석사학위 논문

Value of Ultrasound for Stability Assessment of Isolated Lateral Malleolar Fractures

아 주 대 학 교 대 학 원

의 학 과

서 영 욱

Value of Ultrasound for Stability Value of Ultrasound for Stability Assessment of Isolated Lateral Malleolar Fractures

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이 논문을 의학 석사학위 논문으로 제출함.

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서영욱의 의학 석사학위 논문을 인준함.

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-ABSTRACT-

Value of Ultrasound for Stability Assessment of Isolated Lateral Malleolar Fractures Compared to Stress Radiography and Arthroscopy

This study was performed to evaluate the value of using ultrasound (US) for stability assessment of isolated lateral malleolar fractures compared to simple x-ray, stress radiography, and arthroscopy. This was a prospective cohort study with 25 consecutive patients who underwent arthroscopic exam and subsequent surgery for isolated lateral malleolar ankle fracture. Before operation, simple and external rotation stress radiographs were done. Ultrasound was performed to assess the anterior inferior tibiofibular ligament and medial deltoid ligament prior to operation. Arthroscopic findings were used as reference standard. Sensitivity, specificity and positive and negative predictability were calculated and compared using ROC curve analysis for simple radiograph, stress radiography and US examination. On US or arthroscopy, seven patients had complete rupture of deltoid ligament. Sensitivity and specificity of US for tear of deep deltoid ligament were 94.7% and 66.7% each. But, they were both 100% for complete tear of it. ROC curve analysis showed that US examination is significantly more accurate than simple and stress radiography. In conclusion, US could be used to assess the instability of isolated lateral malleolar fracture.

Keyword: ankle fracture, isolated lateral malleolar fracture, stability, ultrasound

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INTRODUCTION

Ankle fractures are commonly treated orthopedic trauma. There is no doubt of surgical treatment for unstable bimalleolar or trimalleolar ankle fracture. However, treatment of isolated lateral malleolar fracture remains controversial (1-6). Treatment strategy depends on the stability of ankle joint. Conceptualizing the ankle joint as a ring, like pelvis, is helpful in deciding which fractures are stable or unstable. One fracture in the otherwise intact ring is stable (7). Therefore, pure isolated lateral malleolar fracture is stable. However, combined medial deltoid ligament injury will make the ankle unstable. Deep deltoid ligament is recognized as a primary stabilizer of the ankle. It prevents lateral talar shift and external rotation (ER) of the talus (6). Given that the inability to maintain anatomic alignment of the mortise has been correlated with poor out- comes, the assessment of stability is critical.

Ankle stability has been traditionally assessed through clinical findings and simple radiography. If medial tenderness, swelling, and ecchymosis are present on clinical examination in combination with lateral talar shift on simple radiography, medial deltoid ligament injury is suspected. However, just clinical finding is insufficient. Other objective methods are needed to assess the status of the medial deltoid ligament.

In clinical evaluation of stable looking radiography of lateral malleolar fracture with medial tenderness, stress radiography is used to determine medial deltoid injury and stability of the ankle. Medial clear space (MCS), defined as the distance between the lateral border of the medial malleolus and the medial border of the talus at the level of the talar dome (8) is an indicator of deep deltoid

ligament. ER stress test is a popular method for assessing ankle mortise stability (2-5,9). However, it has several problems. It is difficult to make a correct ankle position. Different examiners produce various amount of force. It can cause pain and further injury. The examiner is at risk of radiation hazard. Gravity stress radiography has also been used to assess ankle stability. It is known to be better than ER stress radiography. However, it might give false negative results (10).

Magnetic Reasonance Imaging (MRI) and arthroscopy can be used for stability assessment (2,11,12). However, practical use of these modalities is limited because of their high cost and invasiveness.

Ultrasound (US) is commonly used for musculoskeletal soft tissue injuries. For foot and ankle field, US is quite useful because most tendons, ligaments, and nerves are located just beneath the skin. Furthermore, US examination can be performed during the first visit of patient. It is also likely to be more accurate than the traditional method of palpating ligaments to diagnose possible injury (13). Chen et al. have reported its use for stability assessment of isolated lateral malleolar ankle fracture (14). However, comparison study between US and other diagnostic tools for stability assessment has not been reported yet. Therefore, the objective of this study was to evaluate the value of using US for stability assessment of isolated lateral malleolar fractures compared to simple x-ray, stress radiography, and arthroscopy. The accuracy of US examination in comparison with simple radiography and ER stress radiography and arthroscopy for diagnosing instability of the ankle in isolated lateral malleolar ankle fractures was determined. Our hypothesis was that US could be used as first line examination for assessing unstable ankle fracture.

MATERIAL AND METHODS

This study was approved by our Institutional Review Board. Informed consent for enrollment to study was obtained from each patient. Patients aged at least nineteen years with isolated lateral malleolar ankle fracture of Lauge-Hansen Supination-External Rotation (SER) type who were treated from May 2016 to May 2017 at our institution were eligible for inclusion in the present prospective study. Patients with bilateral ankle fractures, pathologic fracture, previous ankle injury, concomitant tibial shaft fracture, peripheral neuropathy, soft-tissue infection in the region of the ankle, generalized inflammatory arthritis, or unable to walk unaided before injury were excluded. Fractures were classified by a senior foot and ankle surgeon responsible for each patient's care. Of 37 patients who were screened before inclusion, 12 were excluded due to concomitant tibial shaft fracture (n = 5), previous ankle injury (n = 4), peripheral neuropathy (n = 2), soft tissue infection (n = 1), or generalized arthritis (n = 1). Finally, 25 patients were enrolled, including 11 females and 14 males whose mean age was 42.2 ± 15.9 years.

Before radiographic exam, swelling, tenderness, and ecchymosis on the medial deltoid area and syndesmosis area (anterior inferior tibiofibular ligament [AITFL]) were assessed for each patient. All patients had tenderness and swelling over the medial deltoid area. Stability was assessed on initial simple radiography. Each result was recorded as positive when MCS was ≥5 mm, tibiofibular overlap (TFO) was <5 mm, tibiofibular clear space (TFCS) was ≥10 mm, or side to side difference was ≥1 mm. These measurements were adjusted for magnification using a constant source-to-detector distance of 115 cm and a standard 30 mm radiographic marker (10). Two authors measured each distance and calculated

interobserver reliability. Disagreement were resolved through consensus discussion.

For cases with negative simple radiography, manual ER stress radiography (15,16) was performed by one senior foot and ankle surgeon or a senior orthopedic foot and ankle resident who completed foot and ankle training. A total of four surgeons were involved in ER stress test. Each result was recorded as positive when MCS was ≥5 mm or side to side difference was ≥1 mm. Positive cases on either simple or stress radiography was believed to be unstable ankle fracture. Operative treatment was then decided for those patients.

Before surgery, all patients underwent US examination. It was performed with a Logiq 7 unit (LOGIQ P6, GE Healthcare, Chicago, IL, USA) and a linear probe. Each patient was in a sitting position with one leg putting on the examination table. The transducer was placed sequentially over the lateral and medial ankle ligaments, AITFL, and the deltoid ligament. The transducer scanned the deltoid ligament in a fan-shaped fashion in the oblique coronal plane. Normal deltoid ligament appeared as a hyperechoic band at 4 to 5 mm in thickness, connecting the medial malleolus to the posterior talus, sustentaculum tali, navicular, and anterior talus (Fig. 1). Criteria for complete rupture of deltoid ligament were discontinuity and direct contact of the posterior tibial tendon to the expanded articular pouch (Fig. 2). In cases with vague findings whose echo failed to match complete tear or intact ligament, it was regarded as a partial tear.

After surgical fixation of the lateral malleolar fracture (interfragmentary screw fixation and lateral plating), arthroscopic exam was performed by a single senior surgeon. The ankle joint was visualized through standard anterolateral and anteromedial portals. A systematic arthroscopic examination was performed to visualize internal structures (deltoid ligament, medial gutter, talus, talofibular articulation, lateral gutter, AITFL, anterior talofibular ligament, and

calcaneofibular ligament) under arthroscopic visualization to clarify injury of the medial deltoid ligament. Ligaments were inspected visually, and photographs were taken with the foot internally and externally rotated while the midtibial shaft was stabilized. Deltoid ligament complex was manually stressed intraoperatively by applying ER forces to the foot. Integrity of deltoid ligament was classified as intact, partially ruptured, or completely ruptured (11).

The sample size was determined using an area under ROC curve based on a pilot study. Our hypothesis was that US was accurate method for assessing tear of deep deltoid ligament. The sample size was determined by assuming a AUC (Area under curve) of 1.00 for complete tear, 0.807 for total injury of deltoid ligament. We calculated a sample size of 8 patients for complete tear and 24 patients for deltoid injury in total (partial or complete tear). This would permit a type-1 error rate of 0.05, with a type-2 error rate of 0.20.

Sensitivity, specificity and positive and negative predictability were calculated for simple radiograph, stress radiography and US examination, using the arthroscopic findings as a reference. ROC (Receiver-Operating Characteristic) curve analysis was used to calculate associations between simple, stress radiography and US examination as a reference to arthroscopic findings. A p-value < 0.05 was considered statistically significant.

RESULTS

A total of 14 patients had unstable ankle fractures on simple radiography and eleven patients were unstable on stress radiography (Table 1). On US, 7 patients had complete rupture of deltoid ligament (Fig. 1). Thirteen patients showed partial tear while 5 patients had normal deltoid ligament on US (Fig. 2). On arthroscopy, 7 patients had complete rupture of deltoid ligament. Twelve patients showed partial tear while 6 patients had normal deltoid ligament on arthroscopy (Fig. 3).

Sensitivity and specificity of US for tear of deep deltoid ligament were 94.7% and 66.7% each. But, they were both 100% for complete tear of it. (Table 2) ROC curve analysis showed that US examination is significantly more accurate than simple and stress radiography. (Table 3) (fig.4).

Table 1. Details of the total cases

No	Age	Sex	Simple X-ray	Stress X-ray	US Deltoid	AS Deltoid
1	57	F	+		0	0
2	56	F	+		1	0
3	19	F	+		1	1
4	44	F	+		1	1
5	49	F	+		0	1
6	28	M	+		1	1
7	45	M	-	+	2	2
8	22	M	+		1	0
9	24	M	+		2	2
10	59	F	-	+	0	0
11	70	M	-	+	2	2
12	45	M	-	+	1	1
13	23	M	+		2	2
14	40	M	+		1	1
15	56	F	-	+	1	1
16	50	F	-	+	0	0
17	55	F	+		0	0
18	21	M	-	+	1	1
19	49	F	-	+	1	1
20	27	M	+		1	1
21	67	M	+		1	1
22	49	M	-	+	2	2
23	40	M	-	+	1	1
24	19	M	-	+	2	2
25	55	F	-	+	2	2

US, Ultrasound; AS, Arthroscopy; 0, intact; 1, partial tear, 2, complete tear

Table 2. Sensitivity and specificity of simple/stress radiography and ultrasound for complete tear of deep deltoid ligament.

Complete tear	Sensitivity	Specificity	+ predictability	- predictability
Simple X-ray	28.57%	38.89%	15.38%	58.33%
Stress X-ray	50.00%	50.00%	50.00%	50.00%
Ultrasound	100.00%	100.00%	100.00%	100.00%
Injury in total (partial or complete)	Sensitivity	Specificity	+ predictability	- predictability
Simple X-ray	47.37%	33.33%	69.23%	16.67%
Stress X-ray	100.00%	50.00%	83.33%	100.00%
Ultrasound	94.74%	66.67%	90.00%	80.00%

Table 3. Comparison of ROC curves of simple/stress radiography and ultrasound for tear of deep deltoid ligament.

Complete tear	AUC	SE	95%CI	p-value
Simple X-ray	0.663	0.110	0.448 to 0.838	0.138
Stress X-ray	0.500	0.000	0.295 to 0.705	1.00
Ultrasound	1.000	0.000	0.863 to1.000	<0.001
Injury in total (partial or complete)	AUC	SE	95%CI	p-value
Simple X-ray	0.576	0.121	0.383 to 0.786	0.424
Stress X-ray	0.500	0.000	0.295 to 0.705	1.000
Ultrasound	0.807	0.109	0.601 to .0936	0.005

AUC: area under curve, SE: standard error, CI: confidence interval

DISCUSSION

The most important finding of this study was that most patients did not have complete deltoid ligament injury. All patients were diagnosed as unstable ankle fracture by simple or stress radiography. However, most of them did not have severely injured deltoid ligament based on arthroscopic findings.

Measurement of MCS defined as the distance between the lateral border of the medial malleolus and the medial border of the talus at the level of the talar dome has been considered as an indicator of the status of deep deltoid ligament (9). MCS of more than 5 mm on simple or stress radiography suggests a total tear of the deep deltoid ligament. It is believed to be an indication for operative treatment (1,2,9,10,17,18). Recently, several studies have doubts about the accuracy of MCS for predicting injury of deep deltoid ligaments (6,9,11,17,19-21). Koval et al. have reported that MCS measurements on stress radiographic testing do not correlate with MRI findings of deep deltoid rupture (9). Schuberth et al. have also stated that a widened MCS is over emphasized as an indicator of deltoid integrity in their arthroscopy study (11). They have pointed out that accurate diagnosis of deltoid rupture by noninvasive method remains a clinical challenge.

MRI have been used to diagnose soft tissue injury of ankle fracture (1,12,22-24). Vogl et al. have reported that MRI is a highly sensitive and specific tool for the evaluation of syndesmotic injury (24). Nielson et al. have reported that the level of fibula fracture does not correlate with the integrity of IOM inujury (23). However, there are limited studies about their use for stability assessment of isolated lateral malleolar fractures. Koval et al. have found that 19 (90%) of 21 patients have evidence of partially torn deep deltoid

ligament on MRI (9). These patients were treated non-operatively. However, two patients with complete deep deltoid injury on MRI underwent surgery. They stated that all fractures united without evidence of residual MCS widening or posttraumatic joint space narrowing (9). However, Nortunen et al. have found that all patients have an injury involving the deep deltoid ligament on MRI (an edematous ligament, a partial tear and a total tear) regardless of the degree of MCS, even though MCS is increased ($p < 0.001$) according to the severity of deep deltoid ligament injury based on MRI (1). They reported that interobserver agreement of the external-rotation stress test was excellent, whereas the interobserver reliability of the MRI assessments was fair to moderate. Therefore, they did not recommend the use of MRI when choosing between operative and nonoperative treatment of SER-type ankle fractures. Regular use of MRI for assessment of ankle fracture also can become a burden for the patient because of its high cost and inconvenience of examination.

Arthroscopy has been used to assess cartilage lesions and ligament injury in acute ankle fractures. Schuberth et al. have used arthroscopy as a standard to compare with MCS on stress radiography. The value of arthroscopy in assessing the stability of ankle fracture could not be determined by that research (11). Arthroscopic evaluation of deep deltoid ligament in patients with suspected unstable ankle fracture is not a practical diagnostic modality because of its invasiveness even if it might be an accurate assessment method.

Henari et al. have performed similar comparison study between US and arthrography and found that US is a highly accurate diagnostic modality (100% sensitivity and specificity) in the assessment of deltoid ligament (25). Chen et al. have also stated that US is direct and noninvasive evaluation of the deltoid ligament in patients with isolated lateral malleolar fractures (14). They confirmed surgical findings for complete rupture cases of the deltoid ligaments. However,

they could not prove correlation between sonographic findings and real pathology in non-surgical patients (14).

Recently, Sanders et al. published similar functional results between operative and conservative treatment for stress-positive SER IV equivalent fractures (3). Of concern is the fact that 8 patients (20%) in the conservative group developed a malalignment and that 8 patients developed union problems. Similarly, in 2016, Willett et al. published the excellent functional results of conservative treatment for unstable ankle fractures in patients older than 60 years (26). But, 15% of the casting group displayed radiographic malunion as compared with 3% who underwent surgery. These two studies demonstrated only short term follow-up. (1 year and 6 months for each) As previous studies have demonstrated the negative effects of malalignment on contact area, contact pressures, and the development of arthrosis, short-term assessments are unlikely to predict long-term functional outcomes (27,28).

This is the first study that compares US findings to those of arthroscopy for patients with isolated lateral malleolar fractures. Our results confirmed that all patients had complete or partial deltoid ligament rupture surgically. However, only 7 patients had complete rupture of deltoid ligament on US. These findings matched with US findings (Table 4).

Table 4. Sensitivity and specificity of ultrasound for injuries of AITFL and deltoid ligament.

	Sensitivity	Specificity	+ predictability	- predictability
Ultrasound (Complete Deltoid tear)	100.00%	100.00%	100.00%	100.00%
Ultrasound (Deltoid injury in total)	94.74%	66.67%	90.00%	80.00%
Ultrasound (Complete AITFL tear)	80.95%	100.0%	100.00%	50.00%
Ultrasound (AITFL injury in total)	88.00%	100.0%	100.00%	40.00%

This study demonstrated that simple and stress radiographic examinations had poor sensitivity and specificity to assess stability of isolated lateral malleolar fracture. However, US appears to be accurate for assessing complete deltoid ligament tear.

An inherent limitation of this study was the small number of complete deltoid ligament tears. However, the prevalence of complete tears in this study was similar to that reported in previous studies (9,25). In addition, clinical information after treatment was not presented. Surgical or nonsurgical treatment should have been decided by US findings to evaluate the clinical result of treatment protocol using US as in the study of Koval et al. (9). However, the objective this study was to compare radiography, US, and arthroscopy for the diagnosis of unstable ankle fracture. Clinical study needs to be conducted in the near future.

Our study lacks MRI information. However, MRI scan poses big financial burden to patients. In addition, the focus of this study was to compare arthroscopy and US, not MRI.

US is often criticized for its operator dependency. In this study, a single surgeon who had great experience of diagnostic foot and ankle US performed and interpreted US images. Therefore, interobserver reliability could not be calculated. In addition, the surgeon who performed the US also performed the surgery. Therefore, the US operator was not blinded to arthroscopic findings. However, the accuracy of US of this study was similar to that in other studies (25,29).

Even though this study had some limitations, this was the first study that compared US findings and arthroscopy for patients with isolated lateral malleolar fractures. This study proved that US was accurate for detecting ligament injuries in isolated lateral malleolar fractures.

CONCLUSION

Tear of deep deltoid ligaments could be diagnosed on US with high accuracy. Therefore, US could be used as primary or adjunctive diagnostic tool to assess the stability of isolated lateral malleolar fracture.

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– 국문요약 –

외과 단독 골절시 안정성 평가를 위한 초음파 검사의 유용성

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족관절 외과 단독 골절시 안정성 평가를 위한 초음파 검사의 유용성에 대한 연구를 시행하였다. X-선 검사, 부하 X-선 검사, 관절경 검사와 비교하였다. 본 연구는 후향적 코호트 연구로써 족관절 외과 단독 골절 진단 하 관절경 검사 및 수술을 시행한 25 명을 대 상으로 시행하였다. 수술 전 초음파를 이용하여 전하 경비 인대와 내측 삼각인대를 평가하였다. 초음파 소견은 표준 분류법을 사용하였다. 민감도, 특이도, 양성 및 음석 예측도는 ROC 곡선 분석을 이용하여 X-선 검사, 부하 X-선 검사, 초음파 결과를 비교 하였다. 초음파 혹은 관절경 검사에서 내측 삼각인대 완전 파열 환자는 7 명이었다. 심부 내측 삼각인대 파열에 대한 초음파 검사의 민감도는 94.7%, 특이도는 66.7% 였다. 심부 내측 삼각인대 완전파열에 대한 초음파 검사의 민감도와 특이도는 100% 였다. X-선 검사, 부하 X-선 검사에 비하여 초음파 검사의 진단이 더 정확하였다. 결론적으로, 족관절 외과 단독 골절시 안정성 평가를 위한 초음파 검사는 X-선 검사, 부하 X-선 검사에 비해 유용하다.

핵심어: 족관절 골절, 단독 외과 골절, 안정성, 초음파