole is made through the two layers of cortex of the fibula, a tap is introduced to meet and push the near cortex of the tibia. This procedure leads to the gradual diastasis of syndesmosis, while the tap is progressing. If the tibiofibular clear space widens by > 2 mm compared to the contralateral side and the medial clear space is slightly widened (1 ~ 2 mm) due to the talus shift, the distal tibiofibular syndesmosis is injured. The deltoid ligament complex is composed of the superficial talotibial ligament, tibiospring, calcaneotibial ligament, tibionavicular ligament, superficial posterior tibiotalar ligament, anterior deep tibiotalar ligament, and posterior deep ligaments [22]. Superficial and deep ligaments together limit the valgus and posterior slope of the talus, while the deep layer plays a more important role in limiting external rotation and shift of the talus. If the deltoid ligament is intact, the shift of the talus will be significantly limited. Boden et al. found in a cadaver study that when the deltoid ligament was intact, disruption of the interosseous membrane resulted in only 1.4 mm separation in syndesmosis, and when the deltoid ligament was ruptured, the same situation could cause a 4.5-mm separation in the syndesmosis [23]. Wang et al. also reported that in the intact deltoid ligament group, 10 degree malrotation would lead to significant widening of the medial clear space and syndesmosis diastasis; however, in the injured deltoid ligament group, more than 5° of rotational deformity significantly enlarged the volume of medial space and separation of the inferior tibiofibular syndromes [24]. According to our clinical experience, through tap tests we found that in deltoid ligament injury cases including SER, PER and PA injuries, the gap between the tibiofibular syndesmosis and medial clear space was increased to > 4 mm, and repair of the deltoid ligament significantly reduced this gap. This also confirmed that the integrity of the deltoid ligament is the real impact factor for syndesmotic diastasis and widening of the medial clear space, which also provides the theoretical framework for the application of the tap test in the diagnosis of deltoid ligament injury.

This study reported that the tap test had a sensitivity of 100% with a false-negative rate of 0. As mentioned above, deltoid ligament injury can be subtle, and significant widening of the medial clear space can be difficult to see on X-ray, resulting in a very high false-negative rate during diagnosis. Because the tap test has high sensitivity, it is helpful for detecting deltoid ligament injury to avoid misdiagnosis. However, a slightly higher false-positive rate of the tap test was observed, because a gradual force is used to shift the tibia, allowing the talus to shift with the fibula, resulting in the widening of the medial clear space. If the force of the tap screw is > 7.5 N, it could result in an extremely stretched medial deltoid ligament as evidenced by widening of the inner space. Therefore, according to our experience, the application of the tap test for the diagnosis of deltoid

ligament injury should be combined with Lauge-Hansen fracture classification and whether the ecchymosis or tenderness is observed on the medial side. If these symptoms and signs are present and the tap test result is positive, there is a strong indication for exploration of the deltoid ligament. According to the literature [25], relying solely on the above two types of clinical diagnosis may be not very reliable, but combination with the tap test can significantly improve the accuracy of the prediction. Compared with the gravity test, the tap test has the following advantages over such traditional stress tests: (1) the standardized operation increases the operational repeatability; (2) the tap force is gradually increased, instead of the manual stress, resulting in a linear increase in the power during diastasis of syndesmosis; (3) after repairing the deltoid ligament, the tap test could be used to test the stability for surgical outcome (Fig. 2c); and (4) surgeons can avoid radioactivity exposure since they do not need to be present to maintain stress.

However, it should be noted that in patients with osteoporosis, the depth of the tapping screw into the tibia should be closely monitored, as the tap will penetrate the tibial lateral cortical and impact the test results. Also, the tap test is an invasive examination, and it can only be carried out under anesthesia, which could limit its preoperative diagnostic application. In addition, due to the existence of a lateral malleolus fracture, the tap often needs to penetrate into the tibiofibular joint through the plate, which is restricted by the directions of the plate screw path. Sometimes the tap passed by the back of the tibia, which could affect the accuracy of the test. All the above questions should be further investigated in studies with a large sample size.

The limitations of this study include the relatively small sample size, the subjective observation of medial clear space widening, and the diastasis of the ankle syndesmosis resulting in qualitative data but not quantitative data, which could contain the certain degree of systematic error and observation error. Also, the tap test is an invasive examination and due to ethical issues, the contralateral side could not be used as a control.

Conclusions

The tap test is characterized by a high sensitivity and low false-negative rate. Although it has a certain false-positive rate, it also has the advantages of being a simple operation, having good repeatability, and requiring less radiation exposure. Also, it not only provides evidence for the degree of injury to the deltoid ligament but also the surgical indications for surgeons. Moreover, it is also practical for postoperative verification of the stability after deltoid ligament repair. Although it is only applicable to patients with fibular fracture and surgical indications, it can be an option for intraoperative evaluation of the integrity of the deltoid ligament.

Author contributions CB and KW performed the study design, analyzed the results, and contributed to the manuscript. DK and JL contributed to collecting the cases. JH and QW made some meaningful suggestions. CB and KW helped in the drafting and revising of the manuscript. All authors reviewed and approved the final submitted version.

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Availability of data and materials The datasets during and/or analyzed during the current study are available from the corresponding author on a reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interests. There are no ethical/legal conflicts involved in the article.

Ethical approval and consent to participate Shanghai General Hospital's Ethics Committee reviewed and approved this retrospective study. Each participant signed the written informed consent.

Consent for publication Written informed consent was obtained from individual participants.

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