Impact of Nail Geometry on Calcaneal Purchase Length in Hindfoot Fixation: Curved vs. Straight

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INTRODUCTION: Intramedullary nailing is a widely utilized technique in tibiotalocalcaneal (TTC) arthrodesis, particularly for complex conditions such as end-stage osteoarthritis, significant bone loss, chronic instability, or failed prior fusions.[1,2] Despite widespread adoption, optimal implant design remains an area of ongoing investigation, especially with respect to maximizing fixation stability while minimizing soft tissue disruption. Emerging literature suggests that implant conformity to patient anatomy plays a critical role in fixation success and post-operative outcomes.[3] Specifically, in TTC arthrodesis, the anatomy of the calcaneus presents challenges to achieving maximal bony contact and optimal force distribution using straight nails. This is especially pertinent in patients with preexisting hindfoot deformities, such as valgus or varus misalignments, which can further complicate alignment and reduce implant purchase.[4] Therefore, understanding the biomechanical and morphological distinctions between curved versus straight nail designs is crucial for improving surgical strategies and post-operative clinical results. This study compares morphological differences between straight and curved intramedullary nails in hindfoot fixation, specifically focusing on purchase length within the calcaneus.

METHODS: A morphological analysis of hindfoot anatomy (calcaneus, talus, and tibia) was performed using 58 de-identified patient CT scans (age = 58.4 ±19.7 years, 24 female/34 male) with arthritic hindfoot anatomy. Straight and curved nail paths were modeled computationally in MATLAB to determine relevant arc lengths and anatomical intersection points (Figure 1). The purchase length of the calcaneus was computed by determining the insertion and exit point of the curved nail path with the calcaneus. Once these points were computed, the corresponding theta (calcaneus insertion point, curved nail path center, calcaneus exit point) was determined. Finally, the curved nail calcaneus purchase length was computed by multiplying the corresponding θ by the circle radius (constant) of the curved nail. The straight nail length was determined by extending a straight line along the long axis of the aligned tibia. To provide a conservative measurement of the purchase length of the straight nail, the sagittal plane projection was used. The intersection points between the calcaneus and the extended axis were then used to compute the insertion and exit point of the straight nail. The purchase length of the straight nail was determined using the linear distance between these two points.

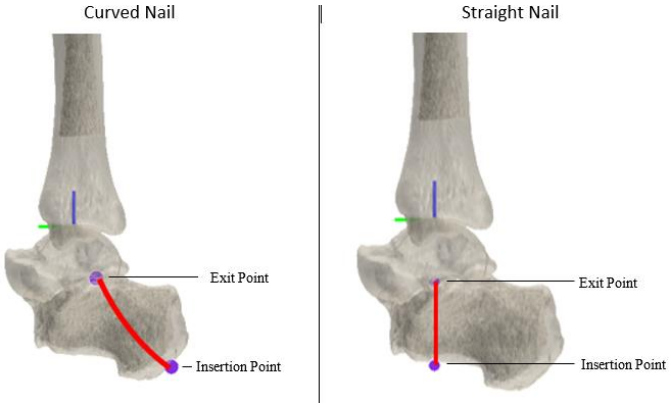

Figure 1: Visual representation of nail insertion and exit points of calcaneus and corresponding length measurements, shown in red, for the curved and straight nail.

RESULTS: The curved nail demonstrated a mean calcaneal purchase length of 61.1 mm (SD = 4.9 mm), significantly ($P<0.001$) longer than the straight nail's mean calcaneal purchase length of 42.0 mm (SD = 4.8 mm). Overall, the curved nail increased calcaneal purchase length by approximately 45.7% compared to the straight nail.

DISCUSSION: The increased calcaneal purchase length observed with curved nails indicates enhanced mechanical stability, likely due to more efficient force distribution along the curvature of the hindfoot anatomy. A longer purchase length translates to an increased bone-implant interface, which can enhance axial load transmission and rotational stability. Improved engagement may be especially critical in patients with compromised bone quality or altered hindfoot alignment, where mechanical reliability is critical for fusion success. Moreover, the trajectory of curved nails aligns more closely with the anatomical arc of the hindfoot. This alignment not only increases purchase but also helps preserve critical soft tissue structures, including the Achilles tendon insertion and the plantar aponeurosis. Increasing purchase length in the calcaneus via a curved path may impact the durability and reliability of fixation, potentially reducing the incidence of implant loosening, failure, and related complications.

CLINICAL RELEVANCE: The findings indicate curved intramedullary nails for TTC arthrodesis may offer biomechanical advantages for patients with compromised bone quality or severe hindfoot deformity, where maximizing fixation strength is essential to promote fusion and avoid revision surgery. Curved trajectory may facilitate more anatomic alignment in cases with hindfoot valgus or varus, reducing the need for extensive corrective maneuvers during surgery. These benefits suggest that curved nails may play a role in optimizing outcomes across a range of challenging clinical scenarios and may prompt reconsideration of nail selection criteria in pre-operative planning.

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