Cutting Performance and Torsional Stability Testing of Various Broach Tooth Designs

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Disclosures: All (3A – Smith & Nephew, Inc.)

INTRODUCTION During total hip arthroplasty (THA) surgery, the design of the broach used to prepare the femoral canal is critical to the final fit and placement of the femoral stem. A rigid connection between the broach handle and broach may give a better representation to the surgeon of the stem stability after implantation, and methods to test the stability of this connection have been published [1]. Since the broach geometry is dependent on the stem geometry, the other primary factor affecting broach stability is the broach tooth cutting pattern. The broach tooth cutting pattern can be optimized for rotational stability in critical areas. The goal of this study was to develop a test method which could assess both the broach tooth pattern cutting performance and rotational stability.

METHODS Broach coupons were created for this study (Figure 1) with various tooth cutting patterns (N=3 each). Coupons were used to isolate the effect of broach teeth on cutting performance and rotational stability while removing the variable of stem geometry. Four broach coupon designs were analyzed: three diamond-shaped tooth patterns with varying aggressiveness based on tooth height and one broach coupon with an annular tooth pattern. Closed-cell polyurethane foam blocks with a density of 0.24 g/cm^3 were prepared by drilling an 8 mm diameter hole in the center of the block. The cavity was enlarged with a femoral reamer to the appropriate size for the broach coupons. A bracket was rigidly attached to the broach coupons, and three passive reflective markers were secured to the bracket. A second bracket with four reflective markers was rigidly attached to the flat surface of the foam blocks. The blocks were supported on the baseplate of a drop weight test frame such that the broach was free to displace downward. An impact energy of 2.52 J was delivered to the flat pommel of the broach coupons for a total of 10 impacts. The marker position was continuously recorded using three motion capture cameras (OQUS 7+, Qualisys, Gothenburg, Sweden) at a rate of 300 Hz. After seating, a fixture was attached to the pommel of each broach coupon and torsion was applied to the coupon by hand. The peak torque required to dissociate the coupon in the block was measured using a handheld torque meter (Versatorq, Snap-On, Kenosha, WI). A local coordinate system was created for each set of markers (broach and block brackets) using Qualisys Track Manager software. The position of the broach coordinate system was calculated with respect to the block coordinate system. The broach position after each impact was reported by normalizing the displacement measurements to the greatest seating depth of the four tested broach tooth designs after 10 impacts.

RESULTS The maximally aggressive broach tooth cutting pattern resulted in the largest average displacement after each impact (Figure 2). After 10 impacts, the average difference in position between the maximally aggressive broach teeth and the minimally aggressive, median aggressive, and annular tooth designs was 5.90 mm, 4.14 mm, and 4.97 mm respectively. The torque required to dissociate each of the diamond pattern tooth designs ranged from 6.67 to 8.59 N-m (Figure 3). There were no statistically significant differences in torque among the diamond tooth designs using ANOVA and post-hoc Tukey test ($p > 0.05$). The torque required to dissociate the annular tooth broach coupons was below the measurable threshold of the torque meter cell.

DISCUSSION The maximally aggressive diamond tooth pattern resulted in the largest displacement under impaction and therefore the largest volume of material removed among the broach tooth designs tested. A newly developed annular tooth design resulted in displacement between the minimally aggressive and median aggressive diamond tooth designs but resulted in less torsional stability. The annular tooth pattern is designed to aid in the removal of bone chips when broaching dense bone. Since the entire broaching process, including alternating extraction and impaction, was not simulated in this study, there may be additional advantages to the annular tooth design. Broach tooth design can be tailored to provide rotational stability in critical regions.

SIGNIFICANCE A test method which can isolate both broach tooth cutting performance and rotational stability was developed. This test method could be used in combination with qualitative validations to direct the broach tooth geometry design by balancing cutting performance and stability.

[1] Schmidig, Greg et al. ORS 2023, Paper No. 742.

Figure 1: Representative image of the broach coupons used in this study.

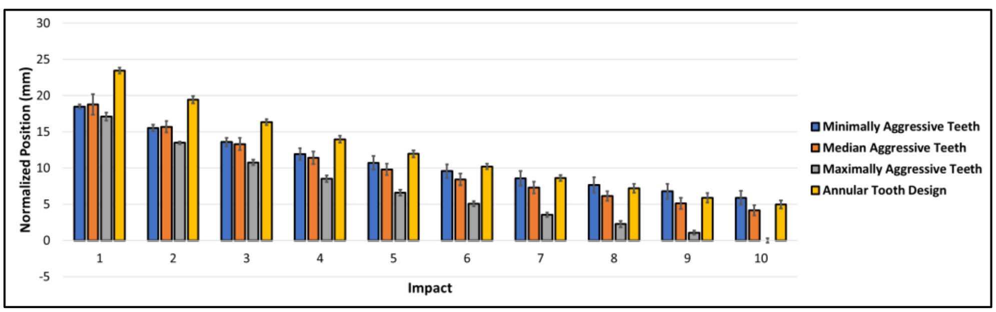

Figure 2: Displacement results of the broach tooth designs after each impact.

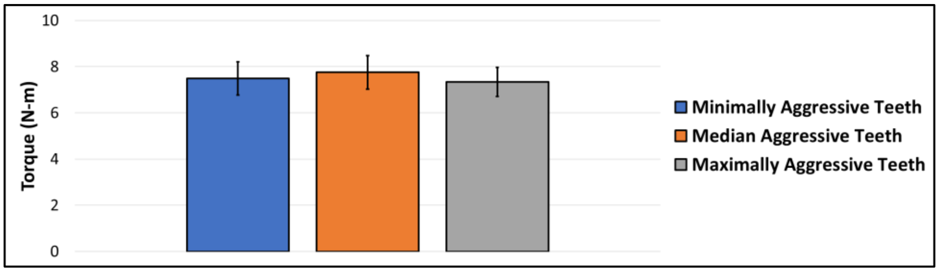

Figure 3: Torsional dissociation results of the broach tooth designs after 10 impacts into the foam blocks.