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Distal fibular malrotation and lateral ankle contact characteristics

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ABSTRACT

Background: Any amount of malreduction of the syndesmotic joint compared with the uninjured syndesmosis has been associated with an adverse effect on functional outcome. The amount of malrotation that may lead to clinically relevant pressure change in this joint has not been reported. Our purpose was to determine whether small degrees of external and internal malrotation would be associated with statistically significant changes in contact pressure in the tibiofibular and talofibular articulations.
Methods: Twelve cadaveric ankles were osteotomized above the syndesmosis and instrumented with a rotatable distal fibula plate. Sensors at the distal tibiofibular and talofibular articulations recorded contact pressure and area at neutral position and at 5 and 10° of external and internal malrotation through a full range of ankle motion.
Results: Compared with neutral rotation, there was a significant decrease in contact pressure at the talofibular articulation with external rotation of 5° (103 ± 113 kPa versus 52 ± 69 kPa; $P = 0.01$) and 10° (43 ± 62 kPa; $P = 0.01$) in plantarflexion.Contact pressure at the tibiofibular articulation in plantarflexion increased with 10° of internal malrotation compared with neutral rotation (56 ± 30 kPa versus 74 ± 38 kPa; $P = 0.05$) in plantarflexion. Contact area decreased significantly with plantarflexion and 10° of external rotation and increased significantly in plantarflexion and after cyclic loading with 10° of internal rotation ($P \leq 0.05$).
Conclusion: Any degree of distal fibular external rotation significantly reduced contact pressure in the talofibular articulation with plantarflexion. A minimal increase in contact pressure was found in the tibiofibular and talofibular joints with plantarflexion and mild internal rotation of 5°, but pressure increased significantly in both articulations with 10° of internal rotation. The findings support clinical findings that subtle degrees of fibular malrotation may be associated with alteration of lateral ankle mechanics.
Level of evidence: Controlled biomechanical study.

1. Introduction

Stabilization of distal tibiofibular syndesmotic disruption with ankle fracture/dislocation has been reported to result in a relatively high rate of syndesmotic malreduction based on CT scan, with significantly worse functional outcome scores [1]. Those investigators also found a higher rate of malreduction with closed reduction compared with open reduction. Both internal and external rotational malreductions were identified. Several studies have recommended open syndesmotic reduction and postoperative CT assessment for reduction of the syndesmotic joint [1–4]

The clinical implications of syndesmotic malreduction on the ankle are unclear. Malreduction of the distal tibiofibular joint has been reported to lead to poor clinical outcomes due to pain [1]. These investigators defined malreduction as any deviation from the uninjured syndesmosis and advised CT comparison of the reduced joint versus the uninjured joint. CT comparison was considered to be warranted despite additional radiation exposure and cost because of the improved functional outcomes observed with an anatomically reduced joint. The degree of malrotation that is associated with poor clinical outcome has not been established.

Our purpose was to study changes in contact pressure of the distal tibiofibular and talofibular articulations in a cadaveric suprasyndesmotic ankle fracture model with various degrees of distal fibular malrotation. We hypothesized that contact pressure at both articulations of the lateral ankle would change significantly with small amounts of external and internal malrotation.

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2. Methods

Six matched pair fresh-frozen lower extremities were used. These were kept in a −4 °C freezer prior to use and thawed for 24 h before testing. The mean age of the donors was 76 years (range, 60–85 years), with three male and three female pairs. Specimens were screened by visual inspection for previous surgery about the foot or ankle.

2.1. Specimen preparation and fracture model

Our fracture model recreated a comminuted Weber C type fracture with preserved fibular length. The distal fibula was exposed leaving all stabilizing ligaments intact. An anatomic 5-hole locking distal fibula plate (Arthrex, Naples, FL) (Fig. 1) was applied to the intact fibula. The distal and proximal border of the osteotomy was marked 7.5 mm above and 7.5 mm below the center point of the center hole of the plate. Then a cut was made along the marked lines to remove 1.5 cm of distal fibular diaphysis. The osteotomy was located approximately 5 cm above the tibiotalar joint line, above the anterior and posterior inferior tibiofibular ligament (AITFL, PITFL). The locking plate was then removed and a custom-made, rotatable version of the same distal fibula locking plate (Fig. 1) was applied at neutral rotation. The (AITFL) and intraosseous ligament (IOL) of the syndesmosis were incised to allow for placement of a digital pressure sensor (Sensor model 6900, Tekscan, South Boston, MA) at the distal tibiofibular articulation and between the lateral talus and medial fibula. Prior to insertion the sensors were calibrated using a two-point method according to the manufacturer's guidelines. The sensors were glued securely into place on the tibia and talus using cyanoacrylate.

The specimen was examined to ensure that ankle range of motion achieved at least 30° in dorsiflexion. If not, percutaneous Achilles tendon lengthening was performed until this range was met. A large fragment screw was placed securely into the medial malleolus at the intersection of the anterior and middle third of the tibia in the sagittal plane to provide a constant point of reference for syndesmotic clamp placement [5]. The syndesmosis was then retensioned using a custom king tongs clamp instrumented with a strain gauge to measure the amount of compression applied. This device was set to 100 N based on tension measurements when we simulated clinical "hand tight" force. Screw or suture button fixation was not considered because of the need for removal and replacement with each rotational condition. The medial prong was applied on the screw head and the lateral tine was applied within the plate at the midline of the fibula at the joint line to create compression along the neutral axis of the tibiofibular articulation [6].

Each specimen was secured proximally in an adjustable stainless steel cylinder and loaded into a materials testing system (MiniBionix, MTS Systems, Eden Prairie, MN) (Fig. 2). At neutral fibular rotation, contact pressure and area were measured through a full range of 30° dorsiflexion and 30° plantarflexion, confirmed with a goniometer. The specimen was then placed foot-flat and loaded through the testing system cyclically to simulate normal walking in a 70-kg male (cyclic force 0–1000 N, frequency 0.5 Hz, total time 10 s) [7,8], and contact pressure and area were measured again. This loading protocol was repeated with the plate at 5 and 10° of external rotation and internal rotation to determine the threshold amount of malrotation to produce changes in contact pressure or area.

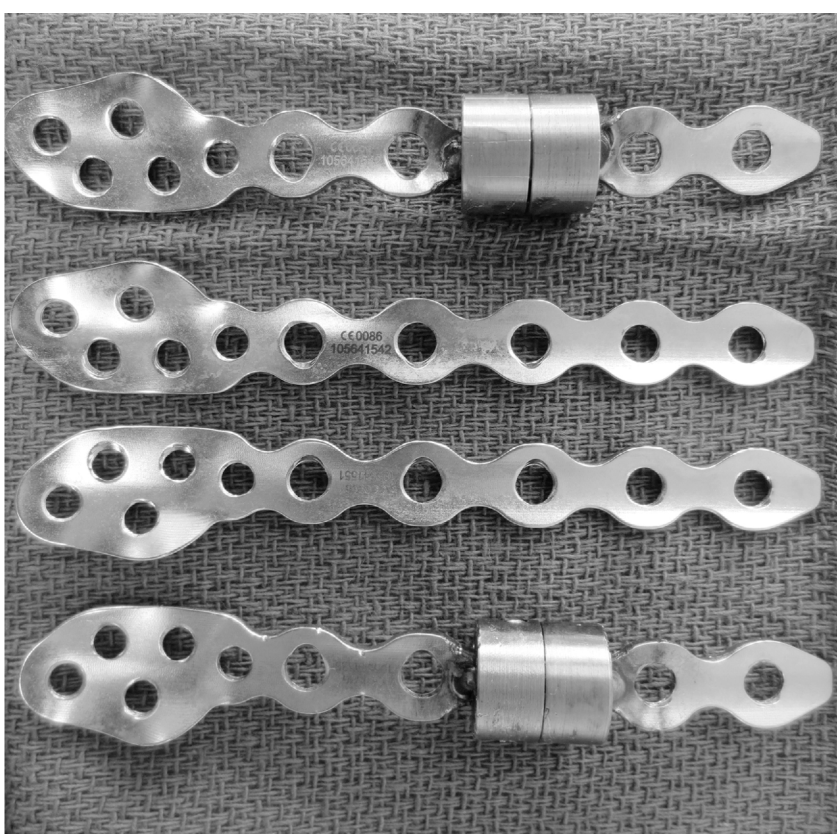

Fig. 1. Custom manufactured anatomic distal fibula locking plate to permit controlled rotation of the distal fibula.

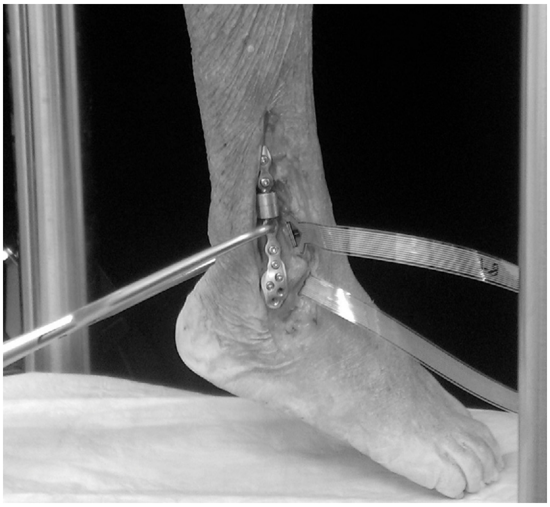

Fig. 2. Experimental set-up showing cadaveric model, locking plate, syndesmotic clamp, and pressure sensors.

Specimens were skeletonized after testing to confirm that no fracture or degenerative change was present at the tibiotalar or tibiofibular articulation below the mid-tibia.

2.2. Statistical analysis

Power analysis based on previously reported literature [9] found that 12 samples per group would provide 80% power to detect significant change in contact pressure with an alpha level of 0.05.

One way repeated measures analysis of variance test was used to compare contact pressure and area within the groups. The Holm–Sidak post hoc test was used to determine where differences occurred if the ANOVA test showed significant results. A P value of ≤0.05 was considered significant.

3. Results

No specimens had fracture or degenerative change below the mid-tibia at the tibiofibular or tibiotalar joint.

Talofibular contact pressure decreased significantly with plantarflexion with 5 and 10° of external malrotation and increased significantly with 10° of internal malrotation. Tibiofibular contact pressure increased significantly with plantarflexion with 10° of internal malrotation (Table 1).

Tibiofibular contact area significantly decreased with 5 and 10° of external malrotation with plantarflexion (Table 2). Talofibular contact area significantly decreased at 10° of external malrotation in plantarflexion and with cyclic loading in internal rotation.

Dorsiflexion of the ankle offloaded the tibiofibular articulation of the syndesmotic joint.

4. Discussion

In a distal fibular malrotation model, external malrotation resulted in significantly decreased contract pressure at the talofibular articulation in plantarflexion, and internal rotation of 10° was associated with increased contract pressure at the tibiofibular articulation. These statistically significant findings suggest that minor malrotation of the distal fibula has an effect on the biomechanics of the lateral ankle articulations. This finding is consistent with clinical results that defined clinically relevant

Table 1
Effect of distal fibular external and internal rotation on tibiofibular and talofibular joint contact pressure using group data (mean ± standard deviation).

Condition	Contact pressure (kPa)						
	Neutral	ER 5°	ER 10°	ER P value	IR 5°	IR 10°	IR P value
Tibiofibular joint							
Plantarflexion	56 ± 30	58 ± 41	54 ± 50	NS	63 ± 42	74 ± 37[a]	0.05
Dorsiflexion	6 ± 8	10 ± 24	3 ± 6.0	NS	4 ± 5	5.0 ± 6	NS
Cyclic loading	27 ± 19	28 ± 19	23 ± 22	NS	23 ± 16	33 ± 26	NS
Talofibular joint							
Plantarflexion	103 ± 113	52 ± 69[a]	43 ± 62[a]	0.01	107 ± 129	149 ± 135[a,b]	0.02
Dorsiflexion	358 ± 211	360 ± 236	361 ± 220	NS	340 ± 223	342 ± 218	NS
Cyclic loading	353 ± 233	322 ± 227	285 ± 269	NS	350 ± 213	386 ± 221	NS

ER, external rotation; IR, internal rotation; NS, not significant (P > 0.05).
[a] Significant difference compared with neutral.
[b] Significant difference between 10 and 5°.

Table 2
Effect of distal fibular external and internal rotation on tibiofibular and talofibular joint contact area using group data (mean ± standard deviation).

Condition	Contact area (mm^2)						
	Neutral	ER 5°	ER 10°	ER P Value	IR 5°	IR 10°	IR P Value
Tibiofibular joint							
Plantarflexion	64 ± 43	49 ± 34[a]	39 ± 32[a]	0.002	61 ± 40	74 ± 36[a]	0.05
Dorsiflexion	4 ± 7	5 ± 11	4.0 ± 8.0	NS	6 ± 12	6 ± 10	NS
Cyclic loading	33 ± 41	25 ± 36	25 ± 37	NS	26 ± 36	28 ± 40	NS
Talofibular joint							
Plantarflexion	25 ± 17	19 ± 15	18 ± 12[a]	0.03	25 ± 17	30 ± 19	NS
Dorsiflexion	87 ± 32	87 ± 35	84 ± 36	NS	90 ± 32	86 ± 32	NS
Cyclic loading	74 ± 43	75 ± 47	69 ± 47	NS	89 ± 41	95 ± 41[a]	0.01

ER, external rotation; IR, internal rotation; NS, not significant (P > 0.05).
[a] Significant difference compared with neutral.

malrotation as any difference between the reduced and the uninjured syndesmosis [1]. Further study is needed to assess the clinical implications of these biomechanical results.

This study is in agreement with previous findings [10] that progressive external rotation beyond 5° resulted in increased contact pressures in the posterolateral aspect of the tibiotalar joint. A report on tibiotalar contact pressures in a fibula-intact model after progressive release of the syndesmotic and deltoid ligaments found that tibiotalar contact pressure increased and center of pressure shifted posterolaterally after sectioning of the AITFL, IOL, and deltoid ligaments [11]. External rotation of the fibula further increased mean contact pressure and reduced contact area. A report on fixation of the distal tibiofibular joint found reduced movement at the syndesmosis after fixation and contact pressure at the tibiotalar joint was normalized after fixation [12]. An analysis of CT scans after syndesmotic screw placement found increased space at the posterior aspect of the joint compared to the central and anterior aspects, consistent with our observed unloading in external rotation as increased space posteriorly accommodated this motion [13].

The clinical implications of distal fibular malrotation are not known. A previous study [14] reported on 155 patients who underwent ORIF either with syndesmotic screw, syndesmotic ligament repair, or both for rotational ankle fractures with syndesmotic instability. Based on CT scan, the mean distal fibular malrotation was 5.8° (range, 0.2°–21°) compared to the contralateral uninjured side. Clinical outcomes based on Foot and Ankle Outcome Scores did not correlate with degree of malreduction at follow-up of 1 year. Other investigators [1] studying syndesmotic reductions in 68 patients (68 injuries) found a 39% malreduction rate associated with worse mean Short Form Musculoskeletal Assessment general health scores than with anatomically reduced injuries (27 ± 23 vs. 12 ± 11 points, $P < 0.05$).

Several previous studies investigating the contact pressure and area characteristics of the tibiotalar joint provide comparisons for the kinematics observed in this study [15–18]. The pressures and areas observed in these studies indicated a predominance of force on the central plafond, with relatively less force and pressure borne by the lateral and medial portions of the tibiotalar joint. Conceptually, outcomes after ankle fracture may be driven by direct cartilage injury or tibiotalar derangement rather than those factors we studied in the talofibular articulation. The rotating plate used in this study could provide a tool for future study of the distal fibula or other long bones.

There are limitations to the present study. The model is cadaveric and subject to the limitations and variability inherent in the measurement of non-living tissues. The 5° increment of rotation doesn't allow for fine definition of the effects of rotation on contact pressure and area. Likewise, the model was limited to 10° of rotation in either direction based on plate design. Syndesmotic compression via clamping has its own rotational effect on the distal fibula [4]. Our test set-up did not recreate the native distal tibiofibular articulation, and therefore our results are only applicable to the pathologic setting where this anatomy is disrupted. Although we inspected specimen anatomy to rule out any degenerative changes or signs of previous ankle fracture, we did not acquire long leg films of each specimen to assess malalignment in the proximal tibia or fibula. A small amount of rotation could be expected at the plate-screw interface, but this was minimized by using a locking construct and bicortical screws where possible. While complete sectioning of all the syndesmotic ligaments was considered to produce a more clinically relevant unstable fracture model, this destabilized the testing sensors to the point of inaccuracy. Commonly, both external rotation and shortening occur in unstable fractures, and this additional deformity may further alter contact pressures beyond what was noted in the present study.

In conclusion, Any degree of distal fibular external rotation significantly reduced contact pressure in the talofibular articulation with plantarflexion. A minimal increase in contact pressure was found in the tibiofibular and talofibular joints with plantarflexion and mild internal rotation of 5°, but pressure increased significantly in both articulations with 10° of internal rotation.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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