Software-Driven Cup Alignment for Avoidance of Edge Loading and Implant Impingement in Total Hip Arthroplasty Patients with Varying Degrees of Spinopelvic Mobility

Joseph S Gondusky, James Irvin Huddleston[1], Brittany Nicole Marshall, Chris Hunt, Casey A Myers, Clare Fitzpatrick, Chadd W Clary[2], Paul Rullkoetter
[1]Stanford Medicine Outpatient Center, [2]University of Denver

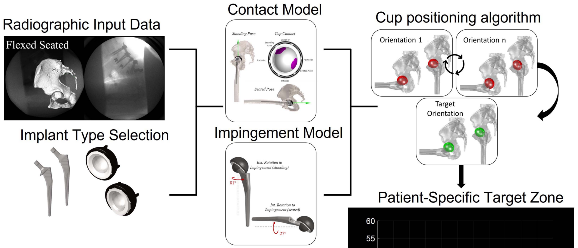
INTRODUCTION: Patient-specific pelvic orientation impacts the functional position of the acetabular cup and dislocation risk in total hip arthroplasty (THA). Currently available planning tools which attempt to incorporate measures of spinopelvic mobility into cup positioning may require preoperative CT, functional x-rays, and manual processes, increasing case time and expense. The objective of the current study was to 1) develop an automated, real-time decision support software for providing acceptable cup orientations that meet conditions for the avoidance of edge loading and implant impingement and 2) demonstrate the software on a set of patients spanning the range of pelvic tilt behaviors.

METHODS:

The developed software automatically assesses cup inclination and anteversion using previously verified models that uniquely incorporate spinopelvic mobility, accounting for edge loading and implant-implant impingement in real-time. Inputs to the algorithm include the anterior pelvic plane angle measured during lateral standing and seated-flexed x-rays as well as the templated implant size/type and planned stem version angle. The software produces a patient-specific output target zone for cup inclination and anteversion that represents the range of inclination and anteversion angles that does not result in either edge loading or implant impingement. Along with the target zone, the centroid of that target zone is also presented to the user in one of the three user selected reference frames (seated, standing, and supine) (Fig. 1). To assess the performance of the algorithm, virtual patients (n=441) were created and evaluated in combinations of standing and seated-flexed pelvic tilt at 5° increments from ±50°. Virtual patients were categorized by pelvic mobility into high and low mobility categories based on previously reported ranges of pelvic mobility in patients (Fig. 2). Pelvic tilt data of 30 real patients were available from a previous study that evaluated a range of patient mobility. Representative patients were selected in the high pelvic mobility category (>25°) and low mobility category (<10°) to demonstrate the differences in the target zone that results from pelvic mobility and selected stem version (Fig. 2). For each patient evaluated, the full target zone of acceptable cup alignments that avoid both edge loading and implant impingement was represented as well as the target zone centroid. To quantify the role of stem version on the target zone, the acceptable cup alignments were compared for a high mobility patient across the range of stem version placement options (-5° to 35°).

RESULTS: The virtual patients were used to determine algorithm performance in three primary ranges of mobility (high, low, and extreme) along with magnitude in anterior/posterior orientation in flexed-seated and standing. The range of cup positions which prevent edge loading and impingement is heavily influenced by the magnitude of the change in pelvic tilt from the standing to seated poses. A high mobility patient [seated tilt angle: 24.0°; standing tilt angle: -11.1°] has a range of acceptable positions of inclination:35°- 50°; version:16°- 37°. Conversely, a low-mobility patient [seated tilt angle: 19.1°; standing tilt angle: 9.3°] with a more functionally anteriorly oriented pelvis will have a target zone determined by that relative anterior position of the pelvis that has a range of potential cup alignments of inclination:30°-59°; version: 18°-49°. This target zone is characterized by higher degrees of inclination and anteversion to effectively avoid edge loading and impingement for a patient that remains in a more anterior pelvis orientation in comparison to the high mobility patient (Fig. 2). While the target zone for a low mobility patients may contain more acceptable cup positions in specific regions indicated by the larger target zone size, this does not indicate that one patient type is at higher or lower risk. The user can then evaluate positions within the target zone to select their preferred orientation for each case. Additionally, cup anteversion is heavily influenced by the level of stem version. In a case where a slightly more retroverted stem (i.e., 5°) would be preferred, the resulting target zone would be 27% smaller and biased toward lower anteversion and higher inclination compared to a neutrally aligned stem (15°) (Fig. 2). The run time of the algorithm to establish the acceptable cup alignments for a patient is 2.8 seconds.

DISCUSSION AND CONCLUSION: We have illustrated the performance of a real-time, automated software system to aid cup placement in THA. Preoperative assessment of pelvic mobility using this surgical planning tool offers patient-specific cup targets and acceptable orientation ranges for the commonly encountered degrees of variation in pelvic mobility that considers the use of all available implant treatment options. The overall range of pelvic mobility as well as the directional magnitude of pelvic orientation are important factors in determining cup positions that characterize the risk of edge loading and implant impingement. This fast-solving algorithm facilitates real-time decision making during preoperative planning and intraoperative execution. Leveraging computationally efficient analytical tools to assess how patients' pelvic mobility affects functional cup alignment and the associated impact of edge loading and impingement will help surgeons address the range of pelvic tilt behavior seen in THA.



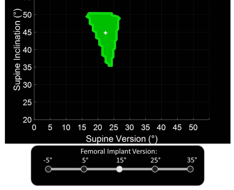


Fig. 1. Algorithm inputs are pelvic tilt angles from the standing and seated flexed positions and a selected implant configuration. The algorithm iterates through all possible cup orientations. The set of cup orientations which do not result in edge loading or impingement are identified using verified real-time computational models. These alignments form a patient specific cup target zone and centroid where the user can select a targeted stem version angle.

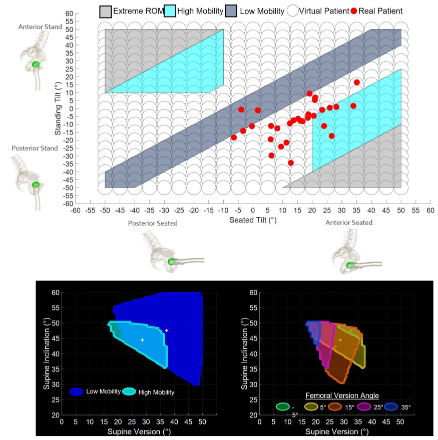


Fig.2. **Top:** Virtual patients (○) with different combinations of pelvic tilt in the seated flexed and standing position were created to assess the performance of the algorithm at varying levels of mobility. Positions were divided into mobility categories for high and low mobility patient groups to adjust algorithm parameters according to mobility. Mobility of greater than 55° was considered extreme. Data of 30 real patients are represented in red. **Bottom Left:** The target zone for high mobility patient compared to a low mobility patient. **Bottom Right:** High mobility patient demonstrating the effect of stem version placement [range -5° to 35°] on the target zone.