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REVIEW ARTICLE

Chronic ankle instability: Biomechanics and pathomechanics of ligaments injury and associated lesions

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Summary The objective of this study was to evaluate the conditions of ankle stability and the morphological and/or lesional factors in sprains that determine when instability becomes chronic. It is based on a review of the literature and the data from the 2008 Sofcot symposium. The biomechanics of the ankle cannot be reduced to a simple flexion—extension movement with one degree of freedom as characterized by the talocrural joint: its function cannot be dissociated from the subtalar joint, allowing the foot to adapt to the ground surface. Functional stability is related to the combination of the particular biometry of the joint surfaces and a multiaxial ligament system. The bone morphology of the talus, shaped like a truncated cone, explains the potential instability in plantar flexion; the radii of curvature of the talar dome have a variable mediolateral distribution: most often the medial radius of curvature is inferior to the lateral radius of curvature (66%), sometimes equal (19%), or inverted (15%). Joint kinematics, combining rotation and slide, can therefore be modulated by the talar morphology, explaining the occurrence of at-risk ankles. Ligament stability relies on the organization in three parts of the lateral collateral ligament and the specific subtalar ligaments: the cervical and the talocalcaneal interosseous ligament. The different injury mechanisms are largely responsible for the sequence of ligament lesions: the most frequent is inversion. The first ligament stabilizers correspond to the cervical and anterior talofibular ligaments; the talocalcaneal ligament, by its oblique orientation, is solicited when there is a dorsal varus-flexion component. In chronic instability, these mechanisms explain the onset of associated lesions (impingement, osteochondral lesions, fibular tendon pathology), which can play a role in instability syndrome. Ligament

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lesions determine laxity, characteristic of mechanical instability. Functional instability goes along with proprioceptive deficiency. There are postural factors such as varus of the hindfoot that favor instability. Knowledge of all these factors, often associated, will provide a precise lesional assessment and treatment adapted to the instability.

Introduction

Understanding ankle instabilities remains difficult because of their complexity, which is related to the interference of a large number of parameters. The risk factors of developing chronic instability have been classified into intrinsic and extrinsic factors. Briefly, the intrinsic factors group individual data, essentially morphological, with their variations (bone, ligament, and posture) and the extrinsic factors with environmental data (injury mechanism occurring in sports and/or professional contexts). The interrelation of these different factors, now better studied [1—6], can explain the passage to chronic instability syndrome. Based on our work and the data reported in the literature, we will analyze these different factors, the knowledge of which will participate in the choice of complementary examinations to undertake in cases of chronic instability of the ankle and the therapeutic strategies available.

From morphology to biomechanics

The mechanical behavior of the talocrural joint cannot be reduced to a flexion—extension movement with a working axis and one degree of freedom reflecting joint ginglymus. Its mechanical function is to transmit the body weight to the entire foot and to distribute a system of vertical stresses to a horizontal system represented by plantar weightbearing. There is a narrow interdependence between the talocrural joint and the subtalar joint, which are functionally indissociable [7,8], with the subtalar joint having a preferential rotation mobility (trochoid joint) allowing the foot to adapt to the ground. Joint kinematics results from a morphology and a biometric organization of the joint surfaces and a very specific multiaxial ligament system that will be clarified below.

Bone factors

The trochlea of the talus was compared to a truncated cone [9,10] whose mean angle at the summit is 24° (±11°); the rotational axis is oriented along a double obliquity: in the coronal plane, below and laterally passing under the tip of the two malleoli (at an angle of $82 \pm 3.6°$ with the tibia axis) and in the transversal plane, back and laterally at a 20°—30° angle with the transversal axis of the knee. This form makes it impossible to take into account certain anatomic details: a lateral edge that has greater inclination than the medial edge, a wider trochlea in front than behind, and a posterior part of the lateral edge that is beveled and triangular (Fig. 1). The wider anterior part of the space between the malleoli is reduced from front to back, as in the tibiofibular mortise: this difference in width between the anterior edge and the posterior edge varies a mean 4 ± 2 mm [11]. The lateral and medial joint surfaces of the body of the talus fall within circles situated in different sagittal planes and have different and variable radii of curvature. According to anatomic studies by Bonnel, Mabit, and Bedin, conducted for the Sofcot 2008 symposium, the study of radii of curvature has made it possible to individualize three types of talus: for type 1, the medial radius of curvature is smaller than the lateral radius of curvature; for type 2, the medial and lateral radii of curvature are identical; for type 3, the medial radius of curvature is larger than the lateral radius. Bonnel found 86% type 1, 11% type 2, and 3% type 3. In their CT study of 32 tali, Bedin and Mabit reported comparable radius of curvature values, but a different typological distribution: type 1 (21/32 cases; 66%) with a mean medial radius of curvature of 17 mm and a mean lateral radius of 20 mm; type 2 (6/32 cases; 19%) with identical medial and lateral radii (mean, 18.6 mm), and type 3 (5/32 cases; 15%) with a mean 21-mm medial radius of curvature, greater than the mean lateral radius of 19 mm (Fig. 2). In addition, Bonnel demonstrated [12] that there were three radii of curvature falling within circles situated in different spatial planes: the lateral edge of the talar trochlea if made up of two circles situated in two different planes: the first circle called ''lateral malleolar'' parallel to the sagittal plane, and the second called ''lateral talar'' inclined 45° compared to the first. These two circles join at the middle and anterior parts of the lateral edge, separating toward the back to form a triangular space (Fig. 1). This triangular space corresponds to the posterior part of the lateral beveled edge. The medial curvature, called ''medial talar'' presents a rounded edge. The space between the two circles is asymmetrical: the presence of the triangular margin, described above, explains the wider aspect in the front than in the back, slightly curved toward the inside of the talar trochlea. The shape analyzed is complex, but it explains highly important kinematic consequences.

As for the joint kinematics, several movement axes have been described. Based on the determination of the curvature centers of the medial and lateral edges of the trochlea, Barnett et al. [13] and Hicks [14] found two different axes, one axis for plantar flexion oriented obliquely from bottom to top and from medial to lateral, and one axis for dorsal flexion oriented from top to bottom and from medial to lateral. This bone segment allows two types of movement, a purely rotational movement and a rolling movement (rotation plus sliding) (Fig. 3). These two movements can be associated. The rolling phase evolves with instantaneous centers of rotation. In most subjects, instantaneous centers of rotation axes are grouped in a more or less extensive zone projected onto the talus body. For Carret [15], this grouping corresponds to perfect congruence of the joint surfaces, whereas dispersion corresponds to joint dysfunction.

In the sagittal plane, the stability of the talocrural joint is both bone- and ligament-based. During the propulsion phase, the shearing forces are neutralized by the talus