Effect of Simulated Bone Resorption on the Biomechanical Performance of Intramedullary Devices for Foot and Ankle Arthrodesis

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INTRODUCTION: Midfoot and subtalar arthrodesis surgeries are performed to relieve pain and correct various foot deformities, such as midfoot collapse from Charcot neuroarthropathy. These complex salvage procedures often utilize intramedullary (IM) devices to promote internal fixation and bone healing as they are both less invasive than external fixation frames. However, static devices lose compression overtime due to changes in loading caused by bone relaxation post-surgery, bone resorption, and joint settling. This loss of compression across the fusion site may lead to serious clinical complications, such as nonunion due to inadequate bone-healing and device failure. A dynamic IM device has been designed to compensate for changes in loading caused by bone resorption due to its unique compressive nitinol element. This study aims to evaluate the biomechanical performance of a dynamic IM device compared to static devices.

METHODS: An axial compression test was performed following the previously established methods [1]. 20-PCF synthetic bone model blocks (Sawbone, Pacific Research Laboratories) were cut to 40mm height with 45mm x 45 mm cross sections. A custom-made mechanism to simulate bone resorption was used in series with a donut load cell (Transducer Techniques) to measure the compressive forces during loading and bone resorption. The load cell was attached on top of two parallel screw-driven plates and resorption was simulated by lowering the drive screws, thus decreasing the displacement between the two plates and loosening the construct. Testing of both the dynamic device (MedShape DynaNail Mini) and the static device (Wright Salvation Beam) took place in a thermal chamber at 37°C. Simulated resorption distance was measured with digital calipers while simultaneously reading the load cell’s compressive force until all compression was lost (n=5/device). The bending stiffness was determined from a four-point bend test at a rate of 1 mm/min from 6.8N to 68.8N for 10 cycles. Synthetic bone model blocks were cut to the dimension 40mm x 40mm x 85mm for the static device and 40mm x 40 mm x 70mm for the dynamic device. Each device was installed into Sawbone according to the manufacturer’s instruction and the Sawbone block with the deployed device was placed between the 4-pt bend fixtures. Resorption was simulated by cutting a 1mm or 2mm gap in the construct at the midpoint and repeating the loading cycles. The linear region of the load-displacement data was analyzed to determine bending stiffness (n=6/group). Data is reported as mean±st.dev. A 1-way ANOVA test with Tukey’s post hoc test was performed to statistically compare results between groups (n=0.05).

RESULTS: In the axial compression test, the 95mm static device had an average initial compression of 186.4N and lost all compression by 0.5mm of simulated resorption. The 150mm static device had an average initial compression of 226.3N and lost all compression by 0.7mm of simulated resorption. The 70mm dynamic device had an average initial compression of 309N, had 224N at 0.5mm resorption, and sustained compression until 2.1mm of simulated resorption. Similar levels of compression were maintained for longer dynamic devices during simulated resorption test, with the 80, 90, 110, and 140mm dynamic devices sustaining compression for 2.98, 3.7, 3.8, and 5.34 mm of simulated resorption, respectively. In the four-point bending test, the static device had an average movement stiffness of 565±69 N/mm when the simulated resorption distance was 0mm, 375±61 N/mm when the gap was 1mm, and 369±126 N/mm when the gap was 2mm. The dynamic device had an average bending stiffness of 652±92 N/mm when the simulated resorption gap was 0mm, 562±67 N/mm when the gap was 1mm, and 603±108 N/mm when the gap was 2mm. There was a statistically significant decrease in bending stiffness for the static device upon simulated resorption (p<0.01). There was no statistically significant change in bending stiffness for the dynamic device upon simulated resorption. At 1mm and 2mm of simulated resorption, the dynamic device has significantly higher bending stiffness than the static device (p<0.05).

DISCUSSION: The purpose of this study was to assess the biomechanical performance of static and dynamic devices in withstanding the effects of simulated bone resorption. Overall, the dynamic device was able to adapt to changes caused by the simulated resorption due to its unique compressive nitinol element. Regardless of device length, the dynamic device was able to adapt to 2 mm to 5.5 mm of simulated bone resorption and sustain compression in the axial compression test, while the static device lost compression rapidly within 1 mm of simulated resorption. The dynamic device was also able to maintain construct stability when resorption was simulated in the 4-pt bending test, while the static device lost construct stability within 1 mm of simulated resorption. The dynamic device’s ability to maintain stability across the joint interface allows for load-sharing to occur between the device and neighboring bone, while the static device’s inability to adapt to resorption leaves the device to bear all applied loads, potentially leading to early device failure. This investigation is limited by use of Sawbone models, prompting further investigation into device performance in cadaveric models.

SIGNIFICANCE/CLINICAL RELEVANCE: Devices for foot and ankle arthrodesis have experienced up to 5 mm of bone resorption [2], thus the dynamic device has the ability to sustain compression during fusion and adapt to clinically relevant amounts of bone resorption.


IMAGES AND TABLE:

![Graph showing compressive force during simulated resorption testing for static and dynamic devices.](image1)

![Graph showing bending stiffness during simulated resorption testing for static and dynamic devices.](image2)

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