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Subtalar joint stability

Talocalcaneal interosseous ligament function studied in cadaver specimens

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We used 6 fresh-frozen foot specimens to evaluate the contribution of the talocalcaneal interosseous ligament (IOL) in stabilizing the subtalar (talocalcaneal) joint. The tibia and ankle joint were secured, and the calcaneus was subjected to a bending and axial force applied circumferentially. The position of the calcaneus relative to the talus was monitored with a magnetic tracking system. Motion was recorded at every half degree in the 0° to 360° arc before and after sectioning of the IOL. The results in the intact feet indicated that, with circumferential loading of the subtalar joint, there were two stable zones (supination stable zone, pronation stable zone) during which little displacement occurred and two transition zones during which the supination and pronation movement occurred.

There was a greater degree of supination displacement after IOL sectioning ($p = 0.008$), but no pronation displacement. The IOL contributed substantially to subtalar joint stability, particularly in supination.

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Multiple structures are involved in stabilizing the subtalar joint, such as the cervical ligament, the calcaneofibular ligament, and the talocalcaneal interosseous ligament (IOL) (Kjaersgaard-Andersen et al. 1987a, b, 1988, Stiehl 1991, Sarrafian 1993). Several investigators have indicated the importance of the calcaneofibular ligament in stabilizing the subtalar joint, but there are conflicting opinions (Cass et al. 1984). Others have concluded that the cervical ligament limits inversion and prevents excessive motion of the subtalar joint (Smith 1958, Cahill 1965).

The talocalcaneal IOL is located in the tarsal canal near the axis of rotation of the subtalar joint. It is a flat, obliquely oriented structure originating in the tarsal canal near the anterior margin of the posterior facet. It extends across the tarsal canal from medial to lateral for approximately 1.5–2.5 cm (Figure 1). The proximal to distal dimensions are 2–4 mm. The fibers of the ligament are obliquely oriented proximally and medially, and they insert into the sulcus of the talus (Lehman and Lehman 1981). Previous authors believed that the IOL was not important in stabilizing the subtalar joint (Smith 1958, Cahill 1965).

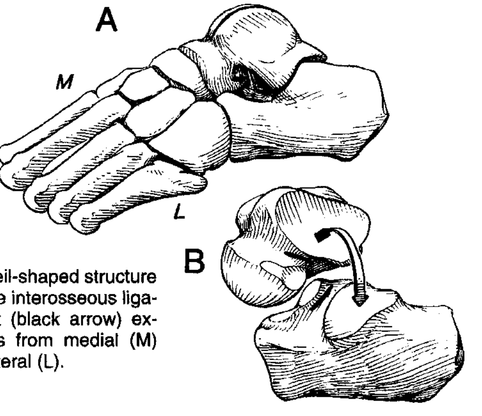
We assessed the contribution of the talocalcaneal IOL in stabilizing the subtalar joint.

Material and methods

Specimen preparation

6 fresh-frozen cadaveric feet, obtained from 3 men and 3 women, were studied. The mean age of the patients was 61 (57–66) years. There were no obvious abnormalities, such as deformities, on visual inspection.

Figure 1. Anatomical position of talocalcaneal interosseous ligament. (By permission of Mayo Foundation.)



A. Veil-shaped structure of the interosseous ligament (black arrow) extends from medial (M) to lateral (L).

B. Location of ligament attachments on the bones with the subtalar joint opened.

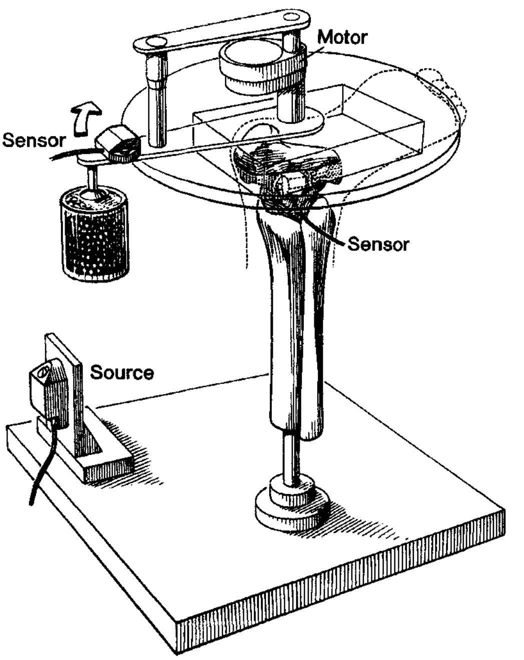


Figure 2. Experimental set-up for left foot. The tibia and talus were fixed in the loading frame with a cemented rod. The calcaneus, embedded in polymethyl methacrylate, was attached to a loading disk. A magnetic source was mounted on the testing frame, and three sensors were attached to the loading arm, calcaneus, and talus (talus sensor not shown). A motor on the plate drives the testing device in a circular direction. A load was applied to the rotating arm. (By permission of Mayo Foundation.)

Specimens were prepared for testing by dividing the tibia and fibula 10 cm above the ankle joint line and removing the skin and subcutaneous tissues. A hole was drilled in the intramedullary canal of the tibia, extending across the ankle joint. An alignment apparatus was used to prepare each specimen consistently. The foot was disarticulated at the talonavicular and calcaneocuboid joints, and the calcaneus was embedded in polymethyl methacrylate. During specimen preparation, care was taken to maintain the orientation of the specimen.

Experimental set-up

The tibia was fixed to the frame of the loading apparatus, and a load was applied to the calcaneus (Figure 2). The calcaneus was mounted on an acrylic disk, 15 cm in radius. A 17-cm acrylic mobile arm was attached to the acrylic plastic disk, and a weight was applied to the arm. In this manner, a bending and axial force could be applied. Because of the considerable variation in anatomy and mechanics of the subtalar joint (such as axis orientation) (Engsberg 1987), the load was applied to the joint circumferentially.

The position of the calcaneus in relation to the talus (and tibia) was monitored with a magnetic tracking system (3Space Tracker System, Polhemus Navigational Sciences Division, Colchester, VT) consisting of a magnetic source, three magnetic sensors, and an electronics unit. The electronics unit interfaced with the host computer, an IBM 486 PC, and contained analog circuitry to generate and sense electromagnetic fields and to digitize the analog signals. The 80286-based processor in the electronics unit provided the drive signals that excited the source. This processor also performed all necessary computations for determining the spatial location of the sensors. The sensor triad measured the field strength, and the electronics unit software calculated the relative source-sensor position and orientation. Because of the potential interference with electromagnetic fields, the use of large metal objects was avoided. According to the manufacturer's specifications, within the 76-cm range from the source the system has a translational accuracy of 2.54-mm root mean squared (RMS) and an angular accuracy of 0.5° RMS. The translational resolution is 0.001 mm/mm range, and the angular range is 0.1°. Field-testing demonstrated that it was possible to achieve greater accuracy and resolution since the source-to-sensor distance was limited. Experiments were performed in this laboratory to test the accuracy of the system and the measurement of joint kinematics. On the basis of our calibration, when the sensors were located within a range of 10 to 25 cm from the source, the translational accuracy was 0.2 mm RMS. In this study, the sensors were placed within this range.

One magnetic sensor was placed on the calcaneus, and a second was placed on the talus to document solid fixation of the tibiotalar joint. A third sensor was placed on the rotating acrylic arm to monitor the motion of the arm, to which a load was applied (Figure 2).

Screw-axis description was used to represent the bony motion (Kinzel et al. 1972, An and Chao 1984, Engsberg 1987, Garcia-Elias et al. 1989, Woltring 1994). The bony rotation around the screw axis represents the total bony rotation. Each rotation component in the Cartesian coordinate system axis represents the bony rotation component in the sagittal, coronal or transverse plane. This screw displacement axis method was employed to describe the 6 degrees-of-freedom spatial motion of a moving segment from one position to another in terms of rotation around and translation along this unique axis (Kinzel et al. 1972, An and Chao 1984, Garcia-Elias et al. 1989, Woltring 1994). Three components of direction cosine vectors defined the orientation of the axis, 3 coordinates de-

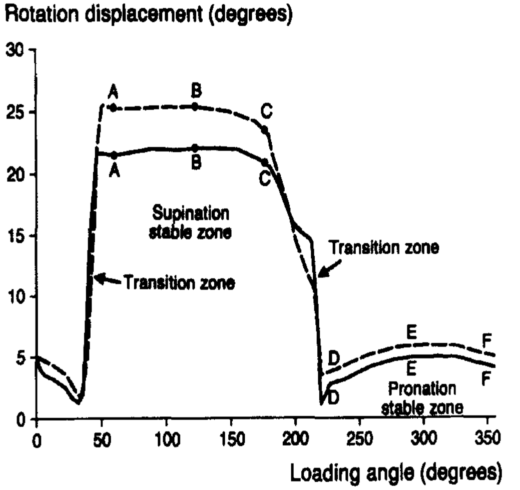


Figure 3. Talocalcaneal motion pattern: total rotation as a function of loading position angle. Solid line, intact talocalcaneal interosseous ligament. Dashed line, Sectioned talocalcaneal interosseous ligament.

fined the position of the axis, 1 component defined the angle of rotation about the axis, and 1 component defined the distance of translation along the axis. For purposes of the study, we focused attention on the 4 rotation variables.

The rotation of the acrylic mobile arm, from which a 125-g weight was suspended, started at the 0°-loading position. In the experiment, the rotation of the mobile arm started from this position in a clockwise direction for the right foot and in a counterclockwise direction for the left foot. Data were collected for every 0.5° of clockwise or counterclockwise movement of the arm from 0° to 360°.

The weight attached to the mobile arm acting in the cephalic direction created a dorsiflexion moment when the mobile arm was located at the anterior (0°) aspect of the foot, a supination moment when the arm was located at the medial (90°) aspect of the foot, a plantar flexion moment when the arm was located at the posterior (180°) aspect of the foot, and a pronation moment when the arm was located at the lateral (270°) aspect of the foot.

The subtalar joint motion was represented as the combination of triplanar components. Supination consisted of adduction-inversion-plantar flexion, whereas pronation consisted of abduction-eversion-dorsiflexion (Engsberg 1987). We determined the total screw axis rotation as a function of the loading position angle. A consistent movement pattern was identified with this method of circumferential loading on the calcaneus relative to the talus. We determined the loading angle position (at which specific movement patterns occurred), the total screw axis rotation angle, and the degree of adduction-abduction, inversion-eversion, and plantar flexion-dorsiflexion before and after sectioning the IOL.

We used a two-tailed paired t-test to determine the significance of the difference in displacement before and after sectioning the IOL. A significance level of 0.05 was used.

Results

We observed a consistent pattern of displacement, with two stable zones in which little displacement occurred and two transition zones in which most normal subtalar joint motion occurred. The degree of displacement in the transition zones was large in magnitude (Figures 3 and 4). Three points (A, B, and C) represented the early, middle and late phases of the supination stable zone. Three points (D, E, and F) represented the early, middle and late phases of the pronation stable zone. The points A,C and D,F were defined to determine the range of the stable zone, and the middle points B and E were defined to compare displacement before and after ligament sectioning.

For the intact specimens, the range of the supination stable zone extended from 71° to 168° loading position angle by a force located at the medial-posterior portion of the foot. The pronation stable zone extended from 238° to 40° loading position angle by a force located at the anterior-lateral position of the foot. After sectioning of the IOL, the supination stable zone changed slightly to 73°–171° loading position angle, and the pronation stable zone shifted to 227°–47° loading position angle (Figure 4). There were no significant differences in the loading position angles corresponding to the stable and transition zones in the intact, as compared to the sectioned, feet (Table 1).

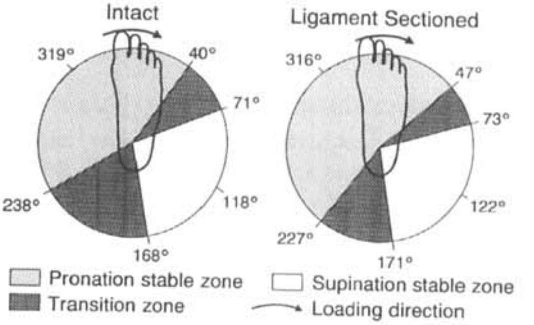


Figure 4. Loading position angle of subtalar joint. Comparison between intact and sectioned talocalcaneal interosseous ligament.

Table 1. Loading position angle in degrees (SD) with comparison of intact and sectioned interosseous ligament

Ligament condition	Supination zone			Pronation zone		
	Point A	Point B	Point C	Point D	Point E	Point F
Intact	71 (16)	118 (7)	168 (11)	238 (29)	319 (10)	40 (31)
Sectioned	73 (17)	122 (8)	171 (7)	227 (23)	316 (11)	47 (20)

Table 2. Total rotation of subtalar joint in degrees (SD) with comparison of intact and sectioned interosseous ligament

Ligament condition	Supination zone			Pronation zone		
	Point A	Point B	Point C	Point D	Point E	Point F
Intact	14 (7) [a]	14 (7) [a]	13 (6) [a]	11 (6)	14 (9)	11 (7)
Sectioned	18 (4) [a]	18 (6) [a]	16 (5) [a]	11 (7)	15 (9)	12 (8)

[a] $p < 0.01$

Table 3. Screw axis orientation of subtalar joint represented by mean direction cosines (SD) with rotation components in abduction, dorsiflexion, and eversion

	Ligament condition	Supination zone			Pronation zone		
		Point A	Point B	Point C	Point D	Point E	Point F
X (Abduction)	Intact	–0.49 (0.14)	–0.52 (0.13)	–0.56 (0.21)	0.53 (0.17)	0.55 (0.15)	0.58 (0.16)
	Sectioned	–0.58 (0.11)	–0.57 (0.12)	–0.56 (0.18)	0.54 (0.15)	0.39 (0.44)	0.57 (0.15)
Y (Dorsiflexion)	Intact	–0.14 (0.12)	–0.19 (0.11)	–0.31 (0.12)	0.32 (0.15)	0.41 (0.10)	0.44 (0.12)
	Sectioned	–0.16 (0.12)	–0.20 (0.11)	–0.30 (0.10)	0.30 (0.15)	0.41 (0.10)	0.46 (0.11)
Z (Eversion)	Intact	–0.84 (0.09)	–0.82 (0.07)	–0.72 (0.13)	0.72 (0.07)	0.71 (0.11)	0.65 (0.12)
	Sectioned	–0.78 (0.08)	–0.78 (0.07)	–0.74 (0.11)	0.75 (0.11)	0.71 (0.11)	0.65 (0.10)

When the total screw axis rotation was compared with the zero position, we found a significant change in supination after sectioning the IOL, as compared to the intact feet ($p = 0.008$), in the early, middle and late phases of the supination stable zone. There were no significant changes in the early, middle and late phases of the pronation stable zone (points D, E, and F) after sectioning the IOL (Tables 1 and 2).

In maximal supination, the predominant motion was in inversion, followed by adduction and plantar flexion. In pronation, the predominant motion was in eversion, followed by abduction and dorsiflexion (Table 3). After sectioning of the IOL, there were changes in total rotation, but we found no significant difference in the screw axis orientation (Table 3).

Discussion

Subtalar joint motion is complex and occurs in three planes (Close et al. 1967, Kjaersgaard-Andersen et al. 1988, Sarrafian 1993). The clinical condition of subtalar instability is difficult to diagnose accurately because it is hard to measure reliably the degree of subtalar joint stability with the commonly available methods, such as two-dimensional radiography. This study demonstrates the complexity of the motion of the normal subtalar joint and how the degree of displacement increases with sectioning of the talocalcaneal IOL, particularly with supination force applied.

The study also demonstrates the pattern of joint motion with two stable zones and two transition zones, which typically occurs in the subtalar joint when a force is applied in a circumduction fashion. Within the range of stable zones, little change in displacement occurred. The subtalar joint position, however, shifted quickly during the transition zones from one stable zone to the next. The loading position angles at which the rapid transition between these stable zones occurred were similar before and after the IOL was sectioned.

In an anatomical study, Cahill (1965) suggested that the primary function of the IOL was to maintain the apposition of the talus and calcaneus in all positions and that it played little if any role in limiting supination and pronation. Stephens and Sammarco (1992), who assessed subtalar stability, believed that the IOL was a stabilizer in all positions of testing. Still others believed that the IOL was mainly important for stabilizing the subtalar joint for eversion stress (Smith 1958, Kjaersgaard-Andersen et al. 1988, Sarrafian 1993). The current study indicated that the IOL contributes substantially to supination stability, but not appreciably to pronation stability.

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