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 has become 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 talocalcaneal height, anterior tibiotalar 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 calcaneal 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 tibiotalar 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 tibiotalar 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 calcaneal 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...
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).

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.
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 7 shows 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).

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

|   | Tibio-talar Angle | Tibio-talar Angle | Tibio-talar Angle | Tibio-talar Angle | Tibio-talar Angle | Tibio-talar Angle |
|---|------------------|------------------|------------------|------------------|------------------|------------------|
| (1) | +10 mm distraction | +5 mm distraction | Normal           | -5 mm compression | -10 mm compression | -15 mm compression |
| S1  | 85               | 77               | 75               | 70               | 88               | 65               |
| S2  | 102              | 90               | 88               | 83               | 83               | 83               |
| S3  | 90               | 88               | 85               | 85               | 83               | 83               |
| 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.

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

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.
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 tibionavicular 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 talonavicular 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

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

|                | 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                                     | 35                                     |
| S6             | 25                                     | 30                                    | 32                        | 32                                   | 34                                     | -                                      |
| S7             | 22                                     | 25                                    | 30                        | 30                                   | 33                                     | -                                      |
| S8             | 25                                     | 30                                    | 32                        | 37                                   | 40                                     | -                                      |

### 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.
height. Fixation to treat calcaneal fractures should aim to restore height to maintain anatomical relations of the talus.

References

1. Cave EF (1963) Fractures of the os calcis: The problem in general. Clin Orthop Rel Res 30: 64-66.
2. Zwipp H, Rammelt S, Barthel S (2004) Calcaneal fractures-open reduction and internal fixation (ORIF). Injury 35: 46-54.
3. Harvey EJ, Grujic L, Early JS, Benirschke SK, Sangeorzan BJ (2001) Morbidity associated with ORIF of intra-articular calcaneal fractures using a lateral approach. Foot Ankle Int 22: 868-873.
4. Infante AF, Heier K, DiPasquale T, Herscovici D, Wailing A, et al. (2000) Operative treatment of 635 displaced intra-articular calcaneal fractures. Read at the annual meeting of the american academy of orthopaedic surgeons. 15-19.
5. Sanders R (1992) Intra-articular fractures of the calcaneus: Present state of the art. J Orthop Trauma 6: 252-265.
6. Thordarson DB, Krieger LE (1996) Operative versus nonoperative treatment of intraarticular fractures of the calcaneus: A prospective randomized trial. Foot Ankle Int 17: 2-9.
7. Michael PC, William EL, Roy WS (2005) Intermediate to long-term results of a treatment protocol for calcaneal fracture malunions. J Bone Joint Surg Am 87: 963-973.
8. Rammelt S, Grass R, Zawadski T, Biewener A, Zwipp H (2004) Foot function after subtalar distraction bone block arthrodesis: A prospective study. J Bone Joint Surg Br 86: 659-668.
9. Buckley R, Tough S, McCormack R, Pate G, Leighton R, et al. (2002) Operative compared with non-operative treatment of displaced intra-articular calcaneal fractures: A prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 84: 1733-1744.
10. Czisy M, Buckley R, Tough S, Leighton R, Smith J, et al. (2003) Displaced intraarticular calcaneal fractures: Variables predicting late subtalar fusion. J Orthop Trauma. 17: 106-112.
11. Howard JL, Buckley R, McCormack R, Pate G, Leighton R, et al. (2003) Complications following management of displaced intra-articular calcaneal fractures: A prospective randomized trial comparing open reduction internal fixation with nonoperative management. J Orthop Trauma 17: 241-249.
12. Richard B, Suzanne T, McCormack R, Graham P, Ross L, et al. (2002) Operative compared with non operative treatment of displaced intra-articular calcaneal fractures: A prospective randomized controlled multicenter trial. J Bone Joint Surg Am. 84: 1733-1744.
13. Rammelt S, Zwipp H (2004) Calcaneus fractures: Facts, controversies and recent developments. Injury 35: 443-461.
14. Sanders R, Fortin PT, Wailing AK (1991) Subtalar arthrodesis following calcaneal fracture. Orthopa Trauma 5: 245.
15. Carr JB, Hansen ST, Benirschke SK (1988) Subtalar distraction bone block fusion for late complications of os calcis fractures. Foot Ankle 9: 81-86.
16. Freeman BJ, Duff S, Allen PE, Nicholson HD, Atkiss RM (1998) The extended lateral approach to the hind foot. Anatomical basis and surgical implications. J Bone Joint Surg Br 80: 139-142.
17. Singh AK, Vinay K (2013) Surgical treatment of displaced intra-articular calcaneal fractures: Is bone grafting necessary? J Orthop Traumatol 14: 299-305.
18. Su Y, Chen W, Zhang T, Wu X, Wu Z, et al. (2013) Bohtler’s angle role in assessing the injury severity and functional outcome of internal fixation for displaced intra-articular calcaneal fractures: A retrospective study. BMC Surg 3: 40-48.