

Dynamic Seating Analysis of a Novel Short Triple-Tapered Hip Stem Design with and without Grooves

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INTRODUCTION Total hip arthroplasty (THA) is a clinically successful procedure, but some concerns remain around the femoral stem regarding subsidence [1] and stress shielding [2] of the bone for a cementless application and their effect on long-term fixation and stability. It has been shown through simulation and mechanical studies that transverse stem grooves may reduce stress shielding in the proximal femur [3,4] due to the larger bone contact area created by the ribs or grooves. Transverse stem grooves may also affect the seating mechanisms of the stem in the femoral canal due to differences in stress transfer to the bone. To investigate the potential differences in the seating profile, a novel short triple-tapered hip stem was analyzed using a dynamic impact seating method in foam blocks.

METHODS Closed-cell polyurethane foam blocks with a density of 0.24 g/cm^3 were prepared by machining a cavity in the center that matches the proximal stem geometry but one size smaller. The blocks were prepared to the final stem geometry by broaching to the correct stem size. Custom broaches were used to create target interference fits of 115, 173, and 230 μm between the stem porous surface and foam blocks on each side of the stem. The stems were modified to rigidly attach a metal bracket with three passive reflective markers. A bracket with four markers was rigidly attached to the top surface of the foam block. An impactor was threaded into the stems, and the stems were placed into the foam blocks by hand. The construct was then placed into a drop tower, and a weight was dropped onto the stem impactor from a specified height to achieve an impact energy of 2.4 J. An overview of the test setup is shown in Figure 1. The marker position was continuously recorded during impact at a rate of 300 Hz using three motion capture cameras (Oqus 7+, Qualisys, Gothenburg, Sweden). A total of 10 impacts were delivered to seat each stem in the foam blocks. A local coordinate system was created for each set of markers (stem and block brackets) using Qualisys Track Manager software. The position of the stem coordinate system was calculated with respect to the block coordinate system, and the displacement after each impact of the stem medial resection level to the block resection level was reported. Two stems of each design (grooves and no grooves) were tested with each interference condition.

RESULTS For the 115 μm press-fit condition, after 5 to 6 impacts, the stems were seated to the resection level (0 mm relative position) and further impacts caused both stem designs to displace below the resection level. Increased interference fit required a greater number of impacts to seat each stem. For each interference condition, the grooved stems had a higher relative average position compared to the stems without grooves after each impact (Figure 2). After 10 impacts, the average seating position for the grooved stems was 0.10, 1.18, and 1.39 mm greater than the non-grooved stems for the 115, 173, and 230 μm interference fit, respectively. The average difference in final seating position increased with increasing press-fit.

DISCUSSION The effect of collared hip stems [5] and splines [6] on stem stability has been investigated, but the understanding of the effect of grooves in the stem design on both seating dynamics and stem stability and subsidence is limited. This study has shown that a dynamic seating method with motion tracking is able to distinguish differences in seating characteristics in a triple-tapered stem design with and without transverse grooves. Grooves increase the proximal contact area between the stem and bone, resulting in greater potential interfacial shear stress and less inferior displacement for a given delivered impact. The effect of stem design on seating mechanics should be considered when designing instrumentation or during implantation to ensure proper seating. More analysis could be conducted to determine if the differences in seating dynamics translate to a greater resistance to subsidence under both static and dynamic *in vivo* joint loads.

SIGNIFICANCE This test method has demonstrated a difference in seating mechanics between a novel stem design with and without transverse grooves. Grooves provide resistance to inferior stem displacement which may decrease subsidence while also decreasing stress shielding as described in the literature.

[1] Ries, Christian, et al. *International orthopaedics* 43 (2019): 307-314. [2] Glassman, A. H., J. D. Bobyn, and M. Tanzer. *Clinical Orthopaedics and Related Research*® 453 (2006): 64-74. [3] Heyland, Mark, et al. *Scientific Reports* 9.1 (2019): 482. [4] Noyama, Yoshihiro, et al. *Bone* 52.2 (2013): 659-667. [5] Whiteside, Leo and James Easley. *Clinical Orthopaedics and Related Research* (1976-2007) 239 (1989): 145-153. [6] Wang, Lin. *Medical Engineering & Physics* (2023): 104020.

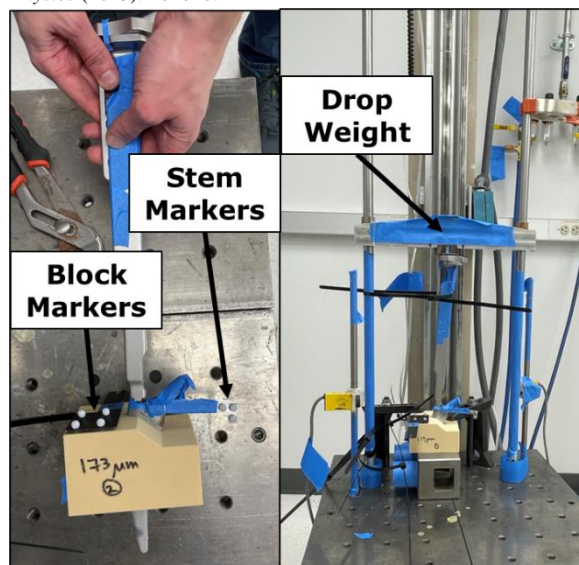


Figure 1: Setup images for the hip stem seating test.

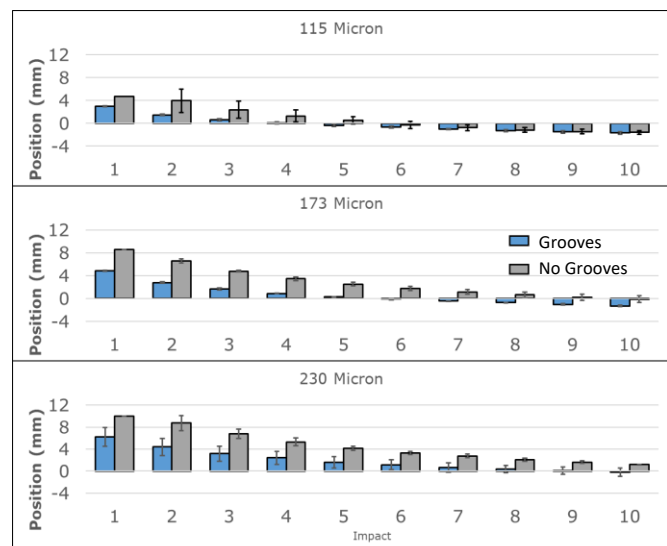


Figure 2: Graphs showing the stem position relative to the resection level after each impact for the various interference fit conditions.