A Biomechanical Assessment of Pullout Forces for Three Cemented Femoral Stems

Lawrence F. Torkan[1, 3], Anan Zhang[1,3], John T. Bryant[1, 3], Gavin C.A. Wood[1, 2, 3], and Heidi-Lynn Ploeg[1, 3]
[1] Human Mobility Research Centre, Queen's University, Kingston, ON, Canada, [2] Department of Surgery, Queen's University, Kingston, ON, Canada,
[3] Department of Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada
Email: lawrence.torkan@queensu.ca

DISCLOSURES: Lawrence Torkan (N), Anan Zhang (N), Timothy J Bryant (N), Gavin CA Wood (Stryker Corporation, MI, USA), Heidi-Lynn Ploeg (N)

INTRODUCTION: A total hip arthroplasty (THA) is a procedure often used to treat end-stage osteoarthritis of the hip, or displaced intracapsular fractures. Cemented hips use poly(methyl methacrylate) (PMMA) cement to secure the stem in the femur and offset osteopenic instability in older patients. They fall into one of two categories: composite beam or taper-slip. Composite beam stems include a collar and a matte surface finish to improve stability at the prosthesis-cement interface. Taper-slip stems, however, are collarless, have a highly polished surface finish, and are designed with either a double (anteroposterior [AP], mediolateral [ML]) or triple taper (additional ML plane). This stem design achieves stability through subsidence of the stem within the cement mantle, which generates radial forces that compress the implant at both the prosthesis-cement and cement-bone interfaces. There are some caveats to using bone cement, such as the risk of aseptic loosening. Under normal circumstances the hip stem experiences a compressive load, but tensile forces can disrupt the cement-prosthesis interface and cause the implant to dislodge. This study sought to determine which common, cemented taper-slip prostheses (C-Stem® [DePuy Synthes], CPT® [Zimmer Biomet], and Exeter® [Stryker]) could be removed with a moderate amount of force to facilitate reoperation in cases of revision, without severely compromising the prosthesis-cement interface. Pullout forces were biomechanically assessed and compared following compressive loading, re-impaction of the stem within its native cement mantle, and re-impaction with compressive loading.

METHODS: Three femoral prostheses were obtained from each company; two stem-types (C-Stem and Exeter) required machining to create a flat plane at the proximal end, perpendicular with the femoral axis, in order for these samples to comply with the pullout apparatus. Pre-tapped M6 holes were also machined in-line with the femoral axis. Standard surgical guidelines for each implant were followed for femoral canal broaching, preparation, and implantation. Surgical Simplex® P bone cement (Stryker) was used for each sample, regardless of stem-type. The femoral stems were first implanted into nine synthetic femur surrogates (Sawbones, USA), allowed to set, and were then placed under a continuous 330 N load for seven days to encourage stem subsidence. Loading occurred in an incubator at 37°C with 100% humidity to simulate a physiological environment. The samples were removed individually at the end of the loading phase and pullout forces were assessed with a materials testing system according to a previously developed protocol. The pullout was displacement-controlled; axial force and time were recorded. Following the first pullout, the stems were impacted into their original cement mantles and their pullout forces were immediately reassessed. The stems were then re-impacted a second time and loaded for seven days under the same conditions as the initial test. Pullout forces were obtained for this third condition. Testing order was randomized for all three conditions.

RESULTS: The mean maximum forces for the pullout of C-Stem, Exeter, and CPT are as follows: initial test, 8381 N (SD ±268.9), 5417 N (SD ±958.6), and 1738 N (SD ±551.2), respectively; re-impacted, 669 N (SD ±284.3), 876 N (SD ±195.4), and 594 N (SD ±231.1), respectively; re-impacted/loaded, 2160 N (SD ±524.5), 1337 N (SD ±333.5), 725 N (SD ±148.1), respectively. Differences between groups and between conditions were analyzed using a one-way analyses of variance (ANOVA) and Tukey honestly significant difference (HSD) post hoc tests; Alpha values of $P<0.05$ were considered statistically significant. Analyses confirmed a significant difference ($P=0.0001$) between groups and between all comparisons ($P<0.004$) for the initial test. For the re-impacted condition, no significant difference existed between groups ($P=0.387$). The re-impacted/loaded condition showed a significant difference between all groups ($P=0.009$). Significant differences existed between all conditions for C-stem ($P<0.0001$), Exeter ($P=0.0002$), and CPT ($P=0.014$).

DISCUSSION: The triple-tapered C-Stem had a significantly greater pullout force compared to the double-tapered stems (CPT and Exeter) for the initial condition. These results corroborated claims that a triple-taper design confers increased fixation and stability, however, a prospective study comparing the C-stem and Exeter found similar clinical and radiological characteristics and reported that neither implant was considered at risk for aseptic loosening.[1] The clinical similarity raises the question of how the excessive force required to displace the C-Stem may affect revision should it ever be required. An analysis of the Nordic Arthroplasty database reported that both C-Stem and CPT had a higher survivorship (aseptic loosening as the endpoint) compared to Exeter,[2] although it is important to note that the total number of Exeter hips was substantially higher than that of C-Stem and CPT, and that the type of bone cement varied. Upon re-impaction, no differences were observed between stems. A similar relationship to that of the initial condition was found between stems in the re-impacted/loaded condition, which outlines the importance of subsidence following loading for maximizing the stem's retention in a cemented system. This study used one type of cement, Simplex P, in order to eliminate cement-type as a confounding variable. In addition, the mean pullout force for CPT was comparable to previously reported values.[3] Although this was the first study to assess cemented stem pullout force following compression loading, future pullout studies would benefit from loading for longer periods of time and using higher compression loads closer to that experienced by the hip during dynamic motion, as defined by Bergmann et al.[4]

CLINICAL RELEVANCE: This study validated the effect of stem subsidence due to load on pullout forces for three femoral hip stems. It was concluded that following loading, Exeter offers a medium pullout force that maintains secure fixation to the cement mantle, yet may allow for a relatively uncomplicated revision that improves both functional outcomes and patient quality of life. Given previous findings and the contrasting pullout forces ascertained by this study, the C-Stem may be accompanied by a more arduous revision compared to both CPT and Exeter.

REFERENCES:

1. Luo X, He S, Li Z, et al. Systematic review of cemented versus uncemented hemiarthroplasty for displaced femoral neck fractures in older patients. *Archives of Orthopaedic and Trauma Surgery* 2012;132(4):455-63. doi: 10.1007/s00402-011-1436-9
2. Junnila M, Laaksonen I, Eskelinen A, et al. Implant survival of the most common cemented total hip devices from the Nordic Arthroplasty Register Association database. *Acta Orthop* 2016;87(6):546-53. doi: 10.1080/17453674.2016.1222804 [published Online First: 2016/08/23]
3. Subramanian KN, Temple AJ, Evans S, et al. Pull-out strength of a polished tapered stem is improved by placing bone cement over the shoulder of the implant. *J Arthroplasty* 2009;24(1):139-43. doi: 10.1016/j.arth.2008.05.029 [published Online First: 2008/10/01]
4. Bergmann G, Graichen F, Rohlmann A, et al. Realistic loads for testing hip implants. *Biomed Mater Eng* 2010;20(2):65-75. doi: 10.3233/bme-2010-0616 [published Online First: 2010/07/02]

ACKNOWLEDGEMENTS: We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC), Ploeg's Research Initiation Grant, and the Human Mobility Research Centre, Queen's University, Kingston, ON, Canada.

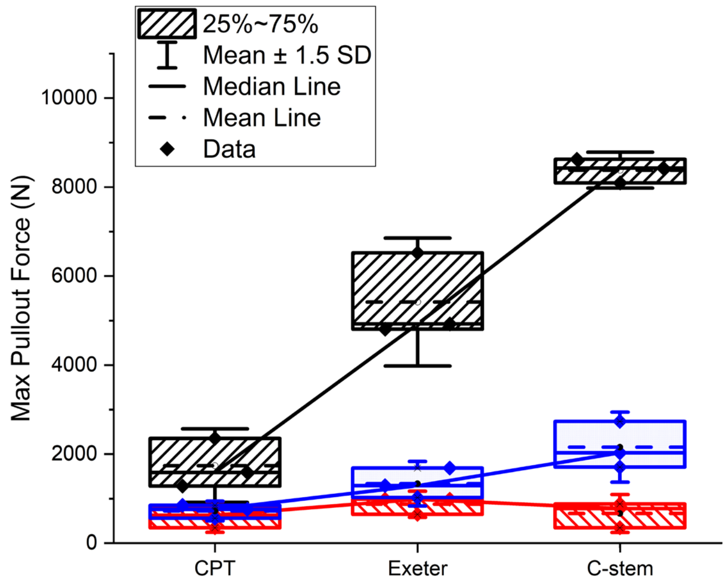

Figure 1. Box plot of maximum pullout forces experienced by each stem type in the initial (black), re-impacted (red) and re-impacted/loaded (blue) conditions.

Figure 2. Pullout apparatus affixed to material testing system.