Ligamentous Injuries of the Foot and Ankle

Diagnosis, Management and Rehabilitation

Pieter D'Hooghe
Kenneth J. Hunt
Jeremy J. McCormick
Editors

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Foreword: Land of Ligaments Text

Ligament injuries of the foot and ankle occur commonly in the athletic or active individual and no joint is spared a possible disruption. Mechanisms accounting for these "sprains" are diverse and often seemingly minor. While many of these ligament injuries present with gross dislocation or joint diastasis, there are just as many that are quite subtle, not apparent on routine exam or imaging. Instability, whether obvious or not, requires early detection and protection to minimize chondral injury and the long-term consequences of arthritis and malalignment.

It is exciting for me to see that what began as an Instructional Course Lecture series for the AAOS has now expanded into print. ***The Land of Ligaments***, the title given to this Academy lecture series, was extremely well received and provided valuable information to the general orthopedist, as well as the subspecialist managing ankle injuries in the active patient. Drs. Hunt, McCormick, and D'Hooghe, the editors of this text, have provided us a more in-depth platform with which to educate the readership to the specifics of a variety of ligament injuries in the foot and ankle. They have enlisted numerous renowned foot and ankle specialists with expertise in this arena, and I am honored to have served as a contributor. The editors had the foresight to create a much-needed text dealing with the complexities of these injuries and basically developing a comprehensive guide to the treatment opportunities. The chapters include a thorough description of not only techniques best utilized for a variety of scenarios but also a thorough description of indications and contraindications. Pertinent anatomy, evaluation pearls, decision-making tips, treatment algorithms, postoperative and rehabilitation protocols are provided for the athlete at all levels of participation. Whether managing the weekend warrior or elite athlete, an understanding of these concepts is necessary—the only real difference being decision-making on the impact of return to play and what risks may be present.

This textbook is extremely timely, given the large number of patients affected by these ligament injuries and those that have suffered the long-term consequences of a missed, underappreciated, or neglected diagnosis. Too often, many foot and ankle providers are challenged by the retired athlete presenting with end-stage arthritis and deformity as a result of an inadequately managed "sprain." I do believe that this text and multiple high-level contributions will heighten the awareness of the practicing orthopedist to the multiple presentations of ligament injuries in the foot and ankle with the end result being a decreased incidence of late disability.

I am proud to have been asked to write the Foreword for this valuable contribution, but most proud given that two of the editors (Drs. Hunt and McCormick) were former fellows of mine. It is a tribute to one's career when the mentor is surpassed by his students, or when the mentor becomes the student. I applaud the editors for guiding this project through and advancing the education and knowledge base of those that follow. Their motivation was to create a platform to enhance the level of understanding to the many potential ligament injuries in the foot and ankle. Overall, this will inspire the reader to be more enlightened, creative, and innovative when managing these particular entities.

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Acknowledgments

This book on managing ligament injuries in the foot and ankle is a product of a tremendous teamwork and collaboration. Topic experts from around the globe have dedicated time, effort, and intellectual energy to share their knowledge and experience with the reader.

We thank all the authors that agreed with passion and enthusiasm to contribute to this project.

As in all such undertakings, the completion and publication of a scientific text requires multiple supporting energies.

We thank all of the chairs, speakers, and moderators who have participated in the AAOS Land of Ligaments Instructional Course Lecture (ICL). Many of these speakers have contributed to this text. This book is dedicated to them.

We acknowledge Dr. Steve Haddad who had the inspiration for the Land of Ligaments ICL and served as its first course chairman. When Steve recruited Dr. Bob Anderson, Dr. Tom Clanton, and Dr. Chris Coetzee as the first course faculty, we suspect that group never thought the ICL would evolve into the text it has become today.

In particular, we thank Dr. Bob Anderson who has been a thought leader and pioneer in the arena of ligamentous injuries to the foot and ankle, serving as a mentor to the editors of this text and countless others.

We must thank and commend Carolyn Jones for her extraordinary help and effort coordinating the completion of each chapter and collaborating with Springer staff.

We thank our families for supporting us in our practices and academic activities. We could not do this without their support and inspiration.

Finally, we thank the Springer team that has backed us in the production of this book dedicated to optimizing the management of ligament injuries in the foot and ankle.

Pieter D'Hooghe
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1 Introduction

Kenneth J. Hunt

Biology of Ligament Healing

Acute ligament injuries are most often caused by extrinsic traumatic injuries that overload a ligament beyond its failure load (or that of the ligament's insertion). Rapid acceleration-deceleration movements are commonly associated with acute sports-related injuries. As a result, lower extremity ligament injuries at work or during sport-related activities are incredibly common and account for more than 20% of all emergency department visits annually [1]. Chronic degenerative changes in ligaments also can lead to susceptibility for ligament rupture or tear. Managing ligament injuries requires at least a general understanding of how ligaments heal. In the foot and ankle, there is significant variation in the ability of some ligaments to heal properly. For example, most high-grade lateral ankle sprains heal without surgical repair, whereas high-grade syndesmosis and Lisfranc injuries often require surgical stabilization in order to assure proper healing and prevent long-term degenerative changes due to a change in joint biomechanics. The location and severity of the injury will also impact treatment and outcomes, such as restoration of joint motion, management of stiffness, swelling, and adhesion formation, and prevention of chronic conditions [2].

Unlike fractures of bones, ligaments do not heal by tissue regeneration but rather through a wound healing process that follows a predictable healing pathway. This includes an early phase, reparative phase, and a remodeling phase that increases repaired tendon tensile properties. The early phase consists of hematoma formation, inflammation, and initiation of cell proliferation at the injury site. The reparative phase consists of proliferating cells from surrounding tissues that begin to heal the ruptured ligament by formation of fibrous tissue that contains a high proportion of type III collagen. This reparative phase can last for many weeks during which time the healing ligament remains mechanically weak and more readily subject to reinjury. During the remodeling phase, the fibrous repair tissue becomes less cellular, and the proportion of type I collagen increases [3]. Eventually, the collagen fibers align with the direction of stress to increase the repaired ligament tensile strength. In some cases, the remodeling phase can last several months. Factors that mediate inflammation, angiogenesis, cell proliferation, and extracellular matrix remodeling seem to be involved in the different phases of healing based on gene expression studies. However, the mechanisms that coordinate these gene expression events are not well understood.

It is also important to recognize that chronic instability may be very different from a ligament

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healing perspective than acute injuries. An example related to the knee was discovered by Brophy et al. who analyzed gene expression between anterior cruciate ligaments that had been torn less than 3 months (acute), between 3 and 12 months (intermediate), or greater than 12 months (chronic) [4]. They harvested a small piece from the ends of the torn ligaments during surgical repair and found that genes involved in extracellular matrix reorganization were expressed in the acute samples, whereas the chronic specimens showed reductions in collagen gene expression a 30-fold decline in periostin expression. Thus, in cases of chronic ligamentous instability conditions, it cannot necessarily be expected that normal ligament healing will occur. Special considerations to supplement a repair with additional material (e.g., collagen-based grafts) or orthobiologics (e.g., concentrated progenitor cells) make sense in these cases, but clinical data is sparse.

Treatment Decision-Making

The vast majority of ligamentous injuries to the foot and ankle heal without surgical intervention, even in cases with complete ligamentous disruption. Immobilization and POLICE (protect, optimally load, ice, compress, elevate) [5] can be a helpful means of accelerating recovery and mitigating pain and gait irregularities during mobility as ligaments heal. However, for some ligamentous injuries in the foot and ankle, long-term consequences can ensue if they are not identified early with proper management initiated. In some cases, surgical intervention is required in order to restore normal (or close to normal) joint kinematics and function and to prevent long-term sequelae associated with some complete ligamentous injuries [6]. In most cases, skilled physical therapy can be an important adjunct to guiding recovery and facilitating return to sports participation [7]. It is critical for the treating clinician to understand surgical treatment considerations for injuries meeting that threshold, including indications, techniques, recovery times, and risks. This should be a shared decision-making process with the patient and their relevant support network. The ligamentous injuries in the foot and ankle that most commonly warrant surgical decision-making are the subject of this text and include lateral ankle sprains, syndesmosis injuries, Lisfranc injuries, turf toe, and plantar plate injuries.

The Role of the Orthopedic Surgeon

The orthopedic surgeon plays an important role in guiding the diagnostic algorithm for ligamentous injuries and determining which injuries warrant consideration for surgical intervention. Further, the orthopedic surgeon must remain up to date on the rapidly evolving milieu of surgical techniques and rehabilitation protocols. There are, and always will be, controversies and differences of opinion with regard to optimal treatment. In most cases, there are no singe right or wrong answers. As we see improvement in the quality of basic science and clinical outcomes data to support various treatments, more broadly accepted best practices emerge. Still, it may not be sufficient to know which treatment approach is appropriate in a given situation but also to have skill and proficiency in surgical and rehabilitation techniques. It is for this reason that foot and ankle subspecialists are increasingly involved in the acute and long-term management of foot and ankle injuries even in the sports arena. It is critical to remain up to date on the literature, skill set, and outcomes data for each injury type.

The Role of the Physical Therapist

While not all ligament injuries require formal physical therapy, most cases at minimum see a benefit from guided formal physical therapy. For many chronic instability conditions and higher-grade injuries, formal physical therapy can be necessary to restore normal joint and gait kinematics and to monitor progression to mitigate the risk of reactive tendinopathies. Thorough exploration of specific rehabilitation modalities is generally beyond the scope of this text. However, each section incorporates current practices in rehabilitation and return to sport considerations for each injury type.

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2 Anatomy and Biomechanics of the Foot and Ankle

Alberto Grassi and Massimiliano Mosca

Introduction

The foot and the ankle form a complex anatomical system that has evolved to allow bipedal walking with minimal energy expenditure and maximum performance during normal daily activities. The 26 bony segments of the foot (28 including distal tibia and fibula if we consider also the ankle), in fact, create a vaulted architecture, supported by three main arches, which discharges the weight on the ground through three support points. In turn, we can distinguish four main regions: the ankle (distal tibia and fibula and talus), the hindfoot (talus and calcaneus), the midfoot (navicular, cuboid, medial, intermediate, and lateral cuneiforms), and forefoot (metatarsals and phalanges of the five rays) (Fig. 2.1). The fifth metatarsal base represents an important structure from a traumatic and surgical perspective since is it the insertion of the peroneus brevis tendon and the location of common fractures (Fig. 2.2).

This complex anatomical structure allows the foot and ankle to dynamically vary its conformation during the gait cycle, thanks to the possibility of winding during the push-off phase to have a more rigid and propulsive conformation (supination), and unwinding during the mid-stance phase to enjoy a conformation that adapts to the soil and acts as a receptor organ (pronation).

To allow these physiological conformation changes while maintaining adequate stability, bone congruence and tenacious ligamentous and tendon structures are needed.

Distal Tibiofibular Syndesmosis

A fibrous joint in which two bone segments are held together by strong ligamentous structures represents the syndesmosis. This definition also applies to distal tibio-peroneal syndesmosis, consisting of a bone portion represented by the distal tibia and fibula and fundamental ligamentous components. In joint characterized by a relatively low mobility, its normal kinematics is important during the load and the extra-rotation [1]. In fact, when the syndesmosis is intact, regarding the distal fibula movements of only 2°–5° in extra-rotation, 0–2.5 mm in medial translation and 1–3.1 mm in posterior translation have been detected [2, 3].

The bone anatomy is characterized by the joint relationship between the convex surface of the distal fibula and the lateral tibial incisura (*incisura fibularis tibiae*). About 6–8 cm from the level of the tibiotarsal joint, the tibial interosseous crest forks in caudal direction in an anterior margin, more voluminous, ending in the Chaput's tubercle, and in a posterior margin, more elusive,

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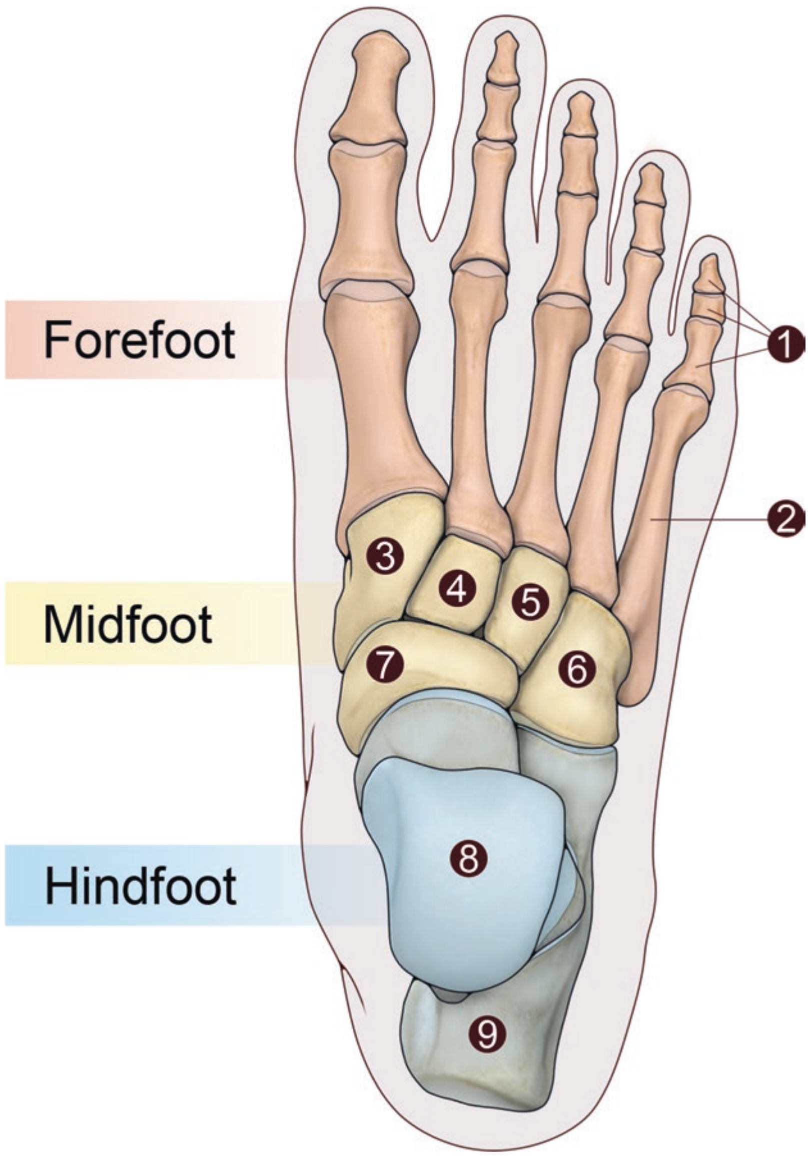
Fig. 2.1 The bony structures of the foot. (1) Phalanxes, (2) metatarsal bones, (3) medial cuneiform, (4) intermediate cuneiform, (5) lateral cuneiform, (6) cuboid, (7) navicular, (8) talus, and (9) calcaneus



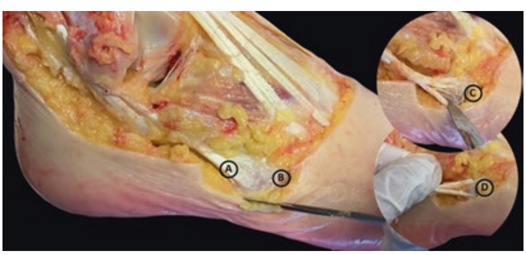


Fig. 2.2 Anatomic specimen of the fifth metatarsal base: (**a**) insertion of peroneus brevis tendon, (**b**) base of the fifth metatarsus, (**c**) bone surface after longitudinal split of the tendon insertion, and (**d**) preserved traction after debridement of fifth metatarsal apex

ending in the Volkmann's tubercle. The base of the triangular peroneal articular surface is formed by the anterior tubercle of Wagstaffe-Le Fort [4].

The stability of the distal tibiofibular syndesmosis is the result in part of the bone congruence of the tibia and fibula. The size and depth of the *incisura tibialis* can vary [5] and are clinically relevant. After a high-ankle sprain, a shallow *incisura tibialis* may predispose to a syndesmosis injury, with the less prominent posterior tubercle serving as the fulcrum for excessive rotation of the distal fibula around its longitudinal axis [6].

A small area of direct contact between fibula and distal tibia, at the base of the syndesmosis, has been described. This area is covered with a thin layer of hyaline cartilage of about 0.5–1 mm [4, 7]. In addition, a synovial recess almost always extends between the fibula and the distal tibia from the tibiocrural joint. Such "recessus tibiofibularis" can have different anatomical characteristics from subject to subject, with a depth that can vary from 4 to 25 mm [4]. The clinical relevance of this finding is represented by the risk of being crossed by K wires, fiches of external fixators or excessively long screws, becoming an entry door in the joint and increasing the risk of septic arthritis [8, 9].

The stabilizers of the distal tibiofibular syndesmosis are four: the anterior inferior tibiofibular ligament (AITFL), the posterior inferior tibiofibular ligament (PITFL), the interosseous ligament (IOL), and the inferior transverse ligament (ITL) (Fig. 2.3). These ligaments, associated with the bone congruence, contribute to axial, rotational, and translational stability.

The anterior inferior tibiofibular ligament (AITFL) runs obliquely from the proximal-medial to the distal-lateral, from the tibial Chaput's tubercle to the anterior tubercle of the distal fibula, crossing the superolateral angle of the tibiocrural joint. Macroscopically, the ligament is composed of three main fascicles (of which the intermediate one is the most resistant), which give it a trapezoidal shape, and has a length between 20 and 30 mm, an average width of about 18 mm and a thickness between 2 and 4 mm [4, 10]. The AITFL represents the weakest of the four syndesmotic ligaments and results often in injured high-ankle sprains (Fig. 2.4).

The Bassett's ligament, an accessory bundle, is present between 21% and 92% of anatomical specimens or MRI imaging, depending on authors [4]. This runs below the AITFL, and it is oblique and intra-articular and frequently crosses the superolateral angle of the tibiocrural joint (Fig. 2.5). The clinical relevance lies in the fact that during the dorsiflexion of the ankle, it comes into contact with the talar trochlea and can be the cause of pain and anterior impingement in the presence of an intact AITFL. Its arthroscopic release does not affect the stability of the syndesmosis and reduces the painful symptoms [11, 12].

The posterior inferior tibiofibular ligament (PITFL) is a particularly resistant ligament, both for its elasticity and for its amplitude. It extends from the posterior malleolus of the tibia to the posterior tubercle of the fibula, running from proximal-medial to distal-lateral. It has a fan shape, like its anterior counterpart, and converges on the posterior portion of the distal fibula [4, 10]. It is clinically important to remember that due to the strength of its fibers, during an ankle sprain, the excessive stress results more often in a fracture-avulsion of the posterior tibial malleolus than in a complete rupture of PITFL [13].

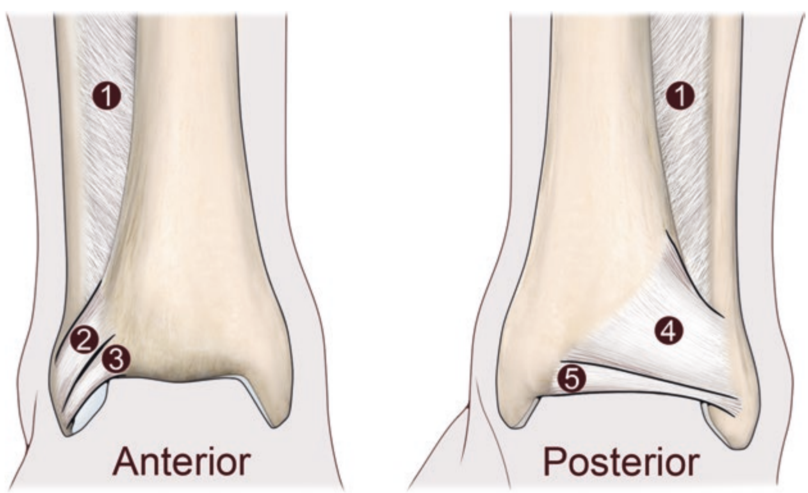


Fig. 2.3 Ligamentous complex of the distal tibiofibular syndesmosis. (1) Interosseous ligament (IOL), (2) anterior inferior tibiofibular ligament (AITFL), (3) Bassett's ligament, (4) posterior inferior tibiofibular ligament (PITFL), and (5) inferior transverse ligament (ITL)

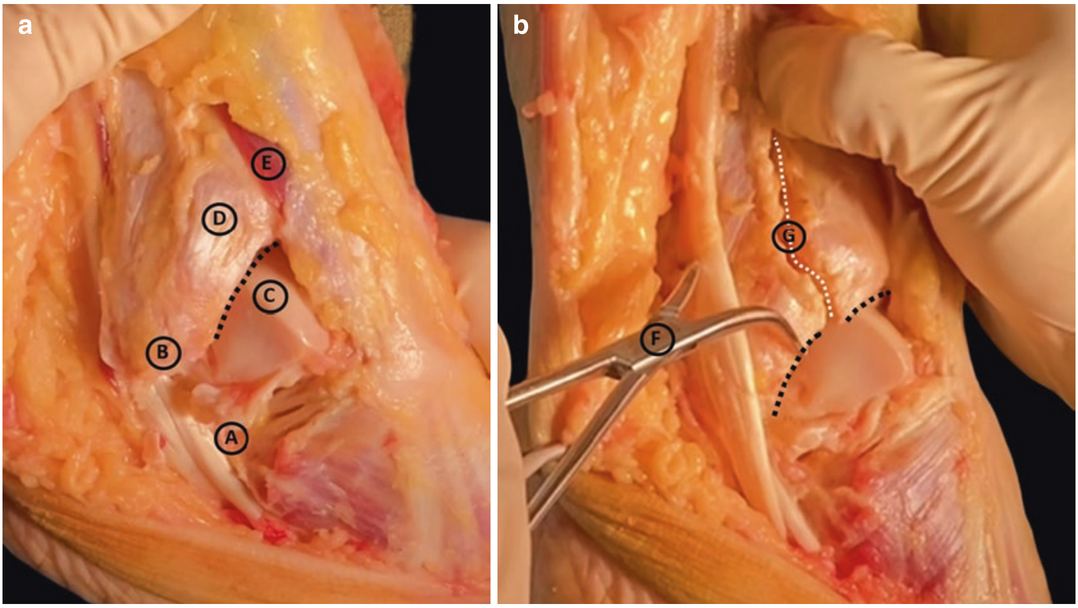


Fig. 2.4 Anatomic specimen of the distal tibiofibular syndesmosis. Figure "**a**" shows the intact syndesmosis (black dotted line), (**a**) cut and reflected anterior talofibular ligament (ATFL), (**b**) apex of lateral malleolus, (**c**) talus surface, (**d**) anterior inferior tibiofibular ligament (AITFL), and (**e**) peroneus tertius. Figure "**b**" shows the disrupted syndesmosis (black dotted line), with the traction of the forceps (**f**) that produces a separation between the tibia and fibula (white dotted line) and a visible gap (**g**)

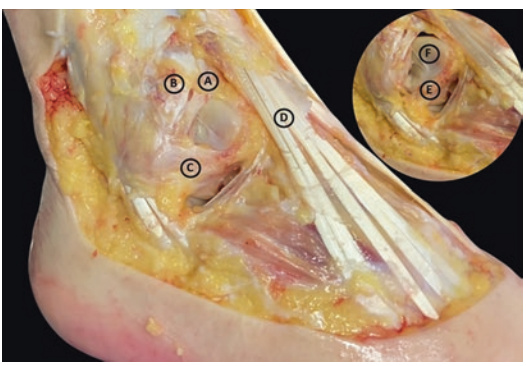


Fig. 2.5 Anatomic specimen of tibial, fibular, and talar ligaments: (**a**) Basset's ligament, (**b**) anterior inferior tibiofibular ligament (AITFL), (**c**) anterior talofibular ligament (ATFL), and (**d**) extensor tendons. After cutting the ATFL (**e**), the talar surface can be displaced (**f**)

The inferior transverse ligament (ITL), of roundish appearance, runs horizontally immediately below the PITFL, making them sometimes difficult to distinguish, and can reach the medial malleolus creating a sort of posterior "labrum." In addition, some fibers can merge with those of PITFL giving rise to what is called intermalleolar ligament (IML) [4, 10]. Controversies over the distinction of individual components are still present in the literature.

The interosseous ligament (IOL) is formed by a thickening of the most distal interosseous membrane portion. It extends deeply between the tibia and fibula and creates a pyramidal space filled with adipose tissue and fibrous fascicles. The most distal bundles originate from the anterior tubercle of the tibia and insert distally on the fibula immediately above the talocrural joint. Its presence is erratic, and in some subjects, it is absent while in others, it is really evident. When present, the space below the IOL is occupied by the syndesmotic recess [4, 10]. The IOL acts both as reinforcement, neutralizing the forces that are created during the heel-strike phase in gait cycle and stabilizing the tibiocrural joint during loading. In this regard, it has been shown how the IOL and the interosseous membrane are subjected to stress throughout the stance phase, placing a rational to the breaking of syndesmotic screws [4, 10, 14].

Lateral Collateral Ligaments of the Ankle

The tibiotalar joint is composed by the talar body, wedge-shaped, which articulates within the tibio-fibular mortise. The normal movement of the ankle consists of dorsiflexion and plantarflexion through an oblique axis passing through the apex of the internal and external malleoli. Varus and valgus movements are allowed, within physiological limits, except in case of maximum dorsiflexion.

Joint stability is guaranteed, under normal conditions, both by intrinsic elements such as bone congruence and by extrinsic elements such as a complex ligament apparatus, divided into two main compartments: the lateral compartment and the medial compartment. The high bone congruence also allows to unload the important force vectors to which the joint is subjected on a wider loading area, reducing joint stress; some authors consider these biomechanical characteristics even better expressed than in the hip or knee [15, 16]. In addition, ligamentous structures also contribute to ankle stability through proprioceptive functions [17].

The ankle lateral ligament complex consists of three ligaments: the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL) (Fig. 2.6).

The ATFL, closely related to the anterolateral ankle capsule, typically consists of two bundles [18] separated by a “vascular window” (Fig. 2.7), though in literature, single-bundle or three-bundle variants have been described [19]. About 15–20 mm long, it originates from the anterior side of the distal fibula, at about 10 mm proximal to the apex of the lateral malleolus, and it inserts on the lateral side of the talus, immediately anterior to the lateral facet. This is more proximal than the lateral talar neck.

Its two fascicles are distinguished in the lower fascicle (ATFLif), extra-articular, and in the upper fascicle (ATFLsf), intra-articular. Overall, the ligament is virtually horizontal with the ankle in neutral position, facing upward with the dorsiflexed ankle and downward during plantarflexion. Only in the latter case, the ligament is tense and placed under stress, becoming vulnerable during sprains [19, 20] (Fig. 2.5). Recently in the literature, a close connection has been reported between the ATFLif and the CFL, which form

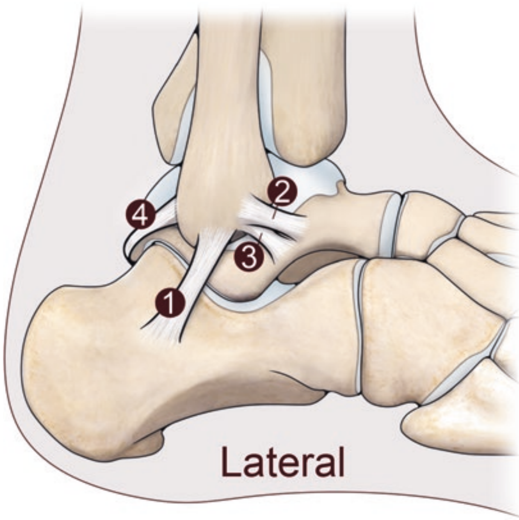


Fig. 2.6 The ankle lateral ligament complex. (1) Calcaneofibular ligament (CFL), (2) superior fascicle of the anterior talofibular ligament (ATFLsf), (3) inferior fascicle of the anterior talofibular ligament (ATFLif), and (4) posterior talofibular ligament (PTFL)

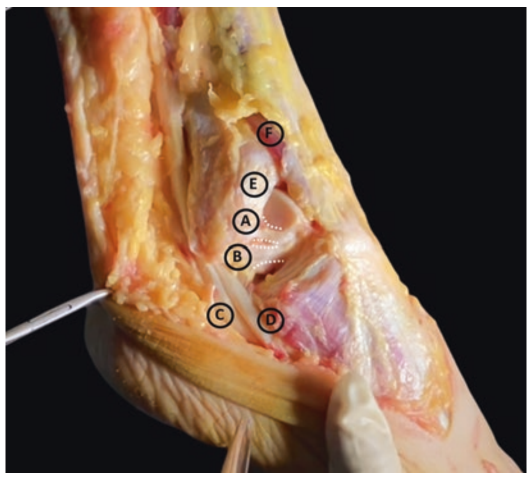


Fig. 2.7 Anatomic specimen of the ankle lateral ligament and tendon complex: (**a**) anterior talofibular ligament upper fascicle (ATFLsf), (**b**) anterior talofibular ligament lower fascicle (ATFLlf), (**c**) peroneus longus tendon, (**d**) peroneus brevis tendon, (**e**) anterior inferior tibiofibular ligament (AITFL), and (**f**) peroneus tertius

what has been defined by Vega J. et al. [20] the lateral fibulotalocalcaneal ligament complex (TCLFL). This complex can be evaluated from the lateral aspect of the ankle where some arcuate fibers connect the ATFLif and the CFL. In this study, LFTCL has been shown to be an isometric structure, unlike ATFLsf [21].

The CFL, positioned anatomically just below the ATFLif, originates from the anterior edge of the lateral malleolus and is inserted on the lateral aspect of the calcaneus, at the level of a tubercle placed supero-posteriorly to the peroneal tubercle of the calcaneus itself, flowing into the sheath of the peroneal tendons. Contrary to popular belief, CFL does not originate from the apex of lateral malleolus [22]. From 2 to 3 cm long and about 4–8 mm wide, it runs in a medium-lateral and proximal-distal direction from its origin [23]. The angle between the CFL and the ATFL is about 104°, which can result to be useful in case of surgical reconstruction [23]. In case of chronic lateral ankle instability in which both ATFL and CFL are damaged, there is disagreement on the usefulness of repairing the CFL [24]. D'Hooghe P et al. [25], in a recent study on cadaver, compared biomechanics in case of isolated repair of ATFL to combined repair of ATFL/CFL. Immediately after an isolated or combined repair, the biomechanical characteristics of the ankle have not changed with respect to the previous "injured ankle." In addition, greater stiffness was highlighted in the case of combined repair, compared to isolated repair, and the CFL proved to be vulnerable immediately after repair, failing before the ATFL.

Anatomical variants have been described in literature. In 35% of cases, the CFL is reinforced by fibers from the lateral talocalcaneal ligament; only in 23%, the two ligaments are totally distinct; and in 42% of the cases, the lateral talocalcaneal ligament is absent and is replaced by anterior talocalcaneal ligament (in the latter case, it is evident that CFL acquires greater biomechanical importance) [19].

PTFL originates from the medial surface of the lateral malleolus and runs horizontally as far as the posterior side of the talus. Its length is about 3 cm and thickness from 5 to 8 mm [26]. Its insertion is wide and involves almost the entire posterior labrum of the talus. Due to its multifascicular structure, its insertion is not well defined, ending at the posterior surface of the talus, on the os trigonum, and merging with the posterior intermalleolar ligament, a consistent finding in dissections [26]. The posterior intermalleolar ligament is located between the ITL and the PTFL, running obliquely from lateral to medial and from downward to upward, finding its clinical relevance as a possible cause of posterior impingement of ankle [19, 27].

Dalmau-Pastor M. et al. [28] has recently pointed out that these ligamentous structures present variable interconnections seen on the medial side. In his study, constant connections between ATFLif and PTFL, ATFL and CFL, and CFL and PTFL were described in all specimens. Only in 42.5% were reported fibrous connections between ATFLsf and PTFL. Connections between ATFLif and CFL (LFTCL complex) have been highlighted in all dissections as arciform formations that cross the lateral aspect of the subtalar joint. These data raise doubts if the lateral ligamentous structures of the ankle are indeed a complex anatomical unit, rather than isolated structures, and the actual possibility of an isolated lesion of a single ligamentous component after an ankle sprain.

Medial Collateral Ligaments of the Ankle

The tears of the deltoid ligament are historically considered rare, according to some authors limited to 5% of ligamentous lesions of the ankle [29], but the incidence could be greater, and with the improvement of diagnostic tools, lesions of the deltoid ligament are being highlighted more often [30].

The deltoid ligament is a robust, multifascicled ligamentous complex that spreads distally from the medial malleolus with a large, fan-shaped insertional area. The ligamentous components are contiguous, difficult to distinguish in classic anatomical specimens, and closely connected to the capsular structures and to the adjacent tendons [19].

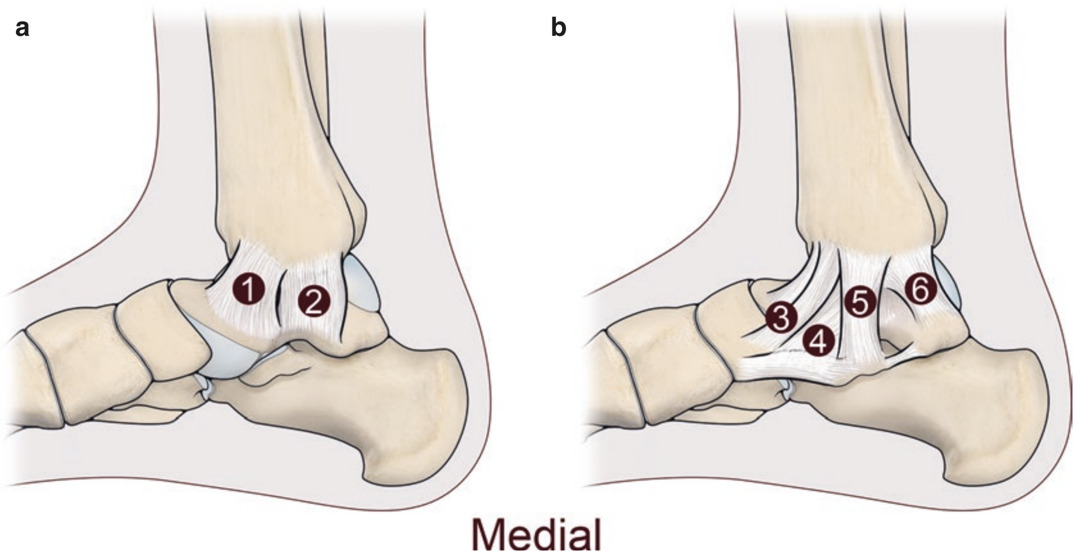


Fig. 2.8 (**a**) Deep layer of the deltoid ligament: (1) deep anterior tibiotalar ligament (DATTL) and (2) deep posterior tibiotalar ligament (DPTTL). (**b**) Superficial layer of the deltoid ligament: (3) tibionavicular ligament (TNL), (4) tibiospring ligament (TSL), (5) tibiocalcaneal ligament (TCL), and (6) superficial posterior tibiotalar ligament (SPTTL)

The literature, however, agrees in distinguishing two layers and six ligamentous components [31] (Fig. 2.8).

The superficial layer, which originates from the anterior colliculum of the tibial malleolus, is composed of four bundles with distinct insertions: the superficial posterior tibiotalar ligament (SPTTL), the tibiocalcaneal ligament (TCL), the tibiospring ligament (TSL), and the tibionavicular ligament (TNL). Only the last two are constant anatomical findings in anatomical specimens, while SPTTL and TCL may vary. In this regard, in a recent study, Amaha K et al. [32] anatomically examined the medial ankle joint, focusing on the deltoid ligament in perspective of the joint capsule. The authors highlighted how the medial capsule can be detached as a continuous layer and consists of three different types of tissues. The fibrous part of the capsule could correspond to the deltoid ligament and the cartilaginous part to the superior part of the spring ligament. This could explain why the number of bundles and the morphology of the deltoid ligament are variable in literature.

Other authors have pointed out that the TCL is to be considered anatomically constant, and where apparently absent, an anatomical variant of the TSL with a Y-shaped configuration serves as a connection between the tibial malleolus and the calcaneus, inserting both on the sustentaculum tali and at the level of the spring ligament [33].

Clinically, the superficial layer helps to maintain the correct alignment of the ankle and the hindfoot as well as to oppose excessive extrarotation and abduction.

The deep layer consists of fibers that run between the medial malleolus and the medial aspect of the talus in two main bundles: the deep posterior tibiotalar ligament (DPTTL), constant, and the deep anterior tibiotalar ligament (DATTL), inconstant. These ligaments, shorter and thicker, flow into the medial capsule of the tibiotalar joint [30, 32].

The orientation of the deep-layer fibers prevents lateral displacement and external rotation of the talus, acting as the main stabilizing mechanism in plantarflexion [30].

Also, after the section of both superficial and deep layers, the anterior instability of the ankle does not increase [22].

Subtalar Joint Ligaments

The subtalar joint has awakened clinical and scientific interest only in recent decades. This joint, which represents an important and complex interface between the lower surface of the talus and the upper surface of the calcaneus, is composed of three articular facets that form the posterior, middle, and anterior subtalar joint. The current literature distinguishes the talocalcaneonavicular articulation (TCN) and the posterior talocalcaneal (TC) joint as two separate entities, separated by sinus tarsi, using the term subtalar only for the posterior TC articulation. Together, they form a functional unit that allows a triplanar movement [34] and is designed to pass from a flexible conformation, suitable to absorb shocks, to a more rigid one, suitable for propulsion.

Although the actual incidence is not known, it is thought that, generally, most subtalar capsuloligamentous lesions occur concurrently with lesions of the ligamentous complex of the ankle. It is estimated that 10% of patients with lateral ankle instability actually present a combined tibiotarsal and subtalar instability [35].

The subtalar ligaments can be divided into intrinsic (cervical ligament, CL; interosseous talocalcaneal ligament, ITCL; the roots of the inferior extensor retinaculum; the anterior talocalcaneal ligament, ATCL or ACaL) (Fig. 2.9) and extrinsic (calcaneofibular ligament, CFL; tibiocalcaneal fascicle of the deltoid ligament).

The extrinsic CFL and deltoid ligament have been previously discussed.

The intrinsic component probably plays a fundamental role in the stability of the subtalar joint, but the literature concerning the anatomy of these ligaments is still somewhat confusing [36].

The inferior extensor retinaculum (also known as “frondiform ligament” or “ligament of Retzius”) is a reinforced portion of the ankle and foot fascia, with a typically Y-shaped stem consisting of a superficial and a deep lamina, inserted

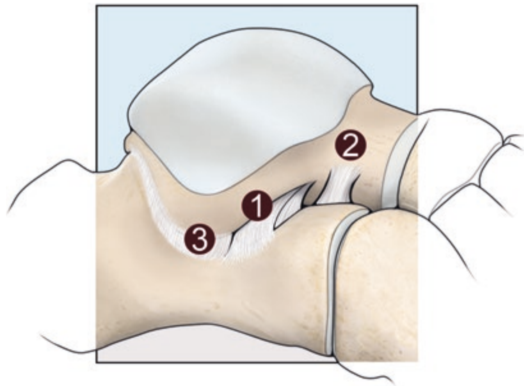


Fig. 2.9 Intrinsic ligamentous components of the subtalar joint. (1) Interosseous talocalcaneal ligament (ITCL), (2) cervical ligament (CL), and (3) anterior talocalcaneal ligament (ATCL or ACaL)

on the upper surface of the heel through three roots (medial, intermediate, and lateral) (Fig. 2.10). The medial root is a particularly complex and high-variability structure that originates from the deepest fibers of the inferior extensor retinaculum and inserts immediately behind the CL. In rare cases, the medial root may be absent [37]. The lateral root runs from the superficial lamina to the lateral aspect of the calcaneus, immediately posterior to the origin of the extensor digitorum brevis muscle. The intermediate root originates from the deep lamina and inserts on the floor of the sinus tarsi.

The CL, a robust quadrangular ligament of the anterolateral region of sinus tarsi, runs obliquely at 45°, from the talar neck to the calcaneus, inserting on its footprint at the level of the floor of sinus tarsi (“cervical tubercle”) [38]. It usually consists of a single bundle though sometimes two [38] or multiple [36] bundles have been described.

The ITCL is a broad and flattened ligament consisting of two lamellae that run obliquely from the sulcus tali to the calcaneal sulcus, with an oblique axis of 35° on the coronal plane [38, 39]. In the central region of the sinus tarsi, the more lateral fibers cross the medial root of the lower extensor retinaculum. Three main morphologies can be distinguished: the band type (93%), the fan type (5%), and the multiple type (3%) [40]. It represents one of the main passive stabilizers of the subtalar joint and, together with

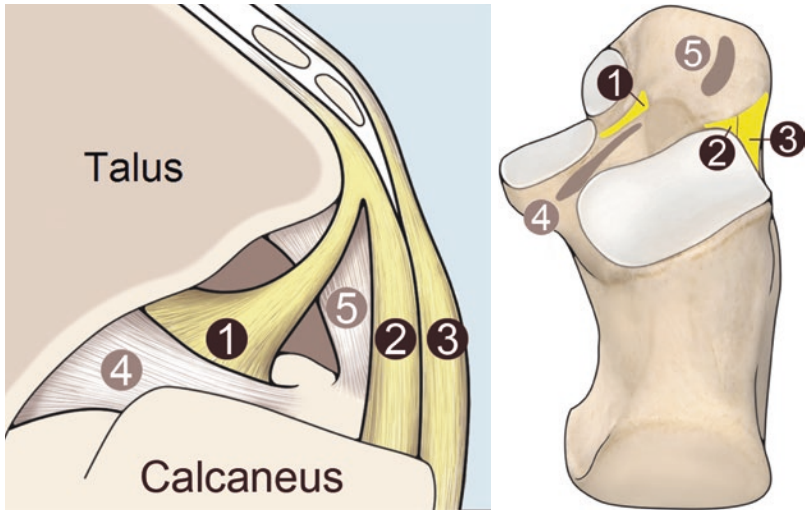


Fig. 2.10 Intrinsic ligamentous components of the subtalar joint, particularly of the inferior extensor retinaculum (coronal view of the sinus tarsi and posterior view of the calcaneus). (1) Medial root, (2) intermediate root, (3) lateral root, (4) interosseous talocalcaneal ligament (ITCL), and (5) cervical ligament (CL)

its proprioceptive characteristics, can be considered as the cruciate ligament of the knee.

The ATCL is represented by a flattened and rectangular bundle and corresponds to a thickening of the anterior capsule of the posterior subtalar joint. Some authors consider the ATCL to be part of the ITCL, and for others, it is a capsular reinforcement. It originates from the anterior edge of the posterior articular facet of the talus, and by running vertically, it is inserted to the front of the anterior edge of the posterior articular facet of the calcaneus [34]. The ATCL is put in tension during foot inversion and during the anterior drawer of the heel.

A recent study showed on cadaver that the intrinsic ligaments of the subtalar articulation present consistent location, presence, morphology, and dimensions, highlighting an important role of the CL and ATCL in joint stability [36].

Chopart Joint Ligamentous Complex

The midtarsal joint complex, or Chopart joint, represents the anatomical connection between the midfoot and the hindfoot, allowing the latter to adapt to the ground while the forefoot remains fixed during the inversion and eversion movements. It is formed by the talocalcaneonavicular joint and the calcaneocuboid joint.

The talocalcaneonavicular joint consists of the anterior articular surface of the talar head, the concave posterior surface of the navicular, and the anterior talar articular facet of the calcaneum. This particular joint morphology has been associated to the hip joint, gaining the name of "coxa pedis," [41] contained by a single capsule.

The calcaneocuboid joint is formed by the triangular surface of the anterior apophysis of the calcaneus and its articular surface of the cuboid.

There are various ligamentous structures that allow the stability of this complex biomechanical structure, often fused into capsular components. They can be subdivided for convenience in ligaments of talocalcaneonavicular pertinence (spring ligament complex, bifurcate ligament, and dorsal talonavicular ligament) and of calcaneocuboid pertinence (dorsal calcaneocuboid ligament and plantar calcaneocuboid ligament).

Among the main ligament structures of the foot, the one of greater anatomical and biomechanical complexity is represented by the spring ligament complex (SLC), also called plantar calcaneonavicular ligament. It is formed by the superomedial ligament, the medioplantar oblique ligament, and inferoplantar longitudinal ligament.

The superomedial bundle has a triangular shape, originating from the anterior margin of the sustentaculum tali, and inserts widely on the navicular tuberosity and on the tibiospring component of the deltoid ligament. Its innermost surface is fibrocartilaginous, giving the impression of being in front of an articular component. Its relationships with the posterior tibial tendon are known, and the structures are separated by a loose connective tissue that allows reciprocal sliding.

The medioplantar oblique bundle, more plantar, runs from the coronoid fossa of the calcaneus and projects medially to the navicular, immediately below the tuberosity.

The inferoplantar longitudinal bundle is the most thick and robust and originates from the coronoid fossa of the anterior process of the calcaneus [42].

SLC is often involved in ankle eversion injuries, producing distraction across the medial aspect of the Chopart joint. The medial distraction may cause traction injury from the superomedial bundle of the SLC, avulsion of the inferoplantar longitudinal bundle of the SLC, and fractures of the navicular bone [43].

The bifurcate ligament is composed of a medial calcaneonavicular bundle and a lateral calcaneocuboid bundle and creates support for the talonavicular and calcaneocuboid joints. The first runs between the intermediary tubercle and the dorsal surface of the cuboid, inserting at about 1.5 cm from the calcaneocuboid joint. The second one extends from the intermediary tubercle of the calcaneus to the posterosuperior slope of the navicular. The bifurcate ligament is placed before the cervical ligament and at the origin of the extensor digitorum brevis muscle.

The dorsal talonavicular ligament represents a capsular thickening stretched between the dorsal slope of the talar neck and the dorsal surface of the navicular bone [44].

The dorsal calcaneocuboid ligament is represented by a thin bundle that runs between the superolateral slope of the anterior calcaneal apophysis, medial to the lateral component of the bifurcate ligament, and the dorsal surface of the cuboid bone.

The plantar calcaneocuboid ligament consists of two components, the long and the short plantar ligaments, and stabilizes the calcaneocuboid joint. The long plantar ligament is more superficial and originates from the plantar surface of the heel. The short plantar ligament merges and strengthens the joint capsule [42].

Lisfranc Ligamentous Complex

The midfoot is composed of a bone and ligamentous complex. Ten bones form the bony component: the navicular, the cuboid, three cuneiform bones, and the bases of the five metatarsals. The proximal portion is called Chopart joint that has been discussed above. The distal portion is the tarsometatarsal joint complex (TMT), also known as Lisfranc joint complex, that encompasses the bases of the five metatarsal bones and their respective joint surfaces for the three cuneiform bones and cuboid [45].

From a biomechanical point of view, Lisfranc's joint represents the point of passage between the midfoot and the forefoot. Its asymmetrical Roman arch structure, with a keystone represented by the base of the second metatarsal, plays a fundamental role in walking, in particular on uneven terrain [46]. In this regard, the stability of the joint complex is essential for a normal gait cycle, and to this end, a complex ligamentous system stabilizes and strengthens the joint capsules.

This joint complex has been described in literature, such as by De Palma et al. [47], based on its position with respect to bone structures in dorsal, plantar, and interosseous.

The seven ligaments that form the dorsal ligamentous complex lie on the dorsal side, uniting cuneiforms and metatarsals.

The interosseous system involves lateral, central, and medial longitudinal ligaments. The medial compartment, also called "Lisfranc ligament," runs distally and laterally between the lateral surface of the medial cuneiform and the medial slope of the second metatarsal (Fig. 2.11). It represents the most voluminous ligament of the joint complex, with its 10 mm of length and 6 mm of thickness. Its importance has been demonstrated by the fact that an isolated lesion of this ligament can lead to instability of the Lisfranc complex [48, 49]. Other ligaments that are part of the interosseous complex are represented by intertarsal ligaments that run between the cunei-

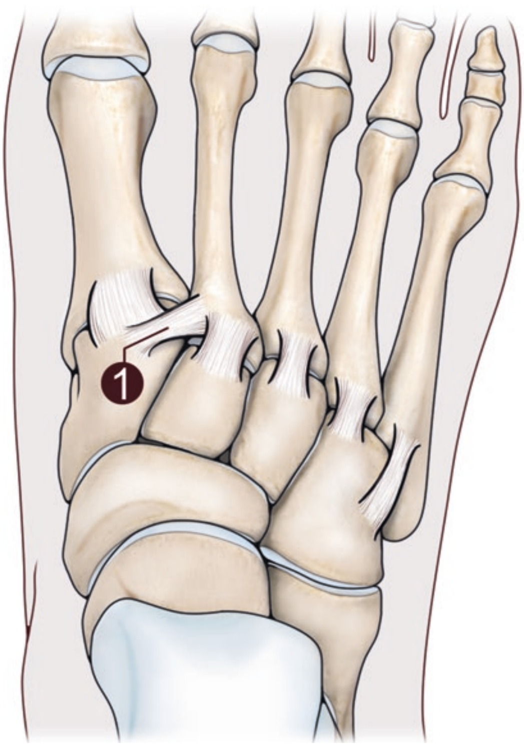


Fig. 2.11 The "Lisfranc ligament" (1), medial component of the tarsometatarsal joint interosseous system

forms and the cuboid and the three intermetatarsal interosseous ligaments that run between the bases of the metatarsals.

The plantar system is variable in number and layout but is arranged on the plantar side and, as interosseous, includes intertarsal and intermetatarsal ligaments.

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Imaging of Ligamentous Injuries in the Foot and Ankle

3

Michael Durst

Introduction

Ligamentous injury of the foot and ankle is a commonly encountered injury in the United States with approximately two million ankle sprains occurring per year, with an estimated incidence rate of approximately 2–7 per 1000 based on emergency room data [1]. The diagnosis commonly relies on a physical exam; however, the utilization of imaging to aid in the diagnosis and treatment is increasingly common [2]. Magnetic resonance imaging has become increasingly utilized for the diagnosis of ligamentous injuries and, in some cases, may help to determine conservative versus surgical management [3].

This chapter will introduce the imaging modalities of utility in the evaluation of ligamentous injuries to the foot and ankle, describe the appropriate utilization of imaging, and provide an overview of the imaging appearance of both the normal and abnormal anatomy associated with these injuries.

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Imaging Modalities

Many imaging modalities lie at the disposal of the orthopedic surgeon when evaluating and diagnosing suspected ligamentous injury to the foot and ankle. Often, the availability, invasiveness, cost-effectiveness, and image resolution dictate the use of each modality [4].

Conventional Radiography

Conventional radiography, or "x-ray," serves as the first-line modality in the evaluation of acute foot and ankle pain. X-ray serves as the quickest and most cost-effective way to evaluate for bony injury, readily demonstrating the presence of a fracture or dislocation. Conventional radiography is of limited clinical utility in the diagnosis of ligamentous injuries, however, often only demonstrating secondary signs of soft tissue injury such as swelling, joint effusions, or associated avulsion fractures [4] (Fig. 3.1). Additionally, stress radiographs can be clinically useful to evaluate for laxity and instability of the foot and ankle [2].

Computed Tomography (CT)

Computed tomography (CT) is often helpful in evaluating traumatic injury to the extremity and

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