Clinically Relevant Provocative Range of Motion Assessment for a Collared Tapered Stem

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Introduction: The current primary stem market shows an increase in use of proximally filling type of stem with a collar for primary stability. This development provides an opportunity to optimize neck geometry to prevent dislocation through impingement in total hip arthroplasty (THA). Traditionally, various design factors have been examined for their role in maximizing impingement-free range of motion (ROM) in THA constructs. These factors encompass femoral head diameter, femoral head-neck offset, femoral neck length, femoral neck cross-section, acetabular shell diameter, and acetabular liner selection. Typical acetabular component placement follows the Lewinnek "safe zone" [1] for inclination and anteversion as it is widely used throughout the literature when assessing joint stability. Also, anteversion of the stem plays a crucial role in ROM in THA as it aids in the determination of a safe zone for combined acetabular cup and femoral stem anteversion. Therefore, the goal of this study was to recreate provocative ROM maneuvers commonly used in clinical assessments [2] while modifying cup position, stem position, femoral head offset, pelvic tilt, and physiological anatomy to assess the possibility of impingement with a specific neck and collar geometry of a triple taper stem.

Methods: Fifty-four ROM to impingement scenarios across several parameters were evaluated: several implant combinations, two provocative motions, and bony/prosthesis impingement were simulated in LifeMOD© (Smith & Nephew, Inc.). An average size hip model was implanted with a 52mm acetabular shell, a 20° lipped liner (aligned at 9:30 o'clock), a medium sized triple taper stem, and a range of 36mm femoral heads (-3, +0, & +4). These simulations aimed to replicate clinically relevant ROM evaluations for both anterior and posterior impingement. The acetabular shell was positioned at 27 different orientations, resulting from every combination of cup inclination values of 30°, 40°, and 50°, along with cup anteversion values of 5°, 10°, and 15°. A constant 15° femoral stem anteversion was selected, based on key outcome variables referenced in Pour et al [3] and low sensitivity to varying stem anteversion in early simulations. Also, collar width and profile were adjusted across two different stem geometries, with a focus on medial coverage versus coverage extending beyond the medial arc, address the potential impingement caused by the collar at the base of the femoral neck. Impingement was assessed during two provocative hip motions associated with dislocation risk: Flexion to 90°, followed by internal rotation until impingement (PIR) (Fig. 1a) and external rotation to 90° followed by extension until impingement (PE) (Fig. 1b).

Results: Bony impingement occurred prior to prosthesis impingement during maximum external rotation (PE) for 9 out of 27 implant combinations at low cup anteversion inclination (5°). In all other max PE simulations, where prosthesis impingement was the limiting factor, the minimum ROM value was 27.7°, achieved with a -3 head offset and at high cup anteversion, combined with low cup inclination. The maximum ROM value was 56.2°, attained with a +4 head offset and mid cup anteversion, along with low cup inclination. For provocative internal rotation (PIR), bony impingement occurred prior to prosthesis impingement in 18 out of 27 implant combinations including every pairing of high cup inclination and mid cup inclination, when combined with high to mid cup anteversion, as well as low cup inclination and when paired with high cup anteversion. In all other max PIR scenarios, the minimum ROM value was 3.9°, achieved with a -3 head offset and low cup anteversion, along with low cup inclination. The maximum ROM value was 26.4°, achieved with a +4 head offset and mid cup anteversion, along with low cup inclination. Max PIR experienced more bony impingement than max PE across all simulations, thus highlighting the importance of a lower neck/stem shoulder. Importantly, prosthesis impingement did not occur at the level of the collar. However, impingement can occur if the collar profile is not optimized around ROM. When comparing the different collar profiles (Fig. 1c), a collar with pure medial overhang as opposed to a collar extending beyond the medial arc reveals an increased likelihood of impingement for PIR, especially as head offset decreases, allowing the shell/liner to get closer to the base of the neck (Fig. 1d).

Discussion: The results of this study might indicate that optimization of lateral neck geometry is especially important when considering ROM to impingement during the design of a primary femoral stem. Our findings demonstrate bony impingement prior to prosthesis impingement in 67% of simulations, using bony anatomy from a 50th percentile subject, with PIR being the primary contributor to bony impingement. Cup placement exerts a substantial influence on the impingement arc's outcome and should be meticulously planned. It is important to note that although we did not observe prosthesis impingement at the collar junction, the protrusion or the size of the collar can increase the chance of iliopsoas impingement [4].

Significance/Clinical Relevance: This article underscores the significant role of bony impingement as a primary determinant of physiologic range of motion. When addressing range of motion and acetabular position, it is important to consider implant features like femoral head offset and blending of the femoral neck into the stem body and medial collar.

References: [1] Lewinnek et al., JBJS, 1978. [2] Klemt et al., J Ortho Res, 2021. [3] Pour et al., J Arthroplasty, 2021. [4] Qiu et al., J Ortho Res, 2020.

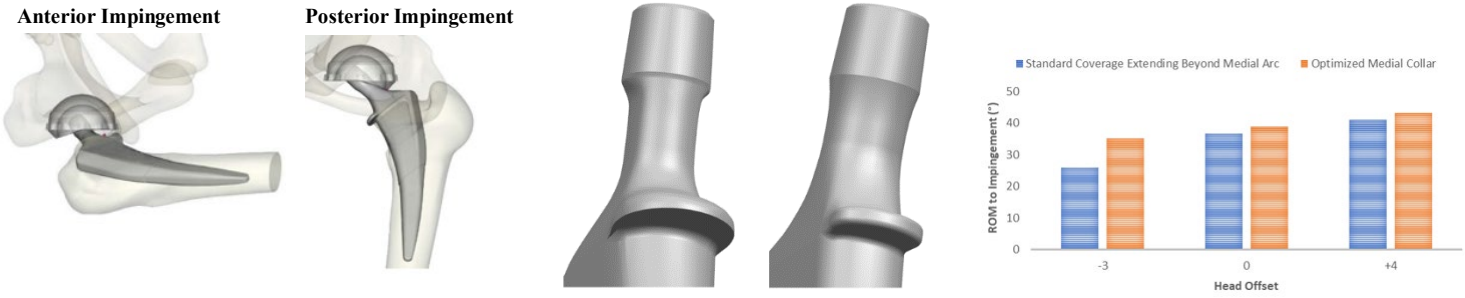

Figure 1: (a) Anterior Impingement scenario representative image (b) Posterior Impingement scenario representative image (c) ROM to impingement data comparison of optimized collar profile vs competitor triple taper stem (d) Standard coverage collar vs optimized collar