Tibiotalar contact and fibular malunion in ankle fractures

A cadaver study

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Six cadaveric ankles were dissected, preserving medial and lateral ligaments; an axial load of 455N was applied to the tibia supported by the foot and ankle. The unconstrained tibia was moved through 20° of flexion and extension to simulate walking. The tibiotalar contact area was defined using carbon black suspension, recorded photographically, and measured using computerized area analysis. Osteotomy of the distal fibula was performed and fixed with a specially modified plate; a selection of plates provided fixation with 0° or 30° of external rotation in combination with 0 or 2 mm of shortening. The contact area was measured for each of the plates and after division of the deltoid ligament.

There were greater than 30 percent decreases in tibiotalar contact with both fibular shortening and external rotation, doubled with a divided deltoid ligament. Anatomic restoration of both fibular length and rotation is essential for normal ankle mechanics. The deltoid ligament has crucial effects on the stability of the ankle mortise.

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The most common pattern of surgically treated lateral malleolar fracture is sustained after a supination-external rotation injury, producing an oblique fracture at the level of the syndesmosis, Weber type B, Lauge-Hansen Type supination-external rotation (SE). It is unclear what amount of displacement of an isolated fibular fragment will in itself cause a secondary change in the mechanics of the ankle joint.

The aim of this study was to assess the degree to which rotation and shortening of the lateral malleolus affects dynamic tibiotalar contact. The added influence of deltoid disruption was also examined.

Material and methods

Six fresh cadaveric legs were harvested by below-the-knee amputation. No specimens were used that had evidence of previous trauma or degenerative disease within the ankle joint. The specimens were wrapped in saline-soaked cloth and stored at –20 °C sealed in polyethylene bags to prevent desiccation.

On the day of testing, the specimens were thawed; and the skin and subcutaneous tissue were excised from the proximal tibia to the hindfoot, preserving the heel pad. The ankle joints were dissected to the anterior capsule, preserving intact the medial and lateral collateral ligaments and tendons, as well as all the posterior structures. The proximal fibula was transfixed in anatomic alignment to the tibia using two threaded 4-mm Schanz screws. The capsule of the joint was excised anteriorly to gain access to the articular surface.

A transverse osteotomy of the distal fibula was performed proximal to the syndesmosis, and the anterior tibiofibular ligament was incised to permit limited external rotation and shortening of this distal fibular fragment, simulating the displacement that occurs in a Weber B ankle fracture. The posterior tibiofibular ligaments were preserved in order not to destabilize the syndesmosis. The osteotomy was fixed with one of a series of especially modified AO 1/3 tubular plates and 3.5 mm screws. The initial plate provided anatomic reduction and fixation of the osteotomy; use of the same screw holes in the fibular fragments and one of the selection of plates permitted fixation with 0° or 30° of external rotation in combination with 0 or 2 mm of shortening (Figure 1). Although fibular rotation of 30° is not usually seen clinically in the absence of extensive lateral ligamentous injury, the rationale for testing such an extremely malrotated position was that the large magnitude of deformity would heighten the alteration in the contact area. A similar testing configura-

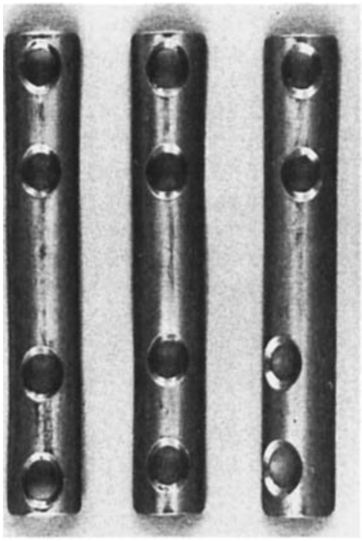

Figure 1. Modified 1/3 tubular plate for fixation of the fibular osteotomy. Offset of the screw holes provides fixation with (from left to right) anatomic alignment, 2 mm of shortening, and 30° of rotation combined with 2 mm of shortening.

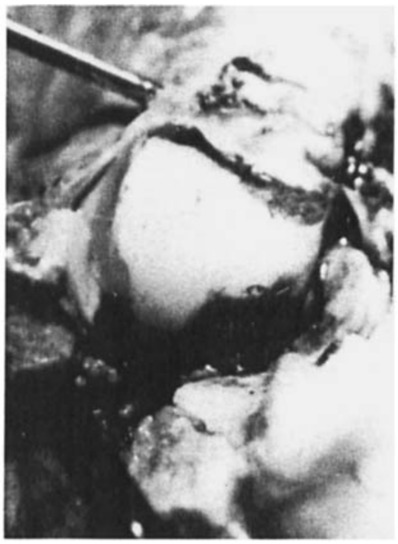

Figure 2. The tibiotalar contact area outlined by carbon black in the normal ankle.

tion has been used by other investigators in studies of contact area and pressure in the ankle (Zindrick et al. 1984).

To provide a dynamic and unconstrained assessment of ankle function, we used the model described by Michelson et al. (1990). A press-fit intramedullary rod was constructed of aluminum with a plate to support four identical circular weights, totaling 455N. The tibia was supported only by the foot and ankle. The unconstrained tibia was moved through 20° of flexion and extension to permit a dynamic measurement of contact areas. No attempt was made to control the free varus/valgus or rotational movements of the tibia and ankle during testing. A carbon black suspension (1 g in 10 mL physiologic saline) was applied as a thin layer to the articular surface of the talus; the area of tibiotalar contact throughout the range of motion was outlined by the area from which the carbon black was selectively removed (Clarke et al. 1991).

After each test run, the weights were removed from the leg and the proximal screws were removed from the plate. This permitted the fibular fragment to be pivoted inferiorly on the lateral collateral ligaments for a clear view of the dome of the talus. The tibiotalar contact area outlined by the carbon black suspension was photographically recorded at a fixed distance from the talar dome (Figure 2). This procedure was performed for each of the fibular plates, with two test runs per plate.

The deltoid ligament was then divided with a scalpel to simulate disruption of the medial side of the ankle mortise, and the testing procedure was repeated with all the combinations of fibular shortening and rotation, including anatomic reduction.

An analysis of the photographs of contact areas was performed by computerized area measurement. The photographic slide was digitized and projected onto the computer screen as a digital representation of the photograph. A mouse-driven cursor was then used to outline the area of the entire dome of the talus and the area within this area was calculated by the computer. The cursor was then used to similarly define the area from which the carbon black had been removed, and this area was calculated (Figure 3). The tibiotalar contact area was expressed as a function of the total talar articular area. For clarity, the total talar dome area will be referred to as the unit of measure. Therefore, a contact area comprising 60 percent of the talar dome is reported as 0.60. All the computer analyses of the slides were performed by a single observer, who was blinded as to the experimental status of the fibula and deltoid ligament.

Because the talar dome area determinations involved two-dimensional measurements of three-dimensional surfaces, nonparametric statistics were employed. A statistical analysis of the results was performed using nonparametric Kruskal-Wallis analysis of variance (ANOVA), controlling the individual

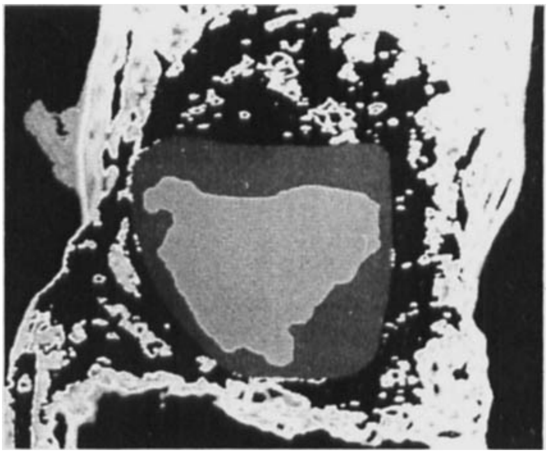

Figure 3. Computerized area analysis of the tibiotalar contact area for an ankle with 2 mm of fibular shortening.

ankles and the variables of interest, i.e., fibular length, rotation, and deltoid ligament disruption. The significance was taken at $P < 0.05$.

Results

The median dynamic contact area for the uninjured ankles was 79 (75–81) percent of the total surface area of the talar dome. All the manipulations of the fibula and deltoid ligament resulted in significant reductions in dynamic tibiotalar contact area. The changes due to fibular rotation and shortening, and deltoid disruption are approximately additive.

With the deltoid intact, the median reduction in contact area following 30° of fibular rotation was 9 (4–15) percent. In the absence of deltoid injury, shortening the fibula by 2 mm resulted in a median contact area reduction of 8 (5–14) percent. The addition of deltoid ligament disruption led to further reductions of the median contact area of 16 (4–18) percent and 14 (2–26) percent in the presence of fibular rotation or shortening, respectively. Overall, cutting the deltoid ligament resulted in a decrease in the median contact area of 11 (4–33) percent.

Discussion

Trauma to the ankle can disrupt the normal mechanics of the joint and result in overloading of the cartilage and subsequent degeneration. Lateral shift of the talus within the ankle mortise has been shown to reduce the contact area within the joint by up to 42 percent (Ramsey and Hamilton 1976, Kimizuka, et al. 1980) and increase peak pressures in the articular cartilage by 50 percent (Zindrick et al. 1985). These changes were measured using static models of loaded ankle joints in which the talus was fixed in a lateral position, and thus did not permit movement within the mortise. It has been suggested that during walking the talus may seek its own position beneath the tibia on loading, tending to reduce the forced lateral subluxation (Vrahas et al. 1990). In one clinical study, it was noted that union of a bimalleolar fracture with 2 mm of lateral displacement of the entire ankle complex (i.e., medial malleolus, talus, and lateral malleolus) under the tibia was compatible with a satisfactory result (de Souza et al. 1985). This suggests a combination of articular incongruency, and superimposed instability may be necessary for degenerative changes to ensue.

It has been shown that the rotational stability of the loaded ankle joint is primarily due to tension in the deltoid and lateral ligaments. Excision of the lateral malleolar articular surfaces did not reduce stability, but division of the deltoid ligament caused a twofold increase in rotational instability (McCullough and Burge 1980). They concluded that a relatively small change in collateral ligament positioning may cause deranged ankle motion, even in the absence of a visible talar shift on static radiographs of the unloaded ankle. Anatomic studies of the medial and lateral ligaments have indicated that the origins of these ligamentous structures suggest that even small variations can result in abnormal ankle mechanics (Morgan and Burks 1991).

Previous work has measured the effects of fibular malunion on pressures within the ankle joint. Two millimeters of fibular shortening increased peak pressures 33 percent, and 30° fibular external rotation increased pressures up to 73 percent (Zindrick et al. 1984). Their model used static loading of a constrained ankle at three different positions of flexion, and did not consider the effect of rupture of the deltoid ligament. Late reconstruction of the fibula has been advocated for malunited ankle fractures. If fibular length and rotation were restored, good results were reliably obtained (Weber and Simpson 1985, Ward et al. 1990).

Our study used an unconstrained dynamic model of ankle motion. In all the specimens, the major cause of tibiotalar contact area reduction was division of the deltoid ligament. Deltoid ligament disruption accentuated the reduction of the contact area that accompanied fibular malposition. Fibular malposition appeared to cause rotatory instability of the ankle mortise that was exacerbated by deltoid ligament division.

The instability pattern consisted of external rotation of the talus from beneath the tibial plafond. The extent of rotation was limited by an intact deltoid ligament that was under tension in the loaded and plantar flexed ankle. Section of the ligament allowed greater external rotation, resulting in significantly greater reductions in contact area with each fibular deformity. Rotational instability has been previously noted in studies of ankle ligaments and has been likened to the anterolateral rotatory instability seen in the anterior cruciate deficient knee (Joy et al. 1974, McCullough and Burge 1980, Bauer et al. 1985, Paar and Ungerechts 1988, Clarke et al. 1991).

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