Abstract

Ankle stability in ankle fractures is dependent on multiple factors. The medial malleolus and the associated deltoid ligament provide for ankle stability on the medial side. Over the years, the relative importance of this medial malleolar osteoligamentous complex (MMOLC) has been debated. This review will describe the evolution of ankle fracture surgery from the perspective of the contribution of the MMOLC to re-establishing ankle stability. Also discussed are the surgical and nonsurgical treatment options, various presentations of medial sided injuries in ankle fractures, and, finally, current recommendations for fixation.

The indications for surgical treatment of ankle fractures are based on an understanding of the structures that stabilize the ankle joint. In the early days of ankle fracture surgery, the medial malleolus was considered by many as the main stabilizer of the ankle mortise. As such, displaced bimalleolar ankle fractures were frequently treated by operative reduction and fixation of the medial malleolus in conjunction with closed reduction of the lateral malleolus. It was not until 1979, when Yablon and colleagues published a landmark paper supporting the unpopular notion that the lateral malleolus is the key to ankle stability, that the approach to ankle fracture surgery changed. Since that time, limited attention has been given to the role of the medial malleolus in ankle fractures despite practical concerns regarding its treatment in the clinical setting. Whether as an isolated injury or part of a complex ankle fracture, the medial malleolus deserves special mention when considering surgical and nonsurgical options.

This paper will review the anatomy around the medial malleolus, its role and contribution to ankle stability, surgical and nonsurgical treatment options, its various presentations in ankle fractures, and current recommendations for fixation.

Anatomy

When discussing the anatomy and function of the medial malleolus, it is important to understand its close interrelationship to the deltoid ligament which originates from its anterior and inferior aspects. The most accurate description of what we will refer to as the medial malleolar osteoligamentous complex (MMOLC) was provided by Pankovich and Shivaram and Skie and coworkers in cadaveric studies.

The osseous component of the MMOLC is the medial malleolus, which is composed of the anterior and posterior colliculi separated by the intercollicular groove. The anterior colliculus is the narrower and most distal portion of the medial malleolus and serves as the anchor for the superficial deltoid ligaments. The intercollicular groove and the posterior colliculus, which is broader than the anterior colliculus, provide the origin of the deep deltoid ligaments. The insertions of the deltoid ligaments (medial tubercle of the talus, navicular tuberosity, and the sustentaculum tali) can also be considered part of the MMOLC.

The deltoid ligament, which is divided into superficial and deep, comprises the rest of the MMOLC. The superficial deltoid, originating from the anterior colliculus, has three main components. The naviculotibial ligament is most anterior portion of the superficial deltoid inserting on the dorsomedial navicular. The strongest portion of the super-
ficial deltoid is the calcaneotibial ligament, which inserts at the sustentaculum tali. The most posterior structure of the superficial deltoid is the superficial talotibial ligament, which inserts at the medial talar tubercle.

The deep deltoid is composed of two structures. The deep anterior talotibial ligament, originating from the intercollicular groove deep to the calcaneotibial ligament, inserts on the medial talus. The deep posterior talotibial ligament originates from the intra-articular aspect of the posterior colliculus and inserts on the medial talus. This ligament is the strongest and thickest ligament of the deltoid complex. Also important to consider is the close approximation of the posterior tibial and flexor hallucis tendons to the deltoid ligament as their tendon sheaths are essentially contiguous with the insertions of the deltoid ligament complex.

The Role of the MMOLC in Ankle Stability
During the 1930s and through the 1960s the vast majority of ankle fractures were treated nonoperatively. However, if surgery was indicated, the recognized standard fixation technique for bimalleolar ankle fractures was an open reduction of the medial malleolus and closed reduction of the lateral malleolus. The teaching was that an anatomic reduction of the medial malleolus was sufficient to reduce the talus and reestablish a stable and congruent mortise and that the integrity of the medial malleolus was considered to be the chief determinant of ankle stability. A number of outcome studies, however, indicated unsatisfactory long-term results for surgically treated displaced ankle fractures. The poor long-term outcome of ankle fractures prompted further critical analysis of the approach to treatment of these fractures.

The dogma of the medial malleolus as the main stabilizer of the ankle joint was first challenged by Yablon and associates, who conducted a combined anatomical and clinical study of unstable ankle fractures. In the anatomical arm of the study, cadaver ankles underwent stress testing after an isolated deltoid ligament division, isolated medial malleolus fracture, isolated division of the fibular collateral ligaments, and a short oblique distal fibula osteotomy with all ligaments intact. Stress testing of these sectioned specimens revealed that both an incompetent deltoid ligament and a medial malleolar fracture contributed little to ankle instability. Both of the lateral lesions (lateral malleolus fracture or ligament disruption) of the ankle, however, caused marked ankle instability. In the clinical arm of the study, 42 patients with bimalleolar ankle fractures and 11 patients with a lateral malleolus fracture and tear of the deltoid ligament (indicated by talar shift) were treated operatively. The 11 patients with a fibula fracture and deltoid ligament tear were treated with isolated fibular plating, and all fractures were anatomically reduced. Of the 42 patients with bimalleolar fractures, the first 17 were fixed with medial malleolar fixation only. Intraoperative radiographs revealed inadequate talar reduction in 14 of these cases, at which point all hardware was removed and the fibula alone was plated. All patients achieved reduction of the talus after lateral malleolar fixation. The investigators concluded that the lateral malleolus is the keystone for ankle stability after ankle fracture.

A study by Svend-Hansen and colleagues corroborated the poor results associated with isolated medial malleolar fixation in bimalleolar ankle fractures. Twenty-nine patients with either supination external rotation 4 (SE4) or pronation external rotation 3 and 4 (PE3, PE4) fractures were treated with isolated medial malleolar fixation and closed reduction of the lateral malleolus. Sixteen of the 29 patients in this series had unsatisfactory results with development of ankle arthritis within the 4.8 years average follow-up period. They attributed the poor results to malunions of the fibula and lack of talar reduction by medial malleolar fixation alone.

Another indication of poor results of ankle fractures treated by isolated medial malleolus fixation was provided by Joy and coworkers. A total of 118 unstable ankle fractures were enrolled and all underwent initial closed reduction. If closed reduction was judged inadequate, open reduction...
was undertaken. Forty-six ankles, therefore, underwent operative fixation of the medial malleolus or suture repair of the deltoid ligament without fibular fixation in any of the fractures. During a follow-up period of 1 to 7.5 years the investigators looked at radiographic criteria of reduction as well as subjective and objective evaluation of function. In the 46 operatively treated fractures, 22 (46%) were considered to have poor results, with similar results in the closed treatment group. An analysis of the factors that most portended a poor result showed a correlation with degree of talar displacement, severity of fracture, and presence of deltoid ligament ruptures. This study concluded that isolated medial malleolar fixation and treatment of the MMOLC was inadequate in restoring a normal tibiotaral relationship, having results similar to nonoperative treatment.

A landmark study by Petterone and associates would be similar to nonoperative treatment. The investigators established radiographic criteria for evaluating the adequacy of lateral malleolar reduction and syndesmotic disruption and then used these criteria to assess ankle fractures treated by medial malleolar fixation versus bimalleolar fixation. Criteria for inadequate reduction were set as follows: lateral malleolar displacement greater than 2 mm on the AP or lateral, medial malleolar displacement of greater than 1 mm on the AP only, deltoid ligament disruption with more than 3 mm medial clear space, syndesmotic injury with tibia-fibular clear space greater than 5 mm or tibia-fibula overlap of less than 10 mm (both on the AP), or a tibia-fibula overlap of less than 1 mm on the mortise view. After these reduction criteria were established, 146 displaced ankle fractures were analyzed. These fractures were either treated closed, treated with open bimalleolar fixation, or with medial malleolar fixation alone. Analysis revealed that the overall result was most affected by the degree of medial and lateral malleolar displacement, integrity of the syndesmosis, and the patient’s age. They concluded that the relative order of importance for structures that require restoration are the lateral malleolus, medial malleolus, deltoid ligament, and, finally, the syndesmosis. Their analysis also revealed that bimalleolar ORIF (open reduction, internal fixation) of both SE4 and PE3 and four equivalents, where disruption of the deltoid ligament was diagnosed clinically by medial tenderness over the ligament and by radiographic confirmation of a widened mortise. In this study, three patients were treated by closed reduction, 18 were managed by ORIF of the fibula alone, and 3 were treated with ORIF of the fibula and open repair of the deltoid ligament when intraoperative radiographs showed persistent medial widening after lateral fixation. Of the 18 patients who underwent ORIF of the lateral malleolus, there were 16 patients with good and excellent results, and two patients with fair and poor results. Two of the three patients who also had a deltoid ligament repair had poor results, while the third had an excellent result. The three patients receiving closed treatment also reported good and excellent results. The investigators’ conclusions were that a reliably good outcome and a good reduction in SE4 and PE3 and four equivalent fractures could be expected with addressing the lateral malleolus only.

Further evidence supporting that the lateral malleolus is most responsible for ankle stability comes from two case reports that report a traumatic extrusion and loss of the medial malleolar fragment secondary to an open fracture. In both cases, an effort was made to repair the deltoid ligament. Lindenbaum13 reports a follow-up of 3 years showing no evidence of arthritis, range of motion 5° less than the contralateral side and stability under a lateral stress radiograph. In a second case report by Hernigou and Goutallier,14 a 20-year follow-up of a patient with a similar absence of the medial malleolus showed roughly equal range of motion in both ankles. This patient’s radiographs, however, showed arthritic changes within the joint. The hypothesis of the investigators was that, although ankle varus and valgus stability is conferred by the lateral malleolus, the rotational stability and articular congruency provided by the medial malleolus is important for maintaining the ankle articulation and preventing arthritis.

Based on the above studies, the standard of care for unstable ankle fractures changed during the 1970s and shifted attention to an anatomic reduction of the fibula. As previously mentioned, much of this shift was stimulated by the study of Yablon and associates and subsequent clinical studies. A number of investigators, however, have shown that dorsiflexion and plantarflexion of the ankle are complex motions that involve some movements out of the plane of motion of the ankle and, therefore, static models of ankle
kinematics such as those of Yablon’s group were flawed. It has subsequently been suggested and shown that during axial loading the talus may seek its own position beneath the tibia tending to reduce the lateral subluxating force.\textsuperscript{15-17} It also had been shown that rotational stability of the talus within the ankle is due to tension in the deltoid and lateral ligaments. Excision of the lateral malleolus articular surface did not reduce rotational stability but division of the deltoid ligament caused a two-fold increase in rotational instability.\textsuperscript{18}

Clarke and colleagues\textsuperscript{19} developed an axially loaded cadaver ankle model testing tibio-talar stability in bimalleolar ankle fractures. Their findings showed that even with a 6 mm lateral displacement of the lateral malleolus there was no significant change on the contact area of the ankle as long as it was axially loaded. However, once the deltoid ligament was sectioned, all ankles showed a significant decrease in tibio-talar contact area. This result was consistent with the observation that the pattern of instability was not a straight lateral translation but rather anterolateral rotation underneath the tibial plafond. In a follow-up study, Michelson and coworkers\textsuperscript{20} used a similar unconstrained, axially loaded cadaver model to assess instability in supination external rotation fracture models. This study confirmed that in an axially loaded ankle isolated lateral fibula fracture without medial malleolus or deltoid ligament disruption there was no appreciable loss of tibio-talar contact and that the deltoid ligament, specifically the deep portion, served as a main checkrein to anterolateral rotation of the ankle.

In another study assessing pronation external rotation ankle injuries, Michelson and Waldman\textsuperscript{21} applied their unconstrained axially loaded cadaver ankle model to show that, in the face of an intact MMOLC, even a syndesmotic injury is not destabilizing. In this iteration of the cadaver experiment, when the MMOLC was disrupted along with a high fibular fracture and a disrupted syndesmosis, the talus dislocated from the mortise. When the MMOLC was intact, the talus remained reduced. Solari and associates\textsuperscript{22} also demonstrated the importance of the medial malleolus in the stability of Weber C fractures in a cadaver study evaluating the need for syndesmotic screws. In this investigation, the rotational component of instability was assessed specifically. A Weber C fracture pattern, where the medial malleolus alone was treated, attained 56% of total rotational talus stability, isolated lateral malleolus fixation attained 36% stability, and fixation of the lateral malleolus and medial malleolus (without syndesmotic fixation) attained 76% of total stability. Their conclusion was that the MMOLC is the single most important contributor to ankle stability in Weber C fracture patterns.

Based on this review, it is safe to conclude that the MMOLC is important for ankle fracture stability when considering the ankle joint in a dynamic state. Clearly all fracture patterns are located on a continuum of severity and their treatment must be individualized. It appears that, although a near anatomic reduction of the lateral side of the ankle is important, the MMOLC must be considered an important ankle stabilizer to anterolateral rotation of the talus.

**Collicular Fractures**

The implications of collicular fractures of the medial malleolus also have been studied. Anterior collicular fractures may occur as an isolated injury or in association with rupture of the deep deltoid ligament and account for 15% to 20% of medial malleolar fractures.\textsuperscript{3} Closed treatment is not recommended due to a risk of painful nonunion occurring and also when the fracture is associated with deep deltoid disruption, as ankle instability may occur.

Anterior collicular fractures typically result from supination external rotation mechanisms and appear as a transverse oblique fracture on the AP (antero-posterior) view. On the lateral view, the fracture can be seen exiting the intercollicular groove. There is no displacement on the AP view, since the deep portion of the deltoid ligament is not disrupted. If displacement is seen on the AP view with this fracture configuration, it indicates that the deep deltoid fibers are disrupted and the entire MMOLC has been compromised; therefore, the ankle is unstable.\textsuperscript{23}

Tornetta\textsuperscript{24} showed that fixation of anterior collicular fractures does not necessarily confer medial stability to the ankle. In a series of 27 bimalleolar ankle fractures, the medial malleolus was fixed initially and an external rotation stress view film was taken. Twenty-five percent of the ankles showed a widened mortise medially. Comparison of fractures with a positive stress and those without revealed significant differences between medial malleolar height and width. After lateral fixation, all ankles demonstrated a reduced mortise. This study concluded that the size of the medial malleolar fragment was the most important variable in predicting deltoid competence. When the medial malleolus fragment was more than 2.8 cm wide (supracollicular fracture), the deltoid ligament was intact and the stress view was negative. When the fragment was less than 1.7 cm wide (anterolateral collicular fracture), the deltoid ligament was incompetent and the stress view was positive. Tornetta advised caution regarding treatment of syndesmotic injuries based only on the assessment of the medial malleolar osseous anatomy, since anterior collicular fractures may represent a hidden disruption of the deep deltoid ligament.

Posterior collicular fractures begin in the intercollicular groove and extend superiorly and posteriorly. These fractures are difficult to visualize and are rarely displaced due to the tendons of the posterior tibialis and flexor digitorum longus, which stabilize the fracture fragment.\textsuperscript{25} Although interposition of the posterior tibial tendon has been reported in the literature in one patient,\textsuperscript{26} posterior collicular fractures are typically nondisplaced and are treated nonoperatively.

Fixation of collicular fractures can be accomplished with a small fragment compression screw when the fracture fragment is transverse. When the orientation is oblique, some investigators recommend tension band fixation as the most...
effective construct in preventing displacement.\textsuperscript{23}

**Stress Fractures**

Stress fractures of the distal tibia are well known. They classically occur in military recruits or athletes and affect the posteromedial distal tibia. The same population is also susceptible to a medial malleolus stress fracture. Devas\textsuperscript{27} was the first to report on medial malleolar stress fractures in two patients, both of whom were treated nonoperatively and progressively returned to full function. Since then, there have been a number of sporadic reports of medial malleolar stress fractures with recommended treatments.

The largest series of medial malleolar stress fractures was reported by Orava and colleagues.\textsuperscript{28} They identified eight competitive athletes who sustained medial malleolus stress fractures. Initial symptoms typically were poorly localized to the medial malleolus; however, then progressed to specific localized pain and swelling. Initial radiographs revealing a fracture line were taken on an average of 4 months after the onset of pain in three patients. Technetium-99 isotope scanning confirmed the stress fracture on the remaining five patients. One of the patients in whom a displacement of the fracture occurred underwent ORIF with interfragmentary screws. Two other patients, who had delayed healing for 8 and 12 months, respectively, underwent drilling across the fracture site with a 2.2 mm drill bit. The average time to healing in the operative group was 5 months. The remaining five patients were treated nonoperatively, with avoidance of sports activities. The average times to healing and a return to previous levels of activity were 9 months from the onset of symptoms and 5 months from the time of diagnosis in the nonoperative group. Orava and coworkers, therefore, recommend an isotope scan on athletes who report 1 month of persistent medial-sided ankle pain and negative radiographs. Once a stress fracture is diagnosed, their recommendation is to avoid all strenuous athletic activity for 4 to 5 months, followed by a gradual return. They further recommend more aggressive treatment for high-level athletes who wish to return to sports earlier.

Shelbourne and associates\textsuperscript{29} reported on their series of six athletes with medial malleolar stress fractures, only two of which were evident on plain films. The other stress fractures were confirmed with a bone scan. Three patients underwent ORIF with the desire and intent to return to sports within the same season. The other patients were all treated conservatively with limitation of activities in an air cast and a progressive return to sports within 2 months. The investigators recommended bone scans for definitive diagnosis and operative fixation for patients who wished to fully return to sports within 8 weeks. The case for operative fixation is not clearly made, however, since they also recommend progressive weightbearing to full level of activity in 6 to 8 weeks in their nonoperative treatment protocol.

Okada and colleagues\textsuperscript{30} reported on two medial malleolar stress fractures, which were all treated nonoperatively, followed by a full return to function within 8 weeks. Shabat and coworkers\textsuperscript{31} reported on a skeletally immature gymnast, who sustained a medial malleolus stress fracture that was treated nonoperatively and returned to full athletic activity at 6 weeks. Two months following the return to gymnastics, the patient sustained a displaced medial malleolus fracture at the site of the previous stress fracture and was treated by ORIF. The investigators, here, recommend operative fixation of these stress fractures in elite athletes only.

The limited number of reports on medial malleolus stress fractures prohibits a definitive conclusion as to their treatment. There does seem to be a consensus, however, among the various investigators that operative fixation is of potential benefit for professional or high demand athletes, although compliance with activity modification will yield the same good results. This entity should, therefore, be handled on a case-by-case basis with regard to treatment.

**Fixation Techniques**

The approach to the medial malleolus is an anteromedially placed incision that curves posteriorly. The structures to avoid are the saphenous vein and nerve in the anterior aspect of the incision and the posterior tibial tendon in the distal and inferior aspect of the incision. This approach allows visualization of the anteromedial articular surface of the ankle, also known as the “axilla” of the joint. Comminuted and loose osteochondral fragments can be removed from the joint with this approach and assessment of articular damage is possible. Rarely, with severe ankle fracture-dislocations, the posterior tibial tendon may subluxate into the fracture site.

After assessment of the fracture configuration and comminution, fixation may be carried out with two 4.0 mm partially threaded cancellous screws, a combination of a screw and K-wire, or a tension band construct. A recent report by Gehr and coworkers\textsuperscript{32} even advocated the use of a miniature intramedullary nail with multiple locking holes for medial and lateral malleolar fixations; however, the relevance of this implant has not yet been established.

Ostrum and Litsky\textsuperscript{33} compared the biomechanical strengths of various medial malleolar fracture fixation constructs on six cadaver specimens. Each specimen was stressed in pronation, first, with K-wires alone, then with the addition of the tension band, and, finally, the tension band and K-wires were removed and two 40 mm 4.0 cancellous lag screws were placed. The results showed that tension band fixation provided the greatest resistance to pronation forces. The tension band was at least four-times stiffer than the two screws which were significantly stiffer than the two K-wires alone. The investigators followed-up their mechanical study with a clinical study, whereby 32 consecutive patients with a medial malleolar fracture were treated with tension band fixation and followed-up to a year. There were no cases of nonunion, one case of asymptomatic malunion and two cases of symptomatic hardware requiring removal.

The radiographic position of implants within the medial
malleolus was assessed by Gourineni and associates. The premise of this study was that the mortise view is often taken to assess implant position within the medial malleolus gives an inaccurate assessment of intra-articular penetration. The reason is the lack of parallelism between the medial and lateral talonavicular spaces caused by the asymmetric shape of the talar dome (wider anteriorly than posteriorly). In this cadaveric study of 10 ankles, the investigators placed medial malleolar wires in parallel and performed 15° and 30° mortise views, followed by an anatomic dissection. The study showed that there was a false appearance of an intra-articular posterior wire on four of the 15° mortise specimens and eight of the 30° mortise views. It was the conclusion of this study that the 15° internal rotation mortise view was best for assessing lateral malleolar fixation, and that the AP view is the most accurate for assessing the medial malleolar implants.

**Conclusion**

The integrity of the MMOLC is important to assess when evaluating an ankle fracture. Contrary to previous beliefs, however, the MMOLC is not the most important structure in establishing ankle stability. As reviewed here, the lateral malleolus reduction is most critical for ankle stability; however, the MMOLC does share in providing for secondary stability and articular congruency. For optimal surgical outcomes in bimalleolar fractures, all lateral malleoli should be anatomically reduced along with any medial malleolar fractures. Repair of deltoid ligament ruptures offer no benefit when not associated with a medial malleolus fracture. Close attention should be focused on anterior collicular fractures, as they may represent an associated deep deltoid ligament disruption that will not be addressed with fixation of the collicular fragment. In these instances, a stress view is required to assess the need for syndesmatic fixation. Stress fractures of the medial malleolus require a case-by-case evaluation, with good results obtained using both operative and non-operative treatments. Optimal fixation for medial malleolus fractures should take into account the fracture configuration and bone quality, although tension band fixation has been shown highly effective.

**Disclosure Statement**

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