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Basic Study

Role of the posterior deep deltoid ligament in ankle fracture stability: A biomechanical cadaver study

Daniel James McCormack, Matthew Solan, Sheweidin Aziz, Radwane Faroug, Sayyied Kirmani, Georgina Wright, Jitendra Mangwani

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Abstract

BACKGROUND

The deltoid ligament is a key component of ankle fracture stability. Clinical tests to assess deltoid ligament injury have low specificity. In supination external-rotation (SER) type-IV ankle fractures, there is either a medial malleolus fracture or deltoid ligament injury. These injuries are often considered unstable, requiring surgical stabilisation. We look to identify the anatomical basis for this instability. This study investigates the anatomical basis for such instability by re-creating SER type ankle fractures in a standardised cadaveric study model, investigating the anatomical basis for such instability.

AIM

To investigate the anatomical basis for fracture instability in SER type ankle fractures.

METHODS

Four matched pairs of cadaveric limbs were tested for stability both when axially loaded and under external rotation stress. Four matched pairs of cadaveric limbs (8 specimens) were tested for stability when axially loaded to 750 N with a custom rig. Specimens were tested through increasing stages of SER injury in a stepwise fashion before restoring the lateral side with open reduction and internal fixation (ORIF). Clinical photographs and radiographs were recorded at each step. We

defined instability in accordance with well accepted radiological parameters: > 4 mm medial clear space opening on a mortise-view radiograph or > 7 degrees of talar tilt.

RESULTS

All specimens with an intact posterior deep deltoid ligament were stable. Once the posterior deep deltoid ligament was sectioned there was instability in all specimens. Stabilisation of the lateral side prevented talar shift, but not talar tilt.

CONCLUSION

If the posterior deep deltoid ligament is intact then SER fractures can be managed without surgery. If the posterior deep deltoid is incompetent, ORIF and cautious rehabilitation is recommended because the talus can still tilt in the mortise.

Key Words: Trauma; Fracture stability; Biomechanics; Cadaveric study; Basic science

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Core Tip: The deltoid ligament is a key component of ankle fracture stability. No fracture with an intact posterior deep deltoid ligament demonstrated instability on axial loading or rotational stress. This study suggests the instability can only occur in the presence of posterior deep deltoid ligament deficiency, supporting the non-operative treatment of many ankle fractures. If the posterior deep deltoid ligament is intact then supination external-rotation fractures can be managed without surgery. If the posterior deep deltoid is incompetent, open reduction and internal fixation and cautious rehabilitation is recommended because the talus can still tilt in the mortise.

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INTRODUCTION

Ankle fractures are common and yet there is wide variation in how they are managed[1]. The concept of ankle fracture stability has long been used to guide whether an ankle fracture can be managed non-operatively or whether operative stabilisation is required[2]. In practice, the criteria used to define a stable ankle fracture have been open to interpretation. Understanding of this issue has progressed over recent years. Many stable fractures are still treated operatively. This leads to increased costs both in terms of surgical admission for treatment and in dealing with complications in fractures which may have been safely managed without surgery[3,4].

To determine whether operative stabilisation is required or not, a precise understanding of the injured parts of the ankle is required. The widely used Danis-Weber Classification, which forms the basis of the AO Classification, is not adequate for distinguishing between stable Weber B fibula fractures and unstable Weber B fibula fractures[5]. The Lauge-Hansen classification offers a better understanding of which bony and ligamentous structures are injured[6].

The Lauge-Hansen Classification was introduced over 70 years ago[6]. The structures that are injured progress in an orderly fashion, depending upon the position of the foot at the time of injury and the type of force applied. The foot is either Supinated or Pronated. The applied force is either rotational (external or internal) or translational (abduction or adduction). Supination external-rotation (SER) injuries are the most common type of ankle fracture. In SER injury, supination of the foot means that the lateral structures are tight and so these are the first to fail. Next to fail, as rotation continues, is the posterior part of the ankle and finally the medial side.

Lauge-Hansen[6] described 4 stages to SER injury. SER-I is injury to the anterior inferior tibio-fibular ligament. With further force, an oblique fibula fracture will occur (SER-II). The next structure to fail is either the posterior malleolus or the posterior inferior tibiofibular ligament (SER-III). In the final stage, deltoid ligament injury or medial malleolar fracture occurs (SER-IV). Lauge-Hansen[6] based his classification upon laboratory simulation with cadaveric specimens. In clinical practice there is variation in both the foot position and force applied. Injury patterns therefore vary from patient to patient.

SER injuries account for 80% of ankle fractures[1]. Diagnostic difficulty arises in cases where there is a fibula fracture (Weber B) but no posterior malleolus fracture or medial malleolus fracture. Where there is a fracture of the medial malleolus then the diagnosis of SER-IV (and instability) is generally considered straightforward. If the medial side of the joint has no fracture, then determining whether the injury is a stable SER-II (with no deltoid ligament injury) or an unstable SER-IV (with injury to the deltoid ligament) is challenging.

Defining the presence of ligamentous medial injury is not straightforward. Traditionally, medial tenderness and ecchymosis have been used as clinical signs of deltoid ligament injury. Studies have demonstrated, however, no correlation between medial tenderness and deltoid ligament incompetence. DeAngelis *et al*[7] examined 55 patients with SER injuries and found that only 25% of patients who were tender medially had a positive external rotation stress radiograph. Twenty-five percent of patients without medial tenderness also had a positive external rotation stress radiograph. This, along with the earlier studies by McConnell *et al*[8] and Egol *et al*[9], demonstrate that clinical findings are of little value in determining ankle fracture stability. Clinical assessment alone is unreliable. Radiological studies with ultrasound and magnetic resonance imaging have also proven of little use in clinical practice[10-15].

It has been argued that a formal examination under anaesthesia (EUA) of the injured ankle will demonstrate instability in “ligamentous bi-malleolar” fractures. Whilst this strategy would reliably discriminate between SER-II and SER-IV, such an approach is impractical given the large number of patients. The Gravity Stress View was introduced to demonstrate, without formal EUA, whether the deltoid ligament complex is competent (no talar shift) or not (talar shift demonstrated)[16,17]. However, this technique has subsequently been shown to have a high rate of false positives[18]. Ankles may appear unstable because of ankle plantarflexion which gives the false impression of a wide medial clear space[19].

Weightbearing radiographs are now considered to be the best means of demonstrating whether a Weber B ankle fracture is stable (SER-II) or unstable (SER-IV)[18]. Properly conducted weightbearing radiographs show whether the ankle is stable under physiological load. The implication of this is that the deltoid ligament is sufficiently competent to maintain the position of the talus in the mortise when the ankle is held at 90 degrees. This study did not address the question of partial deltoid ligament injury and whether that affects stability.

The anatomy of the deltoid ligament has been described in various levels of detail[20]. For the purposes of understanding ankle fractures, the deltoid ligament can be usefully considered to have three components: Superficial; deep anterior tibio-talar and deep posterior tibio-talar. Michelson *et al* [21], in a cadaveric study, investigated stability when both the superficial and deep deltoid ligaments were sectioned, using a gravity stress-view. They showed increased medial clear space in all 8 specimens. This study did not investigate which components of the deltoid ligament complex gave the ankle mortise stability. In particular, the authors did not distinguish between the roles of the two components of the deep deltoid ligament. The superficial ligament is not crucial to the maintenance of the talus in the mortise. The deep deltoid ligament is. It has been shown that the posterior deep deltoid (tibio-talar) ligament is the thickest component[22], that it is tight when the ankle is plantigrade and that the anterior component is tight in plantarflexion[23]. We designed our protocol to investigate the contributors to ankle fracture stability in SER type injuries, including the posterior and anterior portions of the deep deltoid ligaments.

MATERIALS AND METHODS

Thawed fresh-frozen cadaveric specimens from the tibial plateau to the foot were used. The tissues were used in accordance with the Human Tissue Act 2004, with all investigators undergoing appropriate training prior to study commencement. Four matched pairs of specimens were tested using the protocol (8 specimens in total). A bespoke jig was used, capable of axially loading and simultaneously applying torque through a cadaveric specimen. The jig was designed to load the specimens with 750 N and to permit mortise-view and lateral view radiographs to be taken using an image intensifier. 750 N was selected to recreate the single leg standing force of a 75 kg individual. The image intensifier was operated by a radiographer. In this study we re-created a fracture of the lateral malleolus with a subsequent injury to the deltoid ligament in line with Lauge Hansen SER type IV injury. We did not specifically investigate bony medial malleolus fractures.

With the intact specimen in the jig and axially loaded to 750 N, a baseline mortise-view radiograph was taken. This radiographic view was repeated using the image intensifier at each step in a systematic reproduction of SER injury. Structures were divided in the order in which they fail during a Lauge-Hansen SER type injury. The osteotomy was performed using an oscillating saw from the level of the distal most aspect of the syndesmosis posteriorly, to its most proximal aspect anteriorly, completely dividing the fibula. The osteotomy was fixed using a standard AO technique. A single cortical lag screw across the fracture site and a 1/3 tubular stainless steel plate, with 2 uni-cortical cancellous screws and 3 bi-cortical cortical screws fixing the neutralisation plate either side of the fracture. A tri-cortical screw was placed across the syndesmosis. The anterior deep deltoid and posterior deep deltoid were divided

sequentially - firstly the anterior 50% of the ligament, and secondarily the posterior 50% to allow for subtle variations in anatomy and maintain reproducibility between specimens. At each step the specimen was axially loaded with 750 N and radiographs were obtained. Each radiograph was investigated for signs of instability, defined in our study as > 4 mm medial clear space and/or 7 degrees of talar tilt (Figure 1A, Table 1).

RESULTS

None of the 8 specimens showed any evidence of instability either with axial loading or with rotational force until division of the posterior deep deltoid ligament. Apparent stability under axial loading was still evident in all 8 specimens through every step of the experiment, even when the posterior deep deltoid ligament was divided (Figure 1B). When the specimens were subjected to external rotation force, all 8 specimens were stable at steps A to E of the experiment (up to and including division of the anterior deep deltoid ligament). However, instability was demonstrated in all 8 specimens after division of the posterior deep deltoid ligament. Talar tilt and talar shift were both demonstrated (Figure 1C). All specimens demonstrated > 4 mm medial clear space and > 7 degrees of talar tilt.

After fixation of the osteotomy, external rotation stress views and continuous screening showed < 4 mm medial clear space. All 8 specimens demonstrated talar tilt > 7 degrees (Figure 1D). All ankles were stable until we divided the posterior deep deltoid ligament. At this point instability was only reproduced on external rotation stress testing. Even with the posterior deep deltoid ligament divided, specimens showed no talar shift on axial loading with 750 N.

DISCUSSION

Ankle injuries follow patterns that are well understood and these patterns form the basis of the Lauge-Hansen classification[6]. The introduction of a more simple classification, relying solely upon description of the fibula fracture, led to indiscriminate fixation of fibula fractures. The presence of a Weber B fracture was considered an indication for surgery, since the fibula was felt to be the primary stabiliser of the ankle[24]. More recently, demonstrable instability of the talus within the mortise has become the indication for surgery. Interest is currently focused on how best to identify this instability[1-3,25].

This study reproducibly demonstrates that with an intact posterior deep deltoid ligament the talus remains stable beneath the tibial plafond when loaded axially and when subject to external rotation stress testing. Anatomical studies have highlighted different components of the deltoid ligament[22,24,26]. Imaging studies have confirmed that a partial deep deltoid ligament injury can occur and this means that the SER-IV injury is a heterogeneous group[10].

In SER-IV injuries the medial side may have a fracture or ligament injury. The medial malleolus fracture fragment may be large or small. Small fracture fragments may affect the anterior colliculus and this represents the attachment of the anterior deep deltoid ligament[27]. A large fracture fragment of the medial malleolus includes the whole deep deltoid attachment - the anterior colliculus with the anterior deep deltoid ligament and the posterior colliculus with the posterior deep deltoid[28]. After fixation of a large medial malleolus fracture the joint is stable. This highlights the primary importance of the posterior deep deltoid ligament. Medial side integrity determines ankle stability, and the key structure is the posterior deep deltoid ligament. This concept can be extended from medial side fractures to medial side ligamentous injuries. If the deep deltoid is partially injured and the posterior component is intact, then the ankle is stable. However, such stability is only conferred by the posterior deep deltoid ligament when it is tight, with the ankle in a plantigrade position.

Gougoulas *et al*[1] proposed that SER-IV injuries be subdivided into types a and b. They recommended management strategies based on assessment of stability with weightbearing X-rays (Table 2). According to their recommendations, in SER-IVa injuries the posterior deep deltoid is intact (IVa) so the ankle fracture can be immobilized and treated without surgery. The foot should be maintained at 90 degrees to the leg. This is best achieved in a formal below-knee walking cast and not with a removable boot. If the plantigrade position is lost then there is potential for a poor result, with late deltoid ligament insufficiency[29-31]. In SER-IVb injuries, where the posterior deep deltoid ligament is also injured, the ankle is unstable and operative stabilisation of the fibula fracture should be considered.

Our study highlights the importance of the posterior deep deltoid ligament in SER injuries. Only once the posterior deep deltoid ligament was divided did the specimens become unstable. When the posterior deep deltoid ligament is intact (SER-IVa) the injury can be treated non-operatively but, like Gougoulas *et al*[1], we recommend that a formal plantigrade below knee walking cast is used. All SER-IVb injuries were unstable in our study. Gougoulas *et al*[1] recommended open reduction and internal fixation (ORIF) of the fibula for these injuries. In our study, axially loaded specimens still appeared stable, with no talar shift. The bony anatomy and soft tissue envelope are likely factors conferring this

Table 1 Study protocol

Experimental step	Specimen
A	Intact
B	AITFL divided
C	Fibula osteotomy at the level of syndesmosis
D	PITFL divided
E	Superficial and anterior deep deltoid ligament divided
F	Posterior deep deltoid ligament divided
G	Fracture & syndesmosis fixation

AITFL: Anterior inferior tibiofibular ligament; PITFL: Posterior inferior tibiofibular ligament.

Table 2 Management recommendations based on weight-bearing X-rays as suggested by Gougoulas *et al*[1]

Fracture type	NWB XR	WB Xray	Deep deltoid ligament	Management
SER-II	Stable	Stable	Intact (PTTL & ATTL)	Boot & WB
SER-IVa	Unstable	Stable	Partial tear (ATTL only)	WB Cast 6/52
SER-IVb	Unstable	Unstable	Ruptured (PTTL & ATTL)	ORIF

SER: Supination external-rotation; AITFL: Anterior inferior tibiofibular ligament; PITFL: Posterior inferior tibiofibular ligament; ORIF: Open reduction and internal fixation; NWB: Non weight bearing; WB: Weight-bearing.

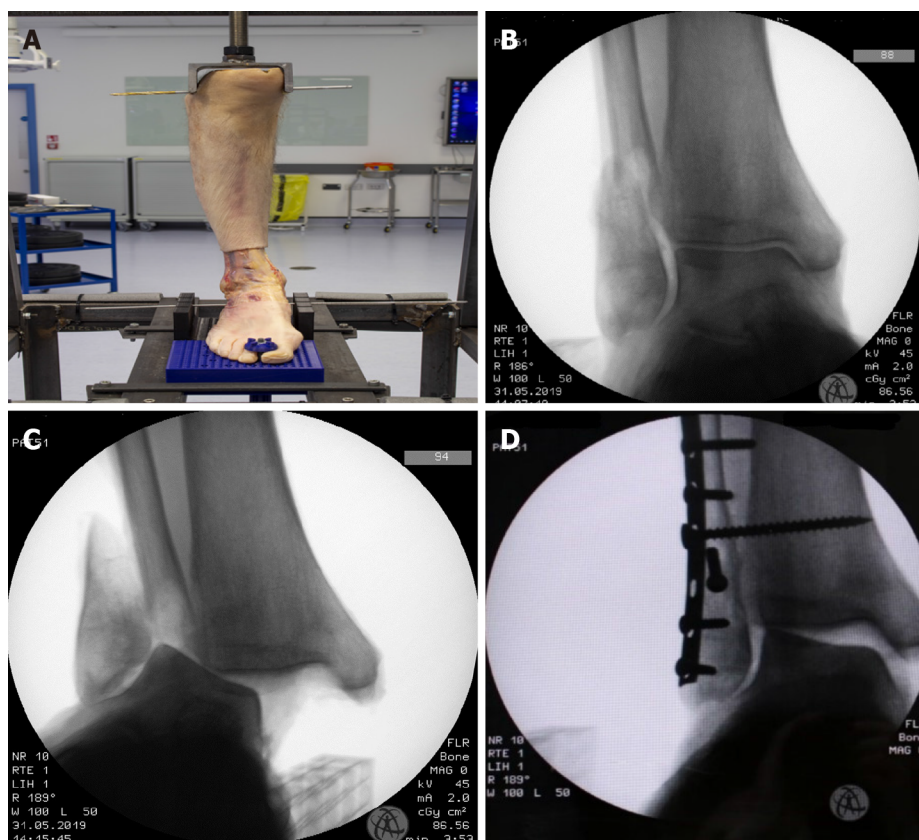
stability. The experimental setup only tested the axially loaded specimens in a plantigrade position. Radiological determinants of instability vary with the position of the ankle[19]. When rotational force was applied the SER-IVb specimens, all were markedly unstable (Figure 1B). This supports the recommendation that ORIF of the fibula should be used to restore stability. When we tested SER-IVb specimens after fibula ORIF, talar tilt was still demonstrable. We would go further than Gougoulas *et al* [3] and recommend that, postoperatively, SER-IVb injuries should be immobilized in a plantigrade position to allow proper healing of the deltoid ligament. Physiotherapy protocols should also be modified to avoid late deltoid insufficiency. Deltoid ligament repair has been suggested as a potential supplementary treatment for SER-IVb injuries, however at this stage, deltoid repair appears to have no effect on functional outcome scores[32].

This study has limitations. Eight specimens is a small sample size, but the uniformity of our results make it highly improbable that the conclusions would differ if further specimens were tested. A syndesmosis screw is not routinely used in the fixation of SER-IV fractures. Some authors advocate a “hook test” after fibula fixation but randomized controlled studies have found no benefit with the addition of a position screw, even when talar shift was observed after fibula ORIF in the short or medium term[33,34]. We added the syndesmosis screw so that the controversial role of mild syndesmosis instability after ORIF could be excluded as a reason for talar displacement.

The results of this study show that if the posterior deep deltoid ligament is intact, the ankle is stable. We did not investigate specifically whether an intact anterior deep deltoid ligament would also afford stability if the posterior deep deltoid is torn. However, Tornetta[27] have already demonstrated the prime importance of the posterior deep deltoid ligament.

The results of our study provide further evidence that the majority of SER injuries can be treated non-operatively. Injury to the posterior deep deltoid ligament is the watershed. Clinicians choosing non-operative treatment for SER-IV fractures - both types a and b - should carefully consider immobilisation and rehabilitation protocols. This is because of our finding that talar tilt occurs even after fibula ORIF when the posterior deep deltoid ligament is divided.

Operative stabilisation of SER-IVb fractures should be followed by cautious postoperative care, holding the ankle in a plantigrade position to allow the posterior deep deltoid ligament to heal. SER-IVa fractures can be successfully managed non-operatively but, since stability depends upon the posterior deep deltoid, immobilisation of the ankle at 90 degrees is indicated. For this reason, a cast rather than a removable boot is suggested. Operative fixation of the fibula might permit more rapid rehabilitation. The merits of surgery, and the potential complications, should be discussed with patients on an individual basis.



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Figure 1 Experiment set-up. A: Experiment set-up; B: Specimen under load at stage E showing no talar tilt or shift; C: Same specimen under dynamic stress testing demonstrating shift and tilt at stage F; D: Specimen after fixation under stress testing demonstrating talar tilt - step G.

This cadaver study demonstrates the critical importance of the posterior deep deltoid ligament in ankle stability after SER-IV fracture. The results increase the body of evidence supporting the non-operative management of ankle fractures, even those injuries that initially appear to be potentially unstable. Our results also suggest that even when treated with ORIF, an SER-IVb fracture may demonstrate talar tilt on external rotation. Whether this leads to detrimental outcomes in patients remains unclear. Deltoid ligament repair is an area of current interest with recent research suggesting although repairing the deltoid ligament may improve radiological parameters, it has yet to demonstrate improved patient reported outcome measures[32].

It is generally accepted that more severe ankle injuries perform worse long term, particularly giving a greater risk of ankle arthrosis or reflex sympathetic dystrophy[35]. Clinical studies are required to further evaluate these recommendations. One area of interest, lies within the fact that all axially loaded specimens with an intact posterior deep deltoid appeared stable until external rotation stress was applied. Further studies could demonstrate whether some of these injuries, apparently stable in a weight bearing cast, are in fact unstable. If held appropriately in cast it is as yet unknown whether this finding is clinically significant. We believe that these findings should stimulate debate regarding the management of SER-IV fractures. Non-operative treatment of SER-IVa injuries relies upon an intact posterior deep deltoid ligament, and this only affords stability when the ankle is plantigrade.

CONCLUSION

If the posterior deep deltoid ligament is intact then SER fractures can be managed without surgery. If the posterior deep deltoid is incompetent, ORIF and cautious rehabilitation is recommended because the talus can still tilt in the mortise.

ARTICLE HIGHLIGHTS

Research background

Ankle fractures are common injuries, with supination external-rotation (SER) type injuries being the most common sub-group. Operative intervention in the form of open reduction and internal fixation (ORIF) should be reserved for patients with unstable fractures. There is debate within the literature as to which ankle fractures should be fixed and why, with some of this controversy relating to the degree of deltoid ligament injury required to create such instability and necessitate operative intervention.

Research motivation

We feel that many SER type ankle fractures are stable injuries which can be treated non-operatively. Reducing the incidence of unnecessary operations will reduce potential morbidity for patients and reduce healthcare costs. Through the authors' previous experience in cadaveric dissection, it was felt the posterior portion of the deep deltoid ligament was usually thick and strong, which may afford an ankle fracture stability. We created our protocol to investigate the anatomical basis for ankle fracture instability.

Research objectives

To identify the anatomical basis for instability in SER type ankle fractures.

Research methods

A bespoke jig was created to load a thawed cadaveric ankle specimen both with axial load and rotational torque. The 8 specimens were loaded both axially and with external rotation during each stage of a SER type ankle fracture, with AP radiographs recorded at each stage. The radiographs were investigated for evidence of ankle fracture instability in terms of talar shift and talar tilt. A detailed description of the study method is included in the research paper. To our knowledge, our study design is unique answering a question which has never previously been answered in a cadaveric basic science study.

Research results

We determined no evidence of radiological instability in any specimen with an intact posterior deep deltoid ligament. Only on disruption of the posterior deep deltoid ligament instability possible under our test conditions.

Research conclusions

Only ankle fractures with a damaged posterior deep deltoid ligament should require operative intervention. With an intact posterior deep deltoid ligament, the ankle can be held in a neutral position, with the ligament reducing the talus within the ankle mortise.

Research perspectives

Clinical studies to investigate the functional outcomes between SER injuries treated operatively and non-operatively may provide further evidence to support the non-operative treatment of ankle fractures with an intact deep deltoid ligament. Further clinical studies are also needed to investigate the functional outcomes of patients following a SER-IVb type injury. It is unclear whether subtle rotational instability may continue following fibular ORIF. Our cadaveric study suggests rotational instability can occur following ORIF of the fibular in these injuries due to the disrupted posterior deep deltoid ligament. It is unknown whether this remains *in vivo* after appropriate immobilisation in a plaster cast. If instability remains, further investigation into the role of deltoid ligament repair is needed.

FOOTNOTES

Author contributions: McCormack DJ, Aziz S, Kirmani S, Faroug R, Wright G, Mangwani J are responsible for performing the experiment; McCormack DJ, Aziz S, Kirmani S, Faroug R, Wright G, Mangwani J, and Solan M contributed to the manuscript preparation.

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