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Assessment of Ankle and Hindfoot Stability and Joint Pressures Using a Human Cadaveric Model of a Large Lateral Talar Process Excision

A Biomechanical Study

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Abstract: Lateral talar process fragment excision may be followed by hindfoot instability and altered biomechanics. There is controversy regarding the ideal fragment size for internal fixation versus excision and a concern that excision of a large fragment may lead to significant instability. The aim of this study was to assess the effect of a simulated large lateral talar process excision on ankle and subtalar joint stability.

A custom-made seesaw rig was designed to apply inversion/eversion stress loading on 7 fresh-frozen human cadaveric lower legs and investigate them in pre-excision, 5 cm^3 and 10 cm^3 lateral talar process fragment excision states. Anteroposterior radiographs were taken to assess ankle and subtalar joint tilt and calculate angular change from neutral hindfoot alignment to 10-kg forced inversion/eversion. Ankle joint pressures and contact areas were measured under 30-kg axial load in neutral hindfoot alignment.

In comparison to the pre-excision state, no significantly different mediolateral angular change was observed in the subtalar joint after 5 and 10 cm^3 lateral talar process fragment excision in inversion and eversion. With respect to the ankle joint, 10-cm^3 fragment excision produced significantly bigger inversion tibiotalar tilt compared with the pre-excision state, $P = .04$. No significant change of the ankle joint pressure and contact area was detected after 5 and 10-cm^3 excision in comparison with the pre-excison state.

An excision of up to 10 cm^3 of the lateral talar process does not cause a significant instability at the level of the subtalar joint but might be a destabilizing factor at the ankle joint under inversion stress. The latter could be related to extensive soft tissue dissection required for resection.

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Abbreviations: AP = anteroposterior, ATFL = anterior talofibular ligament, control = pre-excision study group, CFM = center of force movement, K-wire = Kirschner wire, LTCL = lateral talocalcaneal ligament, PMMA = polymethylmethacrylate, post1 = 5-cm^3 excision study group, post2 = 10-cm^3 excision study group, PTFL = posterior talofibular ligament, STJT = subtalar joint tilt, TCT = talocalcaneal tilt, TT = tibiotalar tilt.

INTRODUCTION

The lateral process of the talus is prone to fracture either as an isolated event or in conjunction with other ankle or talar injuries. Lateral process of the talus fractures are typically caused by axial loading with elements of dorsiflexion and eversion or inversion, and have been identified to have a high prevalence in snowboarders as a result of the particular stresses put on the foot and ankle in the boot-binding complex.[1–5]

Hawkins divided the fractures into 3 groups: a nonarticular avulsion, a single large fragment involving both the talofibular articulation and the subtalar joint, and a comminuted fracture fragment. Displacement of the fragment markedly increases the chance of nonunion or malunions with subsequent degenerative changes of the subtalar joint and pain in the sinus tarsi.[4]

Stress radiography has been recommended to quantify subtalar and tibiotalar instability. In Langer et al's study,[6] he reveals that there is a general acceptance defining ankle and subtalar joint stability. Using lateral, anteroposterior (AP), and 30-degree Brodén view, it has been accepted that a 3-mm increase in anterior tibiotalar translation, 3-degree increase in tibiotalar tilt, a 5-mm increase in medial talocalcaneal motion, and >5-degree increase in talocalcaneal tilt define instability of the ankle and subtalar joints, respectively.

Despite appropriate treatment, whether conservative, open reduction internal fixation, or fragment excision, many patients remain persistently symptomatic and stiff through their subtalar joint requiring further intervention.[7] The size of the fragment and degree of displacement appear to be the critical factors in determining treatment. Less than 1 cm^3 and undisplaced fragments are managed conservatively. For comminuted fragments, most authors recommend primary surgical excision to avoid development of arthritic changes in the subtalar joint.[4,6,8] Displaced (>2 mm) and >1 cm^3 single fragments offer a range of treatment options, from closed reduction to cast immobilization, open reduction internal fixation, and fragment excision.[4,5] It is uncertain what size fragment excision results in subtalar and/or ankle joint instability.

The objective of this study was to biomechanically assess the effect of a simulated large lateral talar process excision (up to 10 cm^3) on ankle and subtalar joint stability and ankle pressures.

MATERIALS AND METHODS

The current study was approved by the AOTRAUMA Research Commission.

Seven fresh-frozen cadaveric lower legs (2 left, 5 right) were thawed for 24 h before experimental preparation. Radiographic evaluation was used to exclude specimens with bony deformities, prior trauma, or arthritis. Ranges of motion of at least 10-degree dorsiflexion and 20-degree plantarflexion in the ankle joint and at least 5-degree eversion and inversion in the subtalar joint were verified using a goniometer. Epidermal, subcutaneous, plantar soft tissue, ligaments, and capsules were preserved.

A minimum of 6 specimens was required in this study as a sample size to achieve statistical power of 0.8 at a level of significance 0.05. This calculation was based on data published by Langer et al[6] for the general acceptance that a 3-degree increase in tibiotalar tilt defines instability of the ankle joint. In addition, an expected 2-degree standard deviation of the tibiotalar tilt within the sample was considered.

A vertical approach to the anterior and posterior ankle was performed. Care was taken to preserve all tendons and ligamentous attachments. Transverse anterior and posterior arthrotomies were performed to allow access for insertion of a pressure sensor into the ankle joint. For radiographic analysis, 3 parallel 8-cm Kirschner wires (K-wires) were laterally placed in the anterior distal tibia, anterior talar dome, and calcaneus (just below the subtalar joint). Each specimen was then fixed with molded polymethylmethacrylate (PMMA; Beracryl, Suter Kunststoff AG, Jegenstorf, Switzerland). The proximal 5 cm of the tibia and fibula were fixed in a PMMA block. Plantarly, a Steinman pin was inserted transversely into the plantar aspect of the calcaneus and was used to augment the fixation of the foot into the PMMA molding. The hindfoot was held in the PMMA molding in 5 degree of valgus to simulate normal plantegrade position. The PMMA mold covered the entire forefoot and midfoot, restricting their motion. Stressing motion was thus limited only in the hindfoot.

A custom-made seesaw rig was designed to simulate inversion/eversion stress loading forces and allow for radiographic and pressure analysis. The rig secures the proximal leg while allowing the distal PMMA base of the foot to rotate on a platform (Figure 1). Because the seesaw rig only allows inversion/eversion motion, the foot was oriented in 10-degree external rotation in relation to the sagittal plane to allow additional plantar and dorsiflexion, therefore simulating hind foot supination and pronation, respectively.[9]

For ankle joint pressure and force measurements, pressure sensors (Model #5033, TekScan Inc, South Boston, USA) were used. These were calibrated at 6 bars on a custom air pressure sensor calibration machine. The calibration resulted in an approximate saturation pressure of 16 bars and the total matrix area was 1025 mm^2 (46×32 sensels, 38.4 mm $\times$ 26.7 mm) resulting in a spatial resolution of 0.696 mm^2 per sensel. Pressure sensors were inserted into the ankle joint in an anterior to posterior direction. Thumbtacks were used to prevent the sensor from shifting during loading. Pressure and force measurements of the tibiotalar joint were obtained before and after loading the ankle with an axial force while the foot was placed horizontally in the custom seesaw rig with the sliding elements of the rig in a locked position (Figure 2). For ankle joint pressure and force measurements, static axial compression was increased from a fixed preload of 2 to 30 kg, according to half body weight. Maximum load was held for 6 s. Load and contact pressure distribution was captured at 30 Hz. Coordinates were laid out in a mediolateral and AP direction. The location and shift of the center of force were determined from the pressure sensor measurements. For data recording, a sensor software package (I-Scan, TekScan Inc, South Boston, USA) was used. Subsequent data evaluation was performed using custom-made software based on Matlab (Mathworks Inc., Natick, USA).

After analysis of the pressure sensor data, the following parameters were analyzed: peak force (N), center of force movement (mm), contact area (mm^2), and contact area pressure (bar). Peak force was defined as the maximum pressure at the highest loaded area (2×2 sensel) at 30-kg load. Center of force movement was defined as the length vector between initial and final center of force positions at 2- and 30-kg loading, respectively. Contact area was defined as final total area of the sensor covered by the tibiotalar joint surfaces at 30-kg load. Contact area pressure was defined as the average pressure of the final contact area of the sensor at 30-kg load. Tibiotalar pressure measurements were repeated after each consecutive fragment excision.

For excision of the lateral process of the talus, we used a modified Ollier approach, centered distal and anterior to the tip of the fibula.[9] Initially, in the pre-excision group, soft tissue dissection was performed, but no osteotomy was carried out. Careful attention was paid to ensure that the lateral ligamentous complex was not compromised during the surgical dissection. A 1-cm osteotome (Depuy Synthes, West Chester, USA) was used to osteotomize the lateral process of the talus. In the 5-cm^3 excision step, 3 cuts were made relative to the apex of the lateral talar process and subtalar joint (Figure 3). The apex of the lateral talar process was determined to be the most inferior point on the talus just above the talocalcaneal articulation and the most lateral aspect of the talus.[4] Cuts were made superior and parallel, medial and perpendicular, and posterior and perpendicular. For final fragment excision of 10 cm^3, additional cuts were made medially, superiorly, and posteriorly next to the previous bony defect to simulate the next size fracture fragment.

Each specimen was tested pre-excision, 5-cm^3 excision, and 10-cm^3 excision. AP radiographs were taken to assess tibiotalar tilt (TT) and subtalar joint tilt (STJT). Twenty-five-degree Brodén views were taken to evaluate the talocalcaneal tilt (TCT). The radiographs were taken in neutral hindfoot alignment, forced inversion and forced eversion with a 10-kg weight, which was attached to the rotating rig platform. The cortical surfaces of the tibia and talus were used for measurement of the tibiotalar tilt angle changes from neutral alignment to inversion and eversion respectively, as demonstrated on the AP radiograph (Figure 4 A, B, C). The K-wires that were inserted into the talus and calcaneus were used as reference markers for indirect measurements of the subtalar joint angle changes as demonstrated on the AP radiograph (Figure 4 D, E, F). The talocalcaneal tilt was calculated using a 25-degree Brodén view measuring the angulated difference created by lines drawn along the cortical surfaces of the talus and calcaneus (Figure 4 G, H, I). The data was analyzed to calculate the mean angle change from neutral alignment to forced inversion and eversion with respect to TT, STJT, and TCT. Pre-excision radiographs were analyzed versus 5-cm^3 fragment excision and 10-cm^3 fragment excision of the lateral talar process.

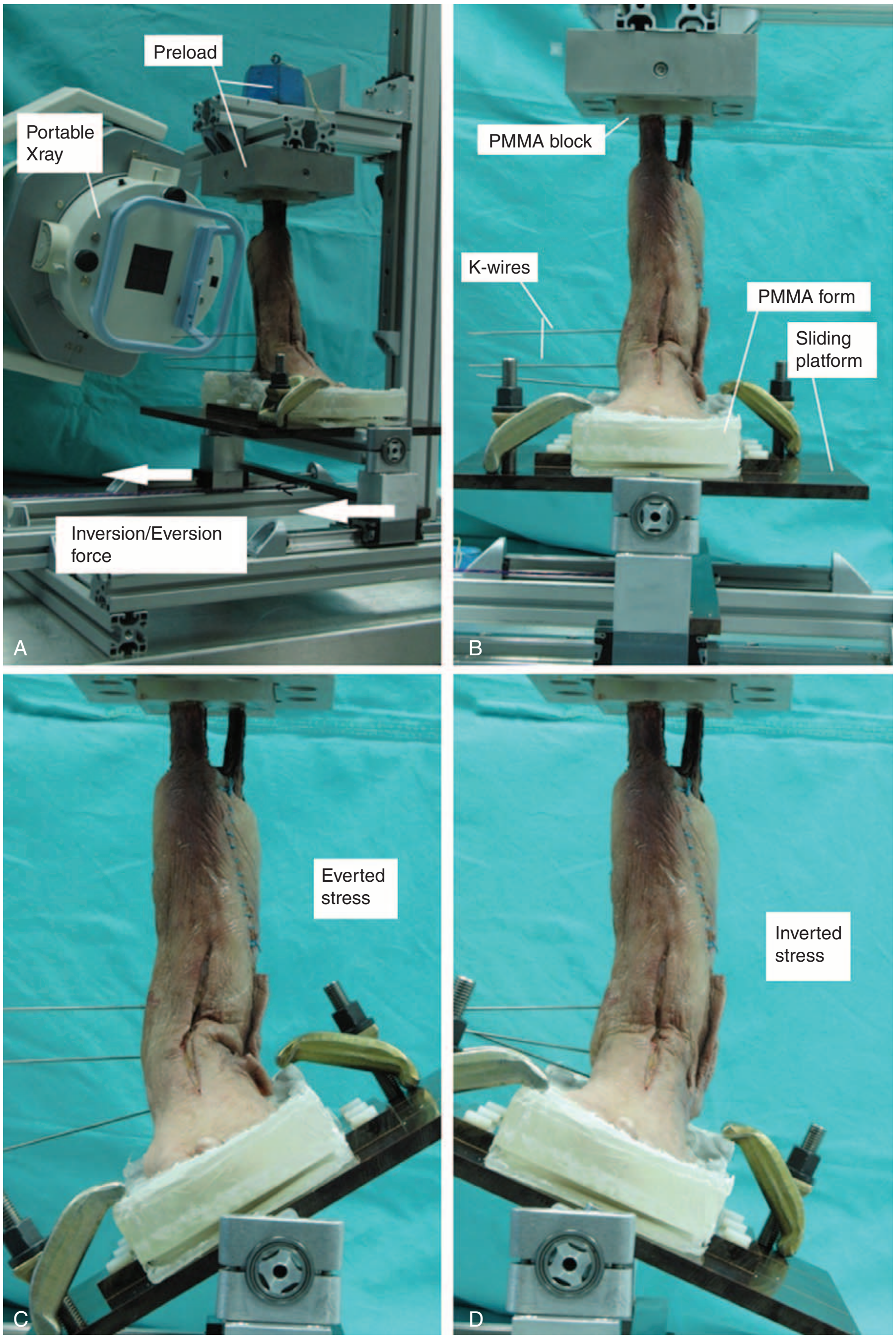

FIGURE 1. (A) (top-left): fresh-frozen cadaver specimen placed in the seesaw test rig setup. The configuration allows for full radiographic assesment with inversion and eversion forces to the specimen. (B) (top-right): specimen is fixed proximally with PMMA block, and plantarly in its PMMA form to the sliding pivoting platform. K-wires are shown in the tibia, talus, and calcaneus, which serve as radiographic markers for biomechanical anaysis. (C) (bottom-left) and (D) (bottom-right): specimen in seesaw test rig with everted and inverted stress load of 10 kg with hanging weights. PMMA = polymethylmethacrylate.

Statistical analysis was done using SPSS statistical software (IBM SPSS, Chicago, IL, USA). After having analyzed all parameters of interest for normal distribution applying the Shapiro-Wilk test, we used Paired-sample *t* tests to compare pre-excision values to 5-cm^3 excision and 10-cm^3 excision values. *P* values were adjusted according to the Bonferroni correction. Level of significance was set to $P = .05$ for all statistical tests.

RESULTS

One specimen was excluded from the study due to fracture of the distal fibula during forced inversion. The remaining 6 specimens were used for statistical analysis. All parameters of interest were normally distributed. Table 1 illustrates the mean ± standard deviation angle changes from neutral hindfoot to forced inversion with 10-kg load in the pre-excision (control),

FIGURE 2. Test setup showing a specimen placed in the custom seesaw rig for ankle joint pressure and force measurements. Pressure sensors were inserted into the ankle joint in an anterior to posterior direction, being fixed with thumbtacks. Static axial compression was increased from a fixed 2-kg preload to 30 kg, according to half body weight.

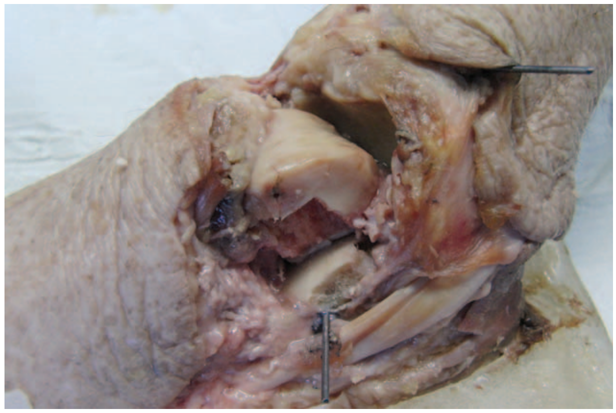

FIGURE 3. Lateral process of the talus after excision of a 5-cm^3 fragment, using a modified Ollier approach. Three cuts were made relative to the apex of the lateral talar process and subtalar joint.

5-cm^3 excision (post1), and 10-cm^3 excision (post2) phases. Average TT angle increased from 2.32 ± 1.40 (control) to 3.22 ± 1.90 degree (post1) and 5.30 ± 2.04 degree (post2). Evaluation of STJT revealed an average angle of 10.88 ± 3.41 degree for the control group, 11.85 ± 4.26 degree in post1 and 11.43 ± 6.90 degree in post2. A continuous increase of the average TCT angle was observed between the excision states with an initial angle of 1.65 ± 1.18 degree (control), further increasing to 2.50 ± 1.64 degree (post1) and finally reaching 4.10 ± 2.45 degree (post2).

Table 2 illustrates the angle changes from neutral hindfoot to forced eversion with 10-kg load in the pre-excision, 5-cm^3 excision, and 10-cm^3 excision phases. A drop in the average TT angle from 0.92 ± 0.64 (control) to 0.77 ± 1.31 degree (post1) was observed while remaining at the same level in the post2 phase with 0.77 ± 0.46 degree. Furthermore, the average STJT angle ascended steadily from 3.33 ± 3.88 (control) to 3.72 ± 4.37 degree (post1) and reached finally 3.80 ± 2.84 degree in post2. However, the average TCT angle dropped initially from 0.58 ± 0.53 (control) to 0.52 ± 0.55 degree (post1) and then leveled up again to 0.58 ± 0.33 degree in post2.

Table 3 illustrates the peak force, center of force movement, contact area, and contact area pressure of the tibiotalar joint after a 30-kg axial load application. Peak force declined from 3.92 ± 0.29 (control) to 3.66 ± 0.23 N (post1), but overreached the initial level after post2 revealing 4.16 ± 0.45 N. Thereby, center of force movement inclined steadily from 2.24 ± 0.50 (control) to 2.38 ± 1.21 mm (post1), measuring ultimately 3.32 ± 0.96 mm (post2). The contact area initially rose from 347.67 ± 80.63 (control) to 417.67 ± 112.32 mm^2 (post1), and settled down to 404.50 ± 111.09 mm^2 (post2). Similarly, the contact area pressure revealed initially 4.37 ± 0.82 bar (control), which increased to 4.85 ± 0.77 bar in post1 and finally dropped to 4.74 ± 0.89 bar in post2.

With respect to forced inversion, the only statistical significance was seen in TT angle change from neutral hindfoot alignment to forced inversion between pre-excision and 10-cm^3 excision ($P = .04$, Table 1). No statistical significance was observed following the 5-cm^3 excision as compared with control group. There were no significant differences in the STJT angle changes from neutral hindfoot alignment to forced inversion in both 5-cm^3 and 10-cm^3 excisions in comparison with control group. A trend was observed in the TCT angle changes when inversion was forced between control and post1 ($P = .08$), respectively between control and post2 ($P = .09$). In view of forced eversion, there were no significant differences in the TT, STJT, and TCT angle changes in both 5-cm^3 and 10-cm^3 excisions as compared with pre-excision (Table 2).

Referring to the ankle joint pressure and force measurements, there was no significant difference in each of the analyzed parameters: peak force, center of force movement, contact area and contact area pressure in both 5 and 10-cm^3 excisions as compared with control group (Table 3).

DISCUSSION

Our biomechanical study demonstrates that excision of large 5 and 10-cm^3 fragments of the lateral process of the talus does not produce significant instability in the subtalar joint. With respect to the ankle joint, a 10-cm^3 fragment excision alone did produce a statistically significant tibiotalar tilt in inversion ($P = .04$) in comparison with the pre-excision phase.

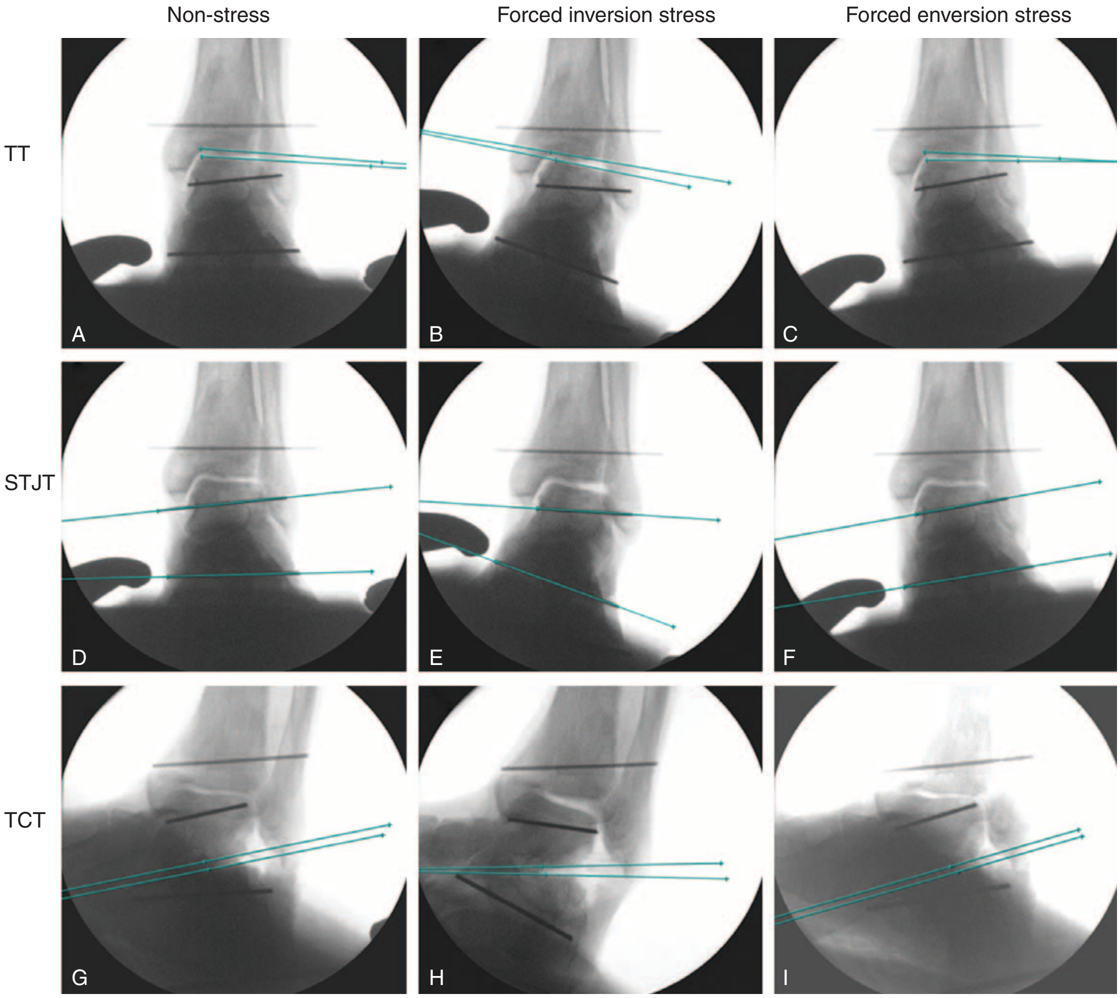

FIGURE 4. Radiographic demonstration of radiological evaluations. Measurements were taken of the angle between lines drawn through cortical surfaces or K-wire markers. (A) Non-stress (neutral hindfoot alignment) AP view showing measurement lines of TT; (B) inversion stress AP view showing measurement lines of TT with 10-kg load; (C) eversion stress AP view showing measurement lines of TT with 10-kg load; (D) non-stress AP view showing measurement lines of STJT; (E) inversion stress AP view showing measurement lines of STJT with 10-kg load; (F) eversion stress AP view showing measurement lines of STJT with 10-kg load. (G) non-stress Brodén view showing measurement lines of TCT; (H) inversion stress Bróden view showing measurement lines of TCT with 10-kg load; (I) eversion stress Brodén view showing measurement lines of TCT with 10-kg load. AP = anteroposterior, STJT = subtalar joint tilt, TCT = talocalcaneal tilt, TT = tibiotalar tilt.

Regarding the compression forces at the ankle joint level, following the excision, no significant changes in peak force, center of force movement, contact area, and contact area pressure were observed in comparison with the pre-excision phase.

Similar results have been shown supporting subtalar stability for smaller 1-cm^3 fragments in previous studies,[6,10] as they demonstrated that instability did not occur until 100% of the footprint of the lateral talocalcaneal ligament (LTCL) origin and approximately 15% of the anterior talofibular ligament (ATFL) and posterior talofibular ligament (PTFL) footprints were reduced. As the LTCL is the only of these ligaments to cross the subtalar joint, it can be expected that additional resection of the ATFL and the PTFL would not result in any further subtalar instability, given that the interosseous ligament remains intact. Based on several anatomical and also biomechanical studies, it has been shown that the talocalcaneal interosseous ligament is the greatest contributor to subtalar joint instability.[11–14]

By resecting a large fragment of the lateral process, the interosseous ligament is not weakened. Clinically, only a resection of a larger fragment in case of an additional subtalar dislocation would lead to subtalar instability. Not a single report in the literature has described ever the combination of a subtalar joint dislocation together with an isolated fracture of the lateral process of the talus.[4,5,15,16] Another reason that the subtalar joint remained stable is the fact that the calcaneofibular ligament remained intact. It has been previously shown that this ligament contributes significantly to the stability of the subtalar joint.[17,18]

The stability was not maintained when evaluating the ankle joint; we measured a significant increase in the tibiotalar angle during inversion stress when resecting 10 cm^3 but not 5 cm^3. By increasing the resection area, more soft tissue resection was required. Several studies have identified the ATFL as the most stabilizing ligament with the foot in neutral position.[19–21] It can be inferred that if the ATFL and the PTFL are removed as part of the fracture and the ankle joint becomes unstable under an

TABLE 1. Angle changes in terms of mean value ± standard deviation, representing the tibiotalar tilt, subtalar joint tilt and talocalcaneal joint tilt of 6 specimens from neutral hindfoot alignment to forced inversion with 10-kg load in pre-excision, 5 cm^3 excision and 10^3 cm excision phases

	Pre-excision	5-cm^3 Excision	10-cm^3 Excision
TT (degree)	2.32 ± 1.40	3.22 ± 1.90 $P = .18$	*5.30 ± 2.04 $P = .04$
STJT (degree)	10.88 ± 3.41	11.85 ± 4.26 $P = .29$	11.43 ± 6.90 $P = .78$
TCT (degree)	1.65 ± 1.18	2.50 ± 1.64 $P = .08$	4.10 ± 2.45 $P = .09$

P values are displayed as compared with the pre-excision phase. STJT = subtalar joint tilt, TCT = talocalcaneal tilt, TT = tibiotalar tilt.
* Statistically significant.

TABLE 2. Angle changes in terms of mean value ± standard deviation, representing the tibiotalar tilt, subtalar joint tilt and talocalcaneal joint tilt of 6 specimens from neutral hindfoot alignment to forced eversion with 10-kg load in pre-excision, 5-cm^3 excision and 10^3-cm excision phases

	Pre-excision	5-cm^3 Excision	10-cm^3 Excision
TT (degree)	0.92 ± 0.64	0.77 ± 1.31 $P = .85$	0.77 ± 0.46 $P = .63$
STJT (degree)	3.33 ± 3.88	3.72 ± 4.37 $P = .62$	3.80 ± 2.84 $P = .66$
TCT (degree)	0.58 ± 0.53	0.52 ± 0.55 $P = .85$	0.58 ± 0.33 $P = .99$

P values are displayed as compared with the pre-excision phase. STJT = subtalar joint tilt, TCT = talocalcanealtilt, TT = tibiotalar tilt.

inversion stress, these ligaments must also have an varus stabilizing effect. We believe that the remaining stability under valgus stress at the level of the ankle joint can be explained by the fact that the integrity of the talar dome is not compromised during resection of the lateral talar process fragment, and the medial deltoid ligamentous complex is substantial.

We chose to excise 5 and 10 cm^3 to test the largest possible fragment that one could take without causing a talar body fracture extending into the talar dome. In a clinical setting in which one has a large comminuted fracture with the lateral process of the talus, we propose that excision with careful soft tissue dissection would not lead to ankle or subtalar instability and moreover, that forces acting on the ankle would not significantly be changed. We are unable to comment on the forces seen at the subtalar joint with this study design, and a large lateral talar process excision may contribute to joint pressure change, which could predispose to subtalar arthorsis. Of course, in the clinical setting, large fragment excision in the lower extremity needs more clinically relevant studies before application in common practice.

TABLE 3. Peak force, center of force movement, contact area and contact area pressure in terms of mean value ± standard deviation, as defined from the pressure measurements in the ankle joint of 6 specimens under axial load in pre-excision, 5-cm^3 and 10^3-cm excision phases

	Pre-excision	5-cm^3 Excision	10-cm^3 Excision
Peak force, N	3.92 ± 0.29	3.66 ± 0.23 $P = .22$	4.16 ± 0.45 $P = .41$
CFM, mm	2.24 ± 0.50	2.38 ± 1.21 $P = .82$	3.32 ± 0.96 $P = .08$
Contact area, mm^2	347.67 ± 80.63	417.67 ± 112.32 $P = .62$	404.50 ± 111.09 $P = .74$
Contact area pressure, bar	4.37 ± 0.82	4.85 ± 0.77 $P = .33$	4.74 ± 0.89 $P = .24$

P values are displayed as compared with the pre-excision phase. CFM = center of force movement.

One major limitation of the current study is that we could not measure the forces in the subtalar joint. This is mainly due to the fact that extensive medial dissection would have to be performed to insert the sensor, which would likely lead to ankle and subtalar instability. However, it could be extrapolated that, due to the axial configuration of the tibia, talus, calcaneus, and ground reaction force, pressure stability in the ankle joint implies subtalar joint stability as well. If there was subtalar joint instability, it might have led to ankle instability. Contributing to this deduction is the fact that our test setup with the PMMA foot form locks the forefoot to the hindfoot only allowing ankle and subtalar joint motion.

The current study has other limitations. We approached the subtalar joint through a modified Ollier approach. It could have potentially happened that the approach has compromised surrounding tissue stabilizing both the ankle and subtalar joint. An anterior drawer pre-test with resected lateral talar process, independent of the size of the fragment, resulted in a complete anterior dislocation of the ankle joint at 10-kg load because the majority of the stabilizing fibers of the talus against an anterior shift (ATFL and LCTL) were dissected together with the resected fragment. During the complete dislocation, the remaining intact fibers of the ATFL and LTCL were completely ruptured and we were not able to use these specimens for any further tests. We therefore elected to discontinue the anterior drawer test.

Measuring angles on stress radiographs to investigate ankle and subtalar instability is a well known method.[11,12,19,22–24] However, ankle and subtalar motion is a complex 3-dimensional process and taking a stress radiograph in a single plane under a uniform stress might be insufficient. Finally, we strongly acknowledge that our ex-vivo investigations were with limitations inherent to all cadaveric studies, with limited number of fresh-frozen human cadaveric lower legs and variability between the specimens that cannot truly mimic the in-vivo situation. The cadaveric limbs were embedded at the level of the mid tibia and tendon actuators were not incorporated in the study design. This would impact the dynamic stabilizers of the ankle and hindfoot. We attempted to account for any affect this might have had by performing the intact measurements after the specimens had been embedded, to mimic the study conditions.

CONCLUSION

We were able to show that an excision of up to 10 cm^3 of the lateral talar process does not cause a significant instability at the level of the subtalar joint but might be a destabilizing factor at the ankle joint under inversion stress. The latter could be related to extensive soft tissue dissection required for resection. Further studies are required to determine the optimal treatment of ligament reconstruction and/or refixation of the detached ligaments following resection of a large lateral talar process fragment and its implication on late ankle osteoarthritis.

REFERENCES

1. Kirkpatrick DP, Hunter RE, Janes PC, et al. The snowboarder's foot and ankle. *Am J Sports Med.* 1998;26:271–277.
2. Nicholas R, Hadley J, Paul C, et al. Snowboarder's fracture'': fracture of the lateral process of the talus. *J Am Board Fam Pract.* 1994;7:130–133.
3. Dimon JH 3rd. Isolated displaced fracture of the posterior facet of the talus. *J Bone Joint Surg.* 1961;43:275–281.
4. Hawkins LG. Fracture of the lateral process of the talus. *J Bone Joint Surg.* 1965;47:1170–1175.
5. Mukherjee SK, Pringle RM, Baxter AD. Fracture of the lateral process of the talus. A report of thirteen cases. *J Bone Joint SurgV 56.* 1974:263–273.
6. Langer P, Nickisch F, Spenciner D, et al. In vitro evaluation of the effect lateral process talar excision on ankle and subtalar joint stability. *Foot Ankle Int.* 2007;28:78–83.
7. Heckman JD, McLean MR. Fractures of the lateral process of the talus. *Clin Orthop Relat Res.* 1985;199:108–113.
8. Langer P, Nickisch F, Spenciner D, et al. Effect of simulated lateral process talus ''fracture excision'' on its ligamentous attachments. *Am J Orthop (Belle Mead, N J).* 2009;38:222–226.
9. Krause F, Blatter S, Waehnert D, et al. Hindfoot joint pressure in supination sprains. *Am J Sports MedV 40.* 2012:902–908.
10. DiGiovanni CW, Langer PR, Nickisch F, et al. Proximity of the lateral talar process to the lateral stabilizing ligaments of the ankle and subtalar joint. *Foot Ankle Int.* 2007;28:175–180.
11. Heilman AE, Braly WG, Bishop JO, et al. An anatomic study of subtalar instability. *Foot Ankle.* 1990;10:224–228.
12. Kato T. The diagnosis and treatment of instability of the subtalar joint. *J Bone Joint Surg.* 1995;77:400–406.
13. Kjaersgaard-Andersen P, Wethelund JO, Helmig P, et al. The stabilizing effect of the ligamentous structures in the sinus and canalis tarsi on movements in the hindfoot. An experimental study. *Am J Sports Med.* 1988;16:512–516.
14. Pisani G. Chronic laxity of the subtalar joint. *Orthopedics.* 1996;19:431–437.
15. Cimmino CV. Fracture of the lateral process of the talus. *Am J Roentgenol Radium Ther Nucl Med.* 1963;90:1277–1280.
16. Fjeldborg O. Fracture of the lateral process of the talus. Supination-dorsal flexion fracture. *Acta Orthopaedica Scandinavica.* 1968;39:407–412.
17. Ringleb SI, Dhakal A, Anderson CD, et al. Effects of lateral ligament sectioning on the stability of the ankle and subtalar joint. *J Orthop Res.* 2011;29:1459–1464.
18. Weindel S, Schmidt R, Rammelt S, et al. Subtalar instability: a biomechanical cadaver study. *Arch Orthop Trauma Sur.* 2010;130:313–319.
19. Clanton TO. Instability of the subtalar joint. *Orthop Clin North Am.* 1989;20:583–592.
20. Kerkhoffs GM, Blankevoort L, van Dijk CN. A measurement device for anterior laxity of the ankle joint complex. *Clinical Biomech (Bristol, Avon).* 2005;20:218–222.
21. Ringleb SI, Udupa JK, Siegler S, et al. The effect of ankle ligament damage and surgical reconstructions on the mechanics of the ankle and subtalar joints revealed by three-dimensional stress MRI. *J Orthop Res.* 2005;23:743–749.
22. Cass JR, Settles H. Ankle instability: in vitro kinematics in response to axial load. *Foot Ankle Int.* 1994;15:134–140.
23. Hertel J, Denegar CR, Monroe MM, et al. Talocrural and subtalar joint instability after lateral ankle sprain. *Med Sci Sports Exerc.* 1999;31:1501–1508.
24. Laurin CA, Ouellet R, St-Jacques R. Talar and subtalar tilt: an experimental investigation. *Can J Surg.* 1968;11:270–279.