Clinical Research on Foot & Ankle
ISSN: 2329-910X

Yousri et al., Clin Res Foot Ankle 2017, 5:2
DOI: 10.4172/2329-910X.1000242

Research Article | OMICS International

The Effect of Alterations of Calcaneal Height on the Ankle and Chopart's Joint: A Cadaveric Study

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Abstract

Fracture of the calcaneum is common, and the majority are displaced intra-articular fracture patterns. Over the last three decades there have been considerable advances in the management of this injury. Open reduction and internal fixation is an accepted treatment for displaced fractures, and percutaneous techniques are now emerging. However, surgical treatment remains controversial, and many fractures are still managed conservatively.

Non-operative management of displaced fractures may result in a disabling fracture malunion. The malunion is often a widened and depressed calcaneum, with subtalar joint disruption. This creates a five time risk of requiring a subtalar arthrodesis within 5 years of injury. Affected patients are frequently men of working age, with potentially significant socioeconomic consequences. Bone Block Distraction Arthrodesis (BBDA) is a technique used for the management of calcaneal malunion. In BBDA, restoration of the talocalcaneal height has been described for reconstitution of the talocalcaneal relationship. By restoring the talo calcaneal height, anterior tibio-talar impingement is relieved and ankle dorsiflexion range improved.

In our clinical experience we have also noted a rotational change in the talus with loss of calcaneal height. We hypothesised that depression of the calcaneal articular surface causes extension of the talus in the sagittal plane, causing anterior tibiotalar impingement, but additionally, incongruity of the talonavicular joint. This hypothesis is important in surgical correction, because classical BBDA may need to be modified to include reversal of the abnormal talar rotation to restore Chopart's joint alignment. Appropriate restoration of the subtalar joint surface and talonavicular joint anatomy is likely to reduce the need for arthrodesis, and improve function.

This cadaveric study is a proof of concept aiming to demonstrate changes in talar inclination and talo-navicular joint alignment following loss of calcaneum height, as is the case in calcaneum malunion, and then following restoration of the calcaneal height as in BBDA.

Keywords: Calcaneum; Fracture; Chopart; Cadaveric

Introduction

Fracture of the calcaneum is common, accounting for 60% of tarsal fractures and 2% of all fractures [1]. The majority are displaced intra-articular fracture patterns. Over the last three decades there have been considerable advances in the management of this injury. Open reduction and internal fixation has become an accepted treatment [2-6] with a good functional outcome [7,8]. Percutaneous techniques are also emerging. However, treatment remains controversial, and many fractures are still managed conservatively [9-13].

Non-operative management of displaced fractures may result in a disabling fracture malunion. Affected patients are frequently men of working age, with potentially significant socioeconomic consequences. Buckley's RCT demonstrated a 5.5X risk of requiring a subtalar arthrodesis following non-operatively managed types II and III calcaneal fractures in patients followed up for 3 years [14]. Car et al. described Bone Block Distraction Arthrodesis (BBDA) for the management of calcaneal malunion. In BBDA, restoration of the talocalcaneal height has been described for reconstitution of the talocalcaneal relationship. By restoring the talocalcaneal height, anterior tibio-talar impingement is relieved and ankle dorsiflexion range improved [15].

In our clinical experience we have also noted a rotational change in the talus with loss of calcaneal height. We hypothesis that depression of the calcaneal articular surface causes extension of the talus in the sagittal plane, and not only do we get anterior tibio-talar impingement, but additionally, incongruity of the talonavicular joint.

This hypothesis is important in that surgical correction undertaken during classical BBDA may need to be modified to include reversal of the abnormal rotation of the talus to restore Chopart's joint alignment.

This cadaveric study is a proof of concept aiming to demonstrate changes in talar inclination and talo-navicular joint alignment following loss of calcaneum height, as is the case in calcaneum malunion, and then following restoration of the calcaneal height as in BBDA.

Methodology

Ethical approval for this cadaveric study was granted from the local research and ethics committee. Four pairs of previously fresh frozen cadaveric adult lower limbs were thawed at room temperature. No gross pathology of the specimens was observed. All of the lower limbs were amputated at the level of the tibial diaphysis. An extended lateral approach was performed on all specimens [16]. The dissected fasciocutaneous flap was then removed to expose the calcaneum. All tendons were preserved during dissection. The peroneal tendons were released from their sheath and mobilised anteriorly to allow

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Received July 05, 2017; **Accepted** July 25, 2017; **Published** July 31, 2017

Citation: Yousri T, Wright SE, Atkins R (2017) The Effect of Alterations of Calcaneal Height on the Ankle and Chopart's Joint: A Cadaveric Study. Clin Res Foot Ankle 5: 242. doi: 10.4172/2329-910X.1000242

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visualisation of the sulcus calcanei. To keep the bone blocks consistent across all specimens, reproducible anatomical landmarks were used to guide the osteotomies. A line was drawn from the sulcus calcanei to the lateral process (Line a, Figure 1). Another line was drawn 1 cm anterior and parallel to this line to mark the anterior limit of the osteotomies (Line b, Figure 1). The osteotomies were then made at 5 mm intervals parallel to the sole of the foot. The posterior limit of the osteotomies was the anterior edge of the achilles tendon. Uni-cortical osteotomies were made using a power a saw, preserving the medial cortex of the calcaneum (Figure 2). The osteotomies were completed after mounting the legs on the frame. To allow axial load through the ankle and hind foot each specimen was mounted on a frame. This consisted of a 2 ring Taylor Spatial Frame (TSF) connected together by 2 struts posteriorly and 2 threaded rods anteriorly. 3 half pins in the tibia were used to fix each specimen proximally. Inferiorly, a half ring was applied underneath the heel to provide a counter force. A 4th half pin was inserted into the 1st and second metatarsal to fix and control the forefoot in the frame (Figure 3).

Radiographic assessment

Before removing the bone blocks from the calcaneum a lateral radiograph of the foot was taken. The most proximal block was then taken from the calcaneum by completion of the osteotomy. Shortening the struts and the rods was used to carry out axial compression. The compression was stopped when the bone surfaces were visualized to have come into contact. A lateral radiograph was then repeated. Similarly, the second and third osteotomy blocks were taken out and further axial compression was applied. Lateral radiographs were performed at each stage (Figure 4).

The image intensifier was set up for each specimen at a standard distance of 1 meter and a trial lateral radiograph was then taken to ensure visualization of the hind foot. The position of the frame was marked on the table to avoid changes in radiograph projections with repeated images.

To study the effect of over restoration of the calcaneum height, blocks of 2.0 cm and 2.5 cm were positioned in the space created by removing the bone blocks only 1.5 cm in size. This simulated over distraction that could occur during calcaneal height restoration in BBDA. Lateral radiographs were performed after each of the blocks was positioned (Figure 5).

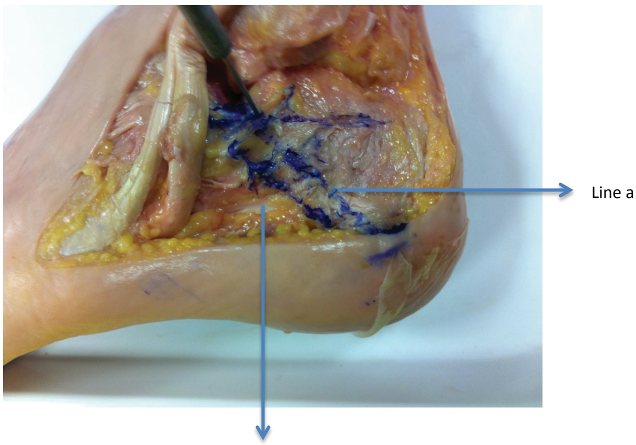

Figure 1: Specimen showing the soft tissue dissection and the lines marked prior to proceeding to osteotomies.

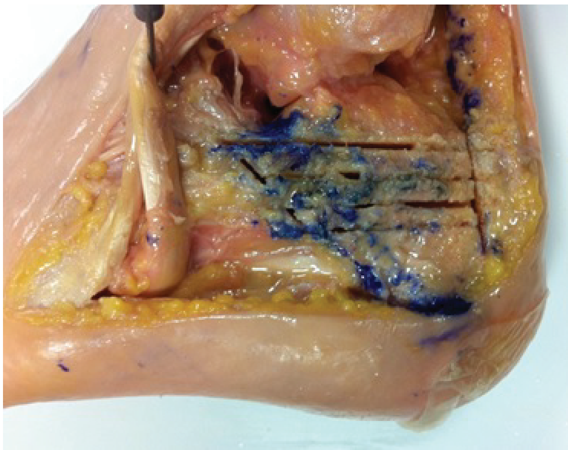

Figure 2: Specimen showing uni-cortical osteotomies prior to mounting on the frame.

Figure 3: Mounting of specimen to TSF.

Figure 4: Lateral radiograph following removal of 1.0cm of bone blocks.

Radiographic measurements

The axis of the talus was defined by a line passing through the anterior-superior corner of the talus bone and tangential to the superior aspect of the posterior process of the talus. The axis of the navicular bone was defined by drawing a line perpendicular to a line tangential to the concavity of the navicular bone. The mechanical axis of the tibia was defined by, drawing a line intersecting the midpoint of two parallel lines perpendicular to the cortex of the tibia (Figure 6).

Wilcoxon signed rank test was used to assess correlation between the angles measured and the compression or distraction applied to the calcaneus. A p value of less than 0.05 was deemed significant.

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Figure 7 shoes an example of the planned osteotomies (top left), bone resection with resultant compression (0.5 cm top right, 1.0 cm middle left, 1.5 cm middle right), followed by distraction (0.5 cm bottom left, 1.0 cm bottom right).

Results

8 specimens (S1-S8) were examined. In 4 of the specimens, 3 osteotomies were undertaken as planned. 4 specimens had calcanei of a smaller height, and only 2 osteotomies were performed to maintain integrity of the specimen during testing (S5–S8).

Tables 1-3 show the measurements for tibio-talar, tibionavicular and talonavicular angles. These measurements were from the intact specimens, following 0.5 cm, 1.0 cm or 1.5 cm of compression, followed by 0.5 cm and 1.0 cm of distraction.

Figure 5: Lateral radiograph following 1.0cm of over distraction of the subtalar joint.

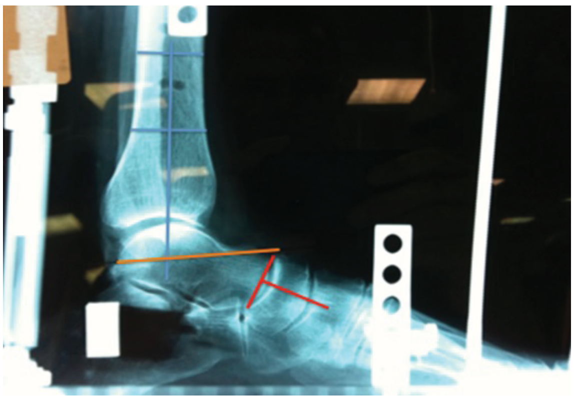


Figure 6: Axis of the tibia, talus and navicular on a lateral radiograph.

Tibio-talar angle

Results show that loss of calcaneal height (compression) was associated with a progressive decrease in the tibio-talar angle, whereby the talus extends in the sagittal plane with calcaneal collapse. Statistical analysis (Wilcoxon test) showed a statistically significant change in the axis of the talus to that of the tibia (P value: 0.012) with loss of calcaneum height.

As expected, following addition of the distraction blocks, a statistically significant change was noticed in the axis of the talus to that of the tibia with over correction of the calcaneum height, with progressive flexion of the talus with restoration of the calcaneum height, and an increase beyond the normal tibio-talar angle for that specimen with over distraction (P value: 0.018).

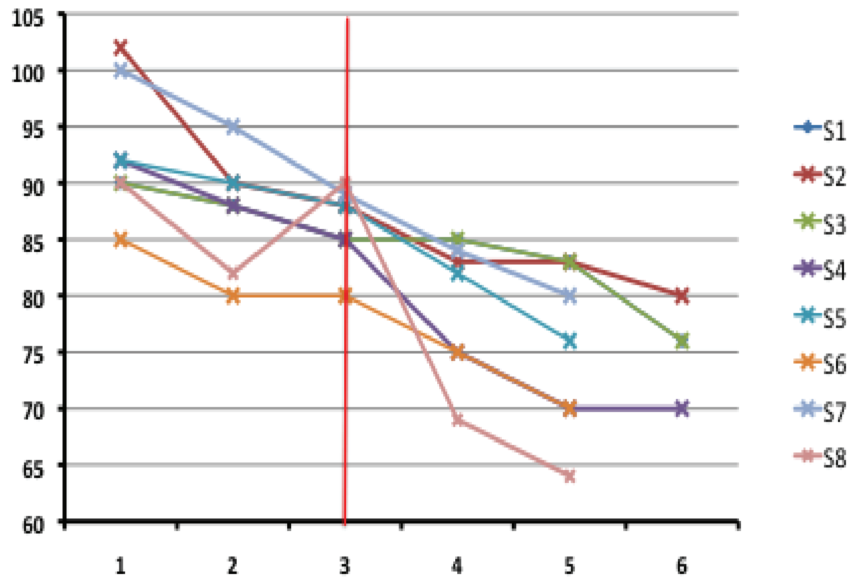
Tibio-navicular angle

A similar decrease in the angle between the axis of the navicular and

Figure 7: An example of the planned osteotomies (top left), bone resection with resultant compression (0.5cm top right, 1.0cm middle left, 1.5cm middle right), followed by distraction (0.5cm bottom left, 1.0cm bottom right).

	(1) Tibio-talar Angle +10 mm distraction	(2) Tibio-talar Angle +5 mm distraction	(3) Tibio-talar Angle Normal	(4) Tibio-talar Angle -5 mm compression	(5) Tibio-talar Angle -10 mm compression	(6) Tibio-talar Angle -15 mm compression
S1	85	77	75	70	68	65
S2	102	90	88	83	83	80
S3	90	88	85	85	83	76
S4	92	88	85	75	70	70
S5	92	90	88	82	76	-
S6	85	80	80	75	70	-
S7	100	95	89	84	80	-
S8	90	82	90	69	64	-

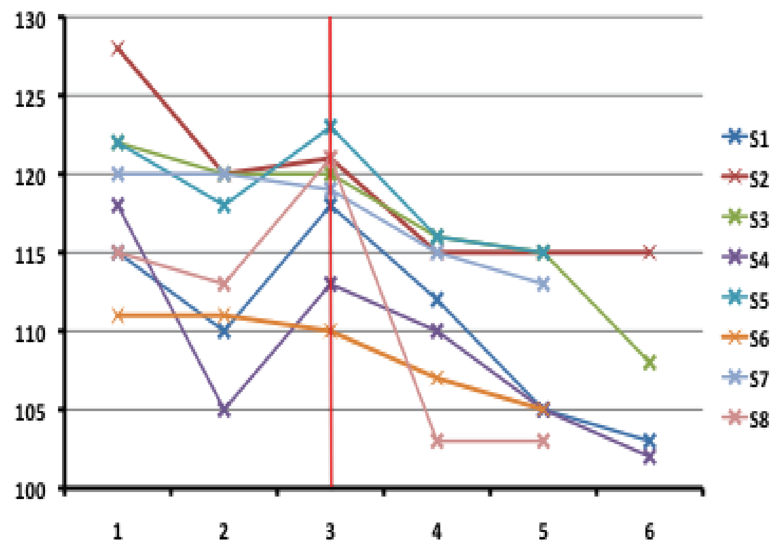
Table 1: Tibio-talar angles following compression and distraction of the calcaneum.



Graph 1: Graphical representation of Table 1. Tibio-talar angles in degrees (Y axis) versus distraction and compression column (X axis). 1=1.0cm distraction. 2=0.5mm distraction. 3=Normal specimen. 4=0.5cm of compression. 5=1.0cm of compression. 6=1.5cm of compression. Specimens labelled S1–S8.

	1) Tibionavicular Angle +10 mm distraction	2) Tibionavicular Angle +5 mm distraction	3) Tibionavicular Angle Normal	4) Tibionavicular Angle -5 mm compression	5) Tibionavicular Angle -10 mm compression	6) Tibionavicular Angle -15 mm compression
S1	115	110	118	112	105	103
S2	128	120	121	115	115	115
S3	122	120	120	116	115	108
S4	118	105	113	110	105	102
S5	122	118	123	116	115	-
S6	111	111	110	107	105	-
S7	120	120	119	115	113	-
S8	115	113	121	103	103	-

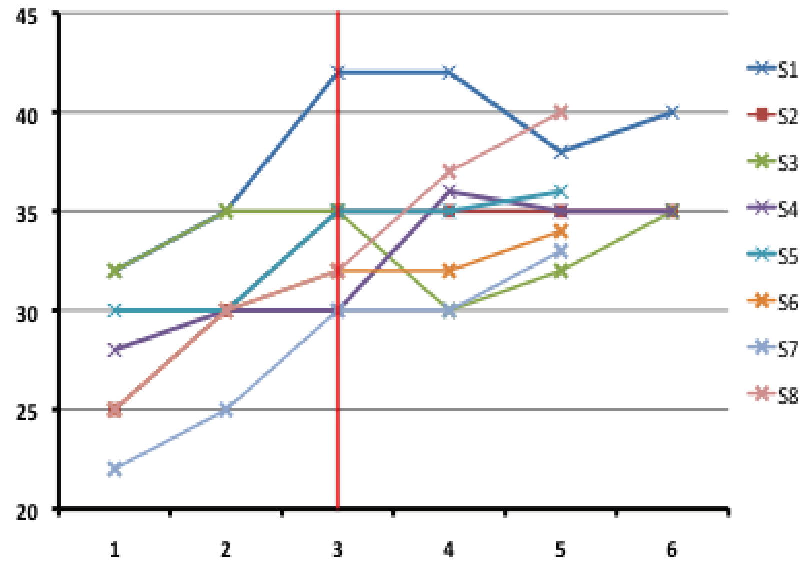
Table 2: Tibio-navicular angles following compression and distraction of the calcaneum.



Graph 2: Graphical representation of Table 2. Tibio-navicular angles in degrees (Y axis) versus distraction and compression column (X axis). 1=1.0cm distraction. 2=0.5mm distraction. 3=Normal specimen. 4=0.5cm of compression. 5=1.0cm of compression. 6=1.5cm of compression. Specimens labelled S1–S8.

	Talonavicular Angle +10 mm distraction	Talonavicular Angle +5 mm distraction	Talonavicular Angle Normal	Talonavicular Angle -5 mm compression	Talonavicular Angle -10 mm compression	Talonavicular Angle -15 mm compression
S1	32	35	42	42	38	40
S2	25	30	35	35	35	35
S3	32	35	35	30	32	35
S4	28	30	30	36	35	35
S5	30	30	35	35	36	-
S6	25	30	32	32	34	-
S7	22	25	30	30	33	-
S8	25	30	32	37	40	-

Table 3: Talonavicular angles following compression and distraction of the calcaneum.



Graph 3: Graphical representation of Table 3. Talo-navicular angles in degrees (Y axis) versus distraction and compression column (X axis). 1 = 1.0cm distraction. 2 = 0.5mm distraction. 3 = normal specimen. 4 = 0.5cm of compression. 5 = 1.0cm of compression. 6 = 1.5cm of compression. Specimens labelled S1 – S8.

tibia was shown with loss of calcaneal height (compression). Statistical analysis (Wilcoxon test) showed a statistically significant change in the axis of the navicular to that of the tibia (P value=0.012) with calcaneal collapse.

Following distraction, no significant change was noted in the tibio-navicular axis. No specimens demonstrated return to pre-osteotomy value, 3 remained under corrected, and 5 became over corrected (P value=0.574).

Talo-navicular angle

The talo-navicular angle increased with loss of calcaneal height. Distraction was powerful at reducing the angle, and reduced it beyond normal for each specimen. The values observed were not statistically significant within this parameter despite the trend seen.

Discussion

This study demonstrates that with calcaneal collapse there is a significant change in the axis of the talus relative to the tibia, whereby the talus extends in the sagittal plane as it falls into the collapsed posterior calcaneal facet. Despite this the talus largely maintains its relationship with the navicular as this also extends relative to the anatomical tibial axis. With distraction, however, this relationship seems to be lost slightly with the talus flexing relative to the navicular.

Zwipp et al radio-graphically assessed the lateral talocalcaneal angle, talar declination angle and talus first metatarsal angle before and after subtalar BBDA in 31 patients with malunited calcaneum fractures and showed significant restoration of these angles towards normality with restoration of the calcaneal height [8]. Singh & Vinay evaluated over 300 patients with calcaneal fractures fixed with a plate, and compared those who were grafted, and those who weren't [17]. Those grafted had better restoration of Bohler's angle both immediately and after 2 years, and were able to bear weight earlier. Su et al showed that post-operative Bohler's angle significantly correlates with improved functional scores [18].

We were expecting to see a more dramatic change in the talo-navicular axis with calcaneal depression. It maybe that the changes we see in clinical practice are the result of chronic altered forces across the Chopart joints as a result of weight bearing with a collapsed calcaneum. It could be that in the acute calcaneal fracture, stabilising ligaments are disrupted, or there is involvement of the calcaneo cuboid joint, neither assessed in this study. Additionally, we only assessed the talonavicular joint on a lateral radiograph and therefore may have missed changes in their relationship in the coronal and axial planes. This is a cadaveric study and functional outcome implications cannot be made. Clinical papers are undecided whether a subtalar or triple fusion is the best salvage procedure following calcaneal fracture.

The concept is supported in our cadaveric model by statistically significant restoration of the talus axis with correction of the calcaneum height. Fixation to treat calcaneal fractures should aim to restore height to maintain anatomical relations of the talus.

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