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Ankle stability in ankle fracture

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ABSTRACT

Restoration of normal ankle kinematics should be the all-encompassing ethos in the approach to management of ankle fractures. To do this, the ligamentous stabilisers must also form part of its assessment and definitive management and be considered during index fracture fixation surgery. This article is a review of the anatomy, mechanics and clinical testing of instability in ankle fractures.

1. Introduction

Understanding what confers stability in the ankle joint is the cornerstone of appropriate management strategies in ankle trauma. Stability of a normal ankle joint can be defined as one that can move within its physiological limits, however defining instability in the context of an ankle fracture is considerably more complex. In instability, the physiological limits are surpassed either passively or actively proving the stabilising structures to be insufficient.[1] In general, stability in the ankle joint is secured passively by the conformity of the bones that make up the joint, the ligamentous structures which surround the joint (laterally, medially and the syndesmosis) and the extrinsic muscles that pass the joint. These stabilising structures can lose their stabilising capacity through trauma, however the extent of trauma to cause instability is poorly defined.

Movement of an ankle joint may be defined as translatory (a moving body moves uniformly in the same line) or rotatory (rotation around an axis), although combinations of the two are most common in any biomechanical system (Fig. 1). In simplistic terms, the main allowable movement of the ankle is in the sagittal plane around the coronal axis (Fig. 2). Several studies have indicated an overall range of motion in the sagittal plane of between 65 and 75°, moving from 10 to 20° of dorsiflexion through to 40–55° of plantarflexion.[2,3] There is debate, if this is coupled with a minor degree of rotation around the sagittal axis in the frontal plane (Fig. 3) to allow inversion and eversion or if this movement is due to the oblique axis of the ankle.[4] The range of motion in the frontal plane is approximately 35°.[3] A minor degree of anterior translation (<9 mm) occurs in the sagittal plane.[1] All other movements are minimal, however there is a wide degree of variability.

When discussing instability in ankle fractures, we have a dichotomy in the literature between injury to the osseous structures and injury to the ligaments. The most commonly used classification systems, Danis-Weber, Lauge-Hansen and the AO/OTA, all fail to address possible ligamentous injury outside of the deltoid complex and complete syndesmosis disruption.[5] Michelson et al. proposed a stability based criteria from a structured analysis of the literature in 2007. The classification is based on known injury patterns that have evidence of causing abnormal biomechanics of the ankle joint. The authors outlined that the following ankle fractures meet the criteria to be considered unstable; 1) Any ankle fracture-dislocation; (2) Any bimalleolar or tri-malleolar ankle fracture; (3) Any lateral malleolar fracture with significant talar shift (usually more than 1–2 mm increase of medial clear space measured relative to the superior clear space) on any plain radiograph view at any time.[6] The outcome of this stability based criteria is binary, if you meet any one of the criteria the injury is unstable and if not the ankle fracture is stable.[7] The latter criterion of "*significant*" talar shift is potentially problematic. Talar shift assessed by the absolute medial clear space or its size compared to the superior clear space is a metric deduced from stress radiographs, gravity stress testing or weight bearing radiographs. Therefore, a definition of stability in ankle fractures is not as simplistic as the definition of stability of the ankle, as the strategy for management is derived from an assessment of stability

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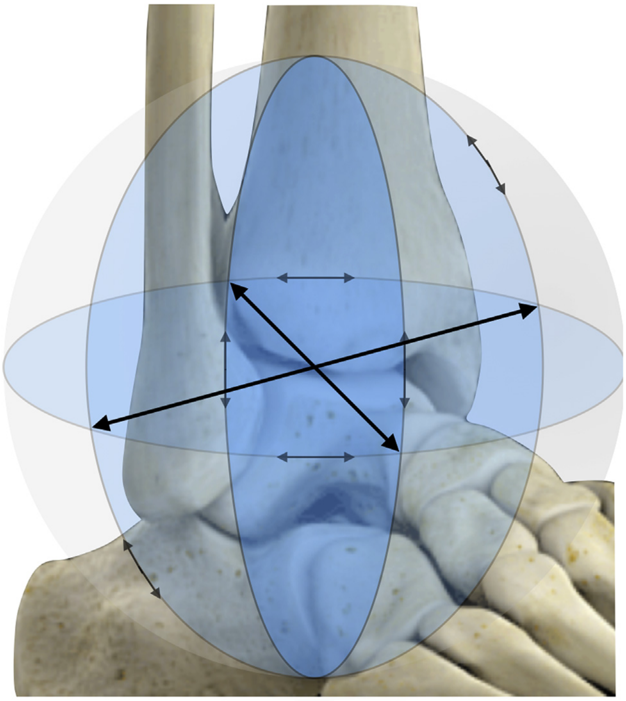

Fig. 1. 3D image of ankle skeleton with a movement sphere overlay showing the possible translation in the sagittal and frontal planes and rotation in the sagittal, frontal and horizontal planes.

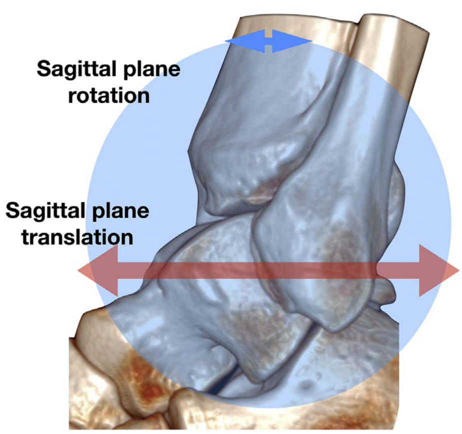

Fig. 2. 3D image of ankle skeleton showing sagittal plane translation and rotation.

with treatment. We therefore define stability in this context, the ability to maintain the talus centralised under the tibia when held in a neutral position and undergoing physiological stress (i.e. weight-bearing).

2. Anatomy of stability

The major determinant of an ankle's stability is a derivative of the osseous configuration of the ankle joint. The bony anatomy that confers stability is composed of the distal end of the tibia and fibula and their articulation with both each other and the talus. In the 'neutral' ankle position, also referred to as the closed pack position, the congruence of the bony architecture of the medial and posterior projections of the tibia (medial and posterior malleoli) and the fibula with the widest part of the talar body gives it its greatest

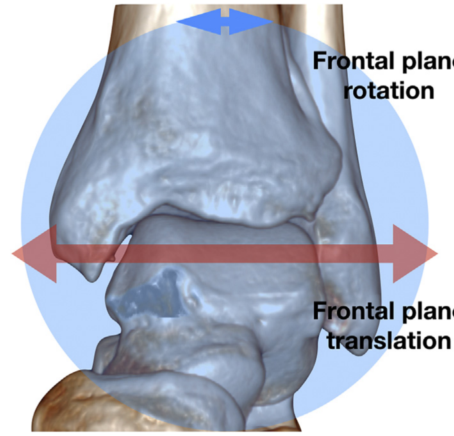

Fig. 3. D image of ankle skeleton showing frontal plane translation and rotation.

stability. The medial and lateral malleoli closely conform to the body of the talus in what is termed the ankle mortise. The convex shape of the articulating surface of the two malleoli, paired with the concavities on either side of the talar body with which they articulate, contribute to stability. This is also true of the complimentary shape of the distal tibia and its articulation with the upper surface of the talar body. Recent literature has indicated that rotation in the horizontal plane (Fig. 4) in this closed packed position, will result in a rotational Pilon, with fracture of the fibular, posterior malleolus and medial malleolus.[8] The bony architecture does however, lose its dominance in stability with increasing degrees of equinus. In the equinus position, ankle ligaments become more important to control translation and rotation in the frontal plane (adduction and abduction) and rotation in the horizontal plane as the talus narrows posteriorly and conformity is lost between the tibia/fibular and the talus.[9]

The ankle joint functionally is dependent on the articulations of the subtalar joint and talocalcaneonavicular joint as each of these articulations have a number of common ligamentous stabilisers and work synergistically in the movement of the hind-foot (Fig. 5). For example, the deltoid ligament complex acts at all three joints. The deltoid ligament can be subdivided in to its constituent parts, each of which are important in stabilising different elements of ankle movement in varied foot positions. The superficial deltoid ligament (consisting of the spring ligament, tibionavicular ligament, and tibiocalcaneal ligament) controls the proximal aspect of the medial longitudinal arch along with talar translation in the frontal plane.[10] Injury to the superficial complex should not be underestimated as early mobility on such an injury may predispose to flatting of the medial longitudinal arch, even with the ankle congruency being intact. The deep deltoid, consisting of the anterior tibiotalar ligament and the posterior tibiotalar ligaments, control the talar tilt and lateral translation. The posterior deep deltoid is the shortest and thickest component of the deltoid ligament complex, and restrains rotation of the talus horizontal and frontal plane, however its action is not apparent unless the foot is in neutral to dorsiflexed position.[11] Table 1 summarises the structures that stabilise movement in all directions.

The lateral ligamentous structures of the ankle are well described. The anterior talofibular ligament (ATFL) primarily resists anterior translation of the talus. Multiple biomechanical studies have also indicated ATFL to be essential in resisting internal rotation, especially when the foot is plantarflexed.[1,4] The calcaneofibular ligament (CFL) is the most significant constituent of the

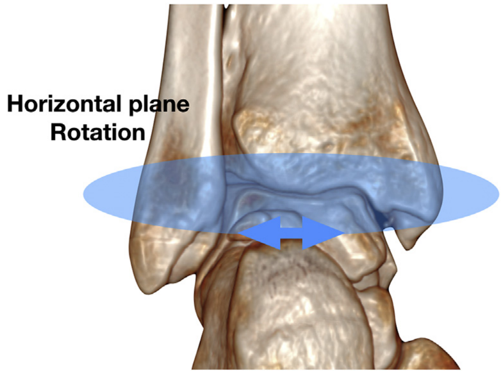

Fig. 4. 3D image of ankle skeleton showing horizontal plane rotation.

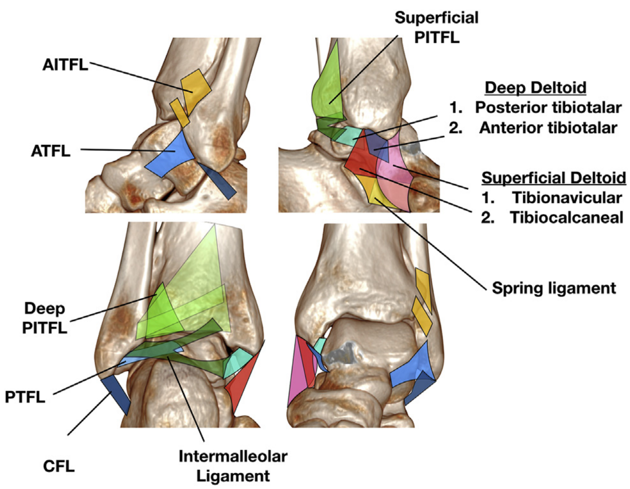

Fig. 5. 3D image of ankle skeleton with schematic representation of the supporting ligaments (ATFL – anterior talofibular ligament, PTFL – posterior talofibular ligament, AITFL – anterior inferior tibiofibular ligament, PITFL – posterior inferior tibiofibular ligament, CFL – calcaneofibular ligament).

lateral collateral complex in preventing inversion of the hindfoot, and does so more in the neutral position than the plantarflexed position.[12,13] The PTFL resists excessive external rotation at the ankle joint and also resists eversion primarily whilst the foot is dorsiflexed.

With regards to the syndesmosis, the distal fibula is convex at its distal articulation with the tibial plafond, where it articulates with a complimentary concave depression on the posterolateral tibia known as the triangular fibular notch (or incisura fibularis tibiae).[4] Malhotra et al., indicated that on weight-bearing CT imaging the fibula translated laterally and posteriorly, and rotated externally with respect to the incisura. The fibula pivots on the posterior inferior tibiofibular ligament, with more rotational movement anteriorly.[14] This is down to the shallower posterior tibial tubercle permitting a degree of posterior escape. In contrast, the more prominent anterior tubercle prevents any anterior translation of the lateral malleolus. The posterior aspect of the incisura is therefore crucial to maintain the normal movement of the fibular, and has been shown to be critical in stabilising the syndesmosis with surgical fixation.[8,15] As previously described, more distally the fibula has a triangular articular facet which articulates with the lateral talar surface. Interestingly, a CT evaluation of patients with high fibular fracture compared to normal controls demonstrated that a shallow and retroverted triangular fibular notch was statistically significant for a syndesmotic injury.[16]

There are three groups of syndesmotic ligaments; anterior inferior tibiofibular ligament (AITFL), posterior inferior tibiofibular ligament (PITFL) and interosseous ligament. The AITFL prevents lateral fibular translation along with the PITFL, which encompasses the intermalleolar ligament.[17] The interosseous ligament constrains the tibia and fibula from separating along their course in the lower leg whilst allowing some small degree of rotational movement and terminates approximately 1 cm proximal to the ankle joint. The syndesmotic ligaments also confer significant rotational stability, with the AITFL preventing approximately 24% of external rotation at the ankle joint and the PITFL being shown to resist internal rotation at the ankle joint.[18,19]

3. Clinical testing

Testing of the stability of the ankle joint is primarily a clinical and radiological assessment. The purpose of these tests are to evaluate the integrity of the supporting structures of the ankle complex, which provide anatomic alignment of the ankle mortise. They are undertaken either pre-operatively to support the indication for how an injury should be managed or post operatively following conservative or operative management, to evaluate efficacy of treatment.

3.1. Preoperative assessment

In the preoperative setting of acute ankle trauma a bimalleolar or trimalleolar ankle fracture is presumed unstable.[20] This is due to the loss of both medial, lateral and sometimes posterior bony restraints and thus loss of stability. In unimalleolar injuries, instability is questionable as it is dependent on the loss of ligamentous restraints. The medial clear space (MCS) is the most utilised parameter in assessing ankle instability in the unimalleolar ankle fracture scenario (Fig. 6).[17] Most studies report >5 mm of MCS to indicate instability in the deep deltoid.[21–24] This parameter can however be variable, with Murphy et al. reporting 5% of males having >5 mm MCS in the normal population.[25] They concluded that in some patients a comparative view is required of the other ankle. On the lateral aspect of the talocrural joint

Table 1
Anatomic structures and the movement direction where they provide stability (ATFL – anterior talofibular ligament, AITFL – anterior inferior tibiofibular ligament, PITFL – posterior inferior tibiofibular ligament, CFL – calcaneofibular ligament, IOL – intraosseous ligament).

Movement	Direction	Primary	Secondary
Sagittal plane translation and rotation (Figs. 1 and 2)	Anterior	ATFL, Superficial deltoid (tibionavicular ligament)	Capsule, extrinsic muscles
	Posterior	Posterior malleolus, PTFL, posterior deep deltoid, superficial posterior tibiotalar band. PTFL and syndesmosis play most important role in dorsiflexion resistance.	Capsule, extrinsic muscles
Frontal plane translation and rotation (Figs. 1 and 3)	Abduction	Fibular, AITFL, PITFL, IOL, posterior deep deltoid, anterior deep deltoid, superficial deltoid (tibiocalcaneal ligament)	Capsule, extrinsic muscles
	Adduction	Medial malleolus, CFL, PTFL in dorsiflexion. ATFL restricts with foot in plantar flexion	Capsule, extrinsic muscles
Horizontal plane rotation (Figs. 1 and 4)	(internal and external rotation)	Posterior malleolus, medial malleolus, fibular, ATFL, AITFL, PITFL, Anterior deep deltoid, posterior deep deltoid	Superficial deltoid, PTFL, Capsule, extrinsic muscles

Fig. 6. Anteroposterior radiograph of left ankle showing medical clear space greater than 5 mm with displaced fibular fracture.

Fig. 7. Intraoperative loss of tibiofibular overlap as a result of an internal rotation test on a type 1 Mason and Molloy posterior Malleolar fracture following fibular fixation (first image). This overlap is corrected on syndesmotic fixation and retesting showed normal tibiofibular overlap on repeat screening (second image).

the syndesmosis is assessed for stability using tibiofibular clear space and tibiofibular overlap. These measurements unfortunately vary with gender, how the measurement was taken[26] and foot position.[27] There is no accepted consensus as to how this measurement should be taken.[28] Fort at al advocates for the routine comparison of tibiofibular clear space and tibiofibular overlap with the contra-lateral uninjured ankle due to this variability.[29]

The use of manual stress examination is not practical in a non-adequately anaesthetised patient secondary to patient pain during the exam and the variability in the magnitude of force applied.[22] As previously stated, instability can only be judged if the ankle fails within normal physiological limits. Gravity stress examination is a constant force; and is reported equivalent to, but better tolerated by patients than manual stress testing.[30] However, with gravity stress views the degree of equinus is not controlled, which can significantly affect the MCS measurement.[31] Weightbearing radiographs reproduce a normal functional stress and control for neutral plantarflexion of the ankle.[11,25]

Weight-bearing radiographs have shifted the paradigm in the last decade and provide a reliable and easily accessible means of assessing ankle stability. By axially loading the talus, this dynamic test indicates how the talocrural joint maintains congruence whilst standing.[32] Resuming this closed pack configuration with a plantigrade foot may be the optimal position to allow for physiological loading.[28] Gougoulias and Sakellariou reported a reduction in requirement for surgery from 45% with gravity stress views to 3% with weight bearing radiographs, concluding that the function of the deep posterior deltoid in a neutral ankle position to be key to its stability.[11] More recently, Fisher et al. have reported that dynamic external rotation stress evaluation using ultrasonography was able to detect a significant difference between the uninjured ankle with a tibiofibular clear space of 4.5 mm and the stage 1 complete injured ankle with a clear space of 6.0 mm.[33] In the future, the increase in access to Weight-Bearing Computed Tomography may improve our diagnostic capability of ankle instability. Patel et al., have already published their work defining the reference values of the normal tibiofibular syndesmosis using the weight bearing CT, which will be useful when this modality becomes more widely available.

3.2. Intra-operative assessment

Manual stress testing is possible intra-operative with a suitable anaesthetised patient. For the syndesmosis, the two standardly used tests, lateral stress test (Hook test or Cotton test) and the external rotation test have poor sensitivity in the intraoperative diagnosis of a syndesmotic injury.[34,35] However, Gosselin-Papadopoulos et al. completed a cadaveric study looking at both tests and the torque test, and found the torque test to be more reliable but all three tests showed significant motion when 2 syndesmotic ligaments were sectioned. The external rotation test is also deemed to be better in elucidating deltoid injury.[29] Mason et al. described the internal rotation test for testing PITFL avulsion injuries, in their clinical paper on posterior malleolar fracture treatment (Fig. 7).[8,19] Arthroscopic testing of syndesmotic stability has been reported by a number of authors to be more sensitive in elucidating syndesmotic instability than stress radiology.[32,36–38]

4. Conclusion

Restoration of normal ankle kinematics should be the all-encompassing ethos in the approach to management of ankle fractures. To do this, all elements of ankle stability in ankle fractures, including the ligamentous stabilisers must be considered when planning treatment. By defining ankle stability in ankle fractures by the ability to maintain the talus centralised under the tibia when held in a neutral position and undergoing physiological stress (i.e. weight-bearing), we can hopefully adequately plan and treat these variable injuries.

CRediT authorship contribution statement

Laura-Ann Lambert: Project administration, Writing - original draft, Software, Methodology, Conceptualization. **Luke Falconer:** Investigation, Data curation, Writing - original draft. **Lyndon Mason:** Conceptualization, Visualization, Supervision, Writing - review & editing.

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