Patient-Specific Finite-Element Analysis of Three Intramedullary Nails for Tibiotalocalcaneal Fusion
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Introduction/Purpose: Tibiotalocalcaneal (TTC) arthrodesis is a salvage procedure for patients with severe osteoarthritis and other degenerative ankle conditions. Oftentimes, an intramedullary (IM) nail is implanted across the joints and then fixed with tibial and calcaneal screws. Maintaining compression and load sharing are both largely desired to promote fusion via primary bone healing; however, compression can be lost due to small amounts of bone resorption and IM nails are now being made from carbon-fiber epoxy to minimize stress shielding. To date, no one has been able to directly characterize or compare the specific amount of these parameters across nails in a single model. The purpose of this study is to compare influence of nail design and materials for compressive and load-sharing properties using a patient-specific finite-element model.

Methods: A titanium nail, a pseudoelastic nickel-titanium nail, and carbon fiber-epoxy nail were investigated for (1) load sharing between the nail body and tibia under gait loading and (2) compression loss as a function of resorption in the talus. A patient-specific model of the ankle, both in geometry and material properties, was generated from a quantitative computed tomography (QCT) scan of a healthy leg. The models were segmented and meshed using SCANIP and exported into ABAQUS for finite-element analysis. Compression in the nickel-titanium nail was simulated by pre-stretching the pseudoelastic compressive element. Conversely, compression in the titanium and carbon-fiber nails were generated by giving the nail jacket an orthotropic contraction coefficient in the model. After compression was set, each nail was subjected to an applied gait load that peaked at 1121N. Resorption was simulated using a thin compressible layer of bone in the talus and decreasing the modulus and Poisson’s ratio.

Results: Surprisingly, the carbon-fiber nail showed similar stress shielding to the titanium nail, with 72% and 77% of the stress being transferred through the devices instead of the ankle, respectively. Even though carbon fiber-epoxy has a significantly lower modulus than titanium (75 GPa vs 110 GPa), the overall stiffness of the nails was still much greater than that of bone (~30,000 N/mm vs. ~44,000 N/mm vs. ~3,000 N/mm, respectively). The pseudoelastic nail only shielded 32% of the stress values by comparison. For the titanium and carbon-fiber nails, over 85% of the initial compression provided by the nail drops with 0.10 mm of resorption. The pseudoelastic nail maintained 90% of its initial compression after 0.10 mm of resorption.

Conclusion: IM nail design and materials played a significant role in maintaining compression and load sharing. The pseudoelastic nail had the lowest degree of stress-shielding (32%) and maintained compression for over 0.10 mm of simulated resorption. Constant compression and the avoidance of “resorption gapping” is paramount to drive primary bone healing in joint fusions due to lack of periosteal/endosteal anatomy crossing the fusion site, thus impairing the ability for secondary bone healing (callus healing). This model allows for direct comparison between devices and can be used pre-operatively to predict patient-specific performance and help aid in device selection for TTC fusion.