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Cadaveric Examination of the Radiographic Safe Zone for Open Reduction and Internal Fixation of the Calcaneus Posterior Facet

Jordan Brand, MD[1], Ali Elaydi, MD[1], Jay Moran, BS[1], and Brad Yoo, MD[1]

Abstract

Background: The purpose of this study is to define a safe zone for screw placement on a lateral radiograph of the calcaneus taking into account the lateral to medial convexity of the posterior facet. Such findings may serve to improve surgical quality during open reduction and internal fixation (ORIF) of the posterior facet of the calcaneus.

Methods: Eleven cadaveric calcanei were harvested and the articular margins of the posterior facet were outlined with a radiopaque wire. Lateral radiographs, similar to those used for intraoperative fluoroscopy, of each specimen were obtained and calibrated to a standardized marker. The proximal-to-distal length of the posterior facet was then divided into quadrants. The greatest height difference between the superolateral and inferomedial surfaces outlined by the radiopaque marker were measured in the 2 most posterior quadrants, as screw insertion in this area would be mostly likely to risk screw penetration during ORIF.

Results: The average distance from the osseous surface to the radiographic marker was 3.3 ± 1.2 mm in the most posterior quadrant (fourth quadrant) and 3.2 ± 1.6 mm in the quadrant just anterior to this (third quadrant). The range for unsafe screw placement was 1.7 to 5.6 mm below the osseous surface in the fourth quadrant and 1.1 to 6.6 mm in the third quadrant.

Conclusion: Intraoperative radiographic assessment of the safety of subchondral posterior facet screws does not correlate to its osteology. Because of the superolateral to inferomedial convexity of the posterior facet of the calcaneus, overly long screws may appear to be radiographically intraosseous, though in actuality the screw may be intra-articular. On average, screws placed in the fourth quadrant of the facet are at less risk if 3.3 mm inferior to the upper margin of the osseous shadow on fluoroscopic imaging and 3.2 mm inferior in the third quadrant. Though limited by a small sample size, this study sets a foundation for future research into this complex osteology.

Level of Evidence: Level V, mechanism-based reasoning.

Keywords: calcaneus, safe zone, posterior facet, ORIF, osteology

Introduction

Calcaneus fractures are the most common of all tarsal fractures and are often the result of significant force transmission through the hindfoot.[7,9,10] Operative fixation through a laterally based approach, whether sinus tarsi or extended lateral, permits access to the posterior facet. Secondary to the osteology of the posterior facet and this lateral vantage point, the posteromedial and medial surfaces of the posterior facet are difficult to directly observe.

Given the osteology of the posterior facet, implant inspection under fluoroscopy may not account for the superolateral to inferomedial convexity of calcaneus. Hardware may appear to be entirely intraosseous on lateral imaging while actually penetrating the medial cartilaginous surface. The objective of this study is to outline a safe zone for screw placement based on the lateral radiograph in hopes of minimizing the risk of unintended intra-articular screw placement.

[1]Department of Orthopaedics & Rehabilitation, Yale School of Medicine, New Haven, CT, USA

Corresponding Author:
Brad Yoo, MD, Department of Orthopaedics & Rehabilitation, Yale School of Medicine, 47 College St, New Haven, CT 06520-8055, USA.
Email: Brad.yoo@yale.edu

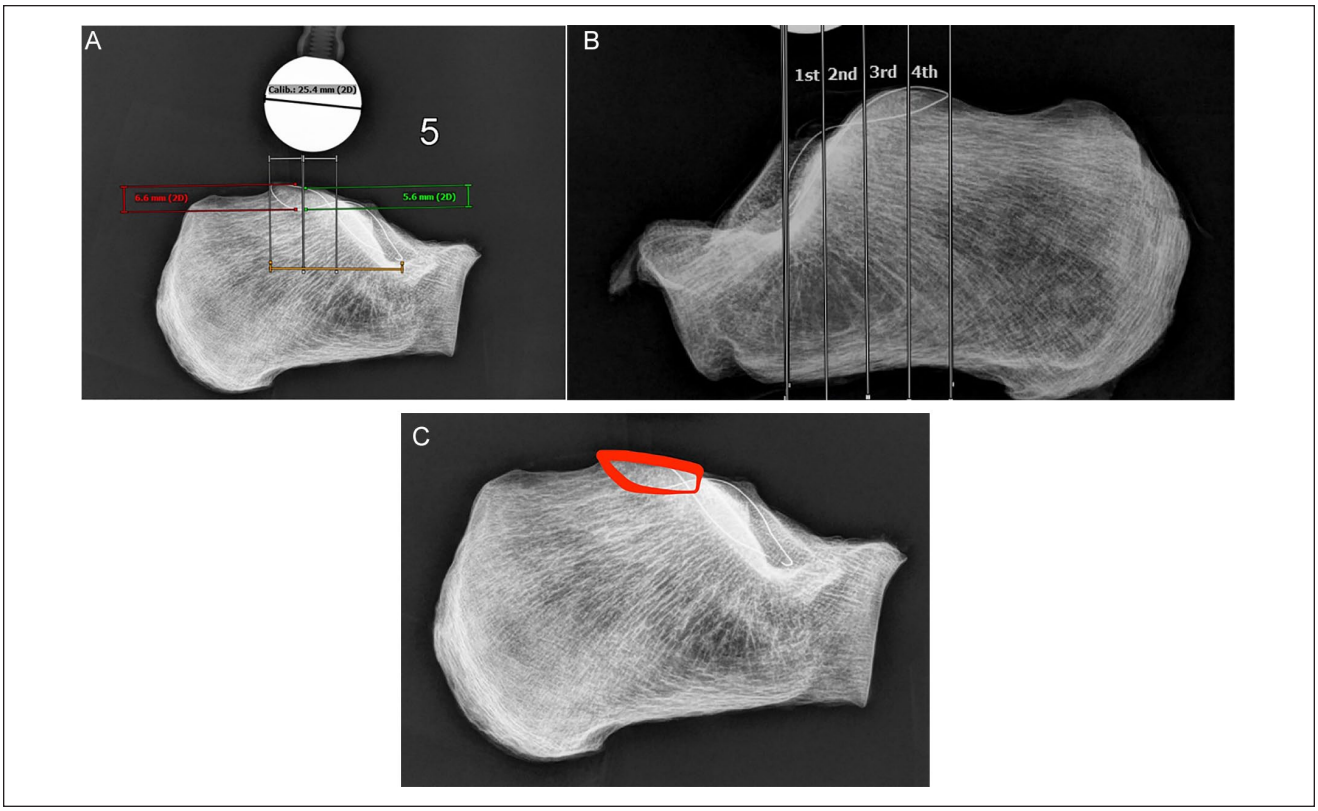

Figure 1. Sample lateral radiographs. (A) The posterior facet is outlined using radiopaque wire. The vertical height of the medial cartilaginous ridge to the lateral cartilaginous ridge in the third and fourth quadrants are annotated with 5.6 and 6.6 mm, respectively, to demonstrate how the authors obtained the measurements. (B) An example of the numbering system and divisions of the first through fourth quadrants are depicted. (C) The articular surface posterior to the inflection point is outlined. Long screws placed in this region are at risk of penetrating the articular surface without being visualized on fluoroscopy.

Methods

Eleven donor cadavers preserved in formaldehyde were provided for the purpose of this study. A single calcaneus was harvested from each donor with all soft tissue attachments removed. The calcanei were allowed to desiccate in an open environment for 1 week at room temperature. A 1-mm-diameter radio-opaque wire was then attached to the posterior facet of each calcaneus around the periphery of the articular surface.

Radiographs of the specimens were then acquired. The specimens were placed on the receiver directly next to a 25.4-mm (1-in.) radiographic marker, which allowed for calibration regardless of object distance from the beam source. The lateral wall of the calcaneus was oriented parallel to the floor and the X-ray beam was directed colinear with the calcaneocuboid joint cartilage, reproducing a lateral radiograph as would be used in the operating room. Examples of these radiographs are noted in Figure 1.

Once radiographs for all eleven calcanei had been acquired, they were calibrated to the 25.4-mm radiographic marker using our institution's imaging software (Visage 7; Visage Imaging, Inc). The proximal-to-distal (PD) length of the posterior facet was measured based on each specimen's individualized calibration. The PD distance was divided into 4 quadrants, numbered 1 to 4. Attention was then turned to the third and fourth quadrants for further calculations, given the inability to visually confirm safe screw placement at the medial aspects of the posterior facet in these locations. Also, these portions of the posterior facet exhibit the most surface convexity, compared with the more anterior quadrants that can be fully visualized and lack such a pronounced convexity.

In each radiograph, there was a measurable distance between the superior margin of the osseous shadow and the radiopaque wire along the medial aspect of the posterior facet. We used the term "height difference" to describe a line perpendicular to the long axis of the calcaneus between the medial aspect of the posterior facet to the upper margin of the osseous shadow. The largest height difference in both the third and fourth quadrant was measured in each specimen. An example of these measurements is illustrated in Figure 1. Once all data were recorded, calculations were performed using Microsoft Excel data analysis Toolpak (Microsoft Excel, version 16.47.1).

Table 1. Demographic Make-up of Cadavers Used for Study.

Specimen	Sex	Age
1	Male	90
2	Male	79
3	Male	64
4	Female	88
5	Male	70
6	Male	89
7	Male	79
8	Female	97
9	Male	74
10	Female	84
11	Male	76

Results

Cadaver demographics are listed in Table 1. The greatest vertical distance from the top of the osseous shadow to the medial articular margin ranged from 1.7 to 5.6 mm in the fourth quadrant and 1.1 to 6.6 mm in the third quadrant. The average distance from the osseous surface to the radiographic marker was 3.2 ± 1.2 mm in the most posterior quadrant (fourth quadrant), and 3.4 ± 1.7 mm in the quadrant just anterior to this (third quadrant). The greatest height difference in all calcanei was less than 20% of the anteroposterior (AP) distance of the posterior facet.

In each specimen, the anteriormost aspect of the posterior facet had a superomedial-to-inferolateral obliquity. However, each specimen had an inflection point on the posterior facet where the obliquity reversed and became superolateral-to-inferomedial. The inflection point was appreciated as the wire crossing itself on the lateral radiograph. However, there was significant variation in where the inflection point occurred. The inflection occurred at a point ranging from 8.1 to 23.1 mm (mean 14.8 ± 4.5) posterior to the anterior apex of the facet. This translated to a distance covering 34.5% to 74.5% (mean 53.3% ± 12.1%) of the AP distance of the posterior facet.

Discussion

Calcaneus fractures result in significant economic costs, patient disability, and high complication rates.[4-6,12,13] Although a number of factors contribute to the difficulty in treating these fractures, a thorough understanding of the osseous anatomy and radiographic correlations may help treating providers improve surgical outcomes.

There is a high incidence of subtalar arthritis following calcaneus fractures, which seems to have a direct correlation with the degree of posterior facet comminution.[8,13] The quality of articular reduction has been directly correlated with patient satisfaction and functional outcome.[3,13] Generally, a direct articular reduction is performed with an open lateral approach, either extended lateral or sinus tarsi.[1,2,11,14] The posteromedial and medial surfaces of the posterior facet are difficult to visualize from this lateral vantage point given the osteology and lateral-to-medial convexity of the posterior facet. Appropriate screw placement may be difficult to assess given the limitations of direct visualization through lateral approaches. Intraoperative fluoroscopy is insufficient to completely assess the complex 3-dimensional topography of the calcaneus, and there is no single view that can accurately depict intra-articular penetration in this area.

In the posterior half of the posterior facet, the medial edge of the cartilaginous surface is located as much as 6.6 mm inferior to the lateral edge. The superolateral to inferomedial slope of the posterior facet puts the observer at risk for misinterpreting both gross observations and radiographic findings of hardware placed below the posterior facet. A screw placed from lateral to medial in the subchondral bone of the posterior facet may radiographically appear safely positioned, yet breach the cartilage medially. Given the overlap of the sustenaculum tali and the anterior processes, the Harris axial view is also unreliable in assessing articular breach of lateral to medial screws. This assessment becomes even more difficult in the presence of medial comminution. Because there is no reliable radiograph that can accurately assess for proximal posterior facet penetration, surgeons must rely on both the available imaging views and his or her knowledge of anatomy to achieve safe screw placement.

The primary limitation to this study is the sample size. Utilization of donated cadavers from our institution's medical school resulted in a finite number of calcanei available for observation. This secondarily limits the demographic variety in specimens and thus likely narrows the range of measurements for each parameter. If a greater sample size with a broader age distribution was used, ideally with a 1:1 ratio of male-to-female cadavers, it would more accurately approximate the true parameters of the general population. A larger sample size would also help understand whether absolute values are clinically useful as opposed to ratios, as different size feet may have different size safe zones. As noted in our Results section, the measured height difference in each quadrant was noted to be less than 20% of the AP distance of the posterior facet. If this holds true in future studies with larger samples, it may turn out that a ratio of the AP distance describes a more reliable safe zone than an absolute value. Future anatomic and computed tomography studies with a larger sample size are warranted.

Nonetheless, the information gleaned from this research is applicable to clinical practice. Surgeons should be especially cautious when placing screws within 5-6 mm of the posterior facet and cannot fully rely on direct visualization or fluoroscopy to judge extra-articular screw placement. Alternative methods of evaluating for intra-articular screw penetration include arthroscopy and intraoperative 3-dimensional imaging. However, these methods portend

to significantly increased costs and equipment requirements. Arthroscopy may also require the patient to be repositioned during the procedure and depends on a surgeon who is familiar with foot and ankle arthroscopy. Three-dimensional imaging also comes with significantly increased radiation exposure. Moreover, both of these techniques can only evaluate for screw penetration once it has already occurred, whereas using anatomical knowledge may altogether prevent this occurrence.

Conclusion

Intraoperative radiographic assessment of the safety of subchondral posterior facet screws does not correlate to its osteology. Owing to the superolateral to inferomedial convexity of the posterior facet of the calcaneus, overly long screws may appear to be radiographically intraosseous, though in actuality the screw may be intra-articular. On average, screws placed in the fourth quadrant of the facet are at less risk if 3.3 mm inferior to the upper margin of the osseous shadow on fluoroscopic imaging, and 3.2 mm inferior in the third quadrant. This study has a small sample size, and future investigation of the osteology of the posterior facet of the calcaneus is warranted.

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Ethical Approval

Ethical approval was not sought for the present study as the cadavers were donated to Yale School of Medicine for the sake of scientific research, and there was no associated information related to the identities of the bodies.

Declaration of Conflicting Interests

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ORCID iD

Jay Moran, BS, https://orcid.org/0000-0001-6247-3047

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