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The impact of functional combined anteversion on hip range of motion: a new optimal zone to reduce risk of impingement in total hip arthroplasty

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Aims

Pelvic tilt (PT) can significantly change the functional orientation of the acetabular component and may differ markedly between patients undergoing total hip arthroplasty (THA). Patients with stiff spines who have little change in PT are considered at high risk for instability following THA. Femoral component position also contributes to the limits of impingement-free range of motion (ROM), but has been less studied. Little is known about the impact of combined anteversion on risk of impingement with changing pelvic position.

Methods

We used a virtual hip ROM (vROM) tool to investigate whether there is an ideal functional combined anteversion for reduced risk of hip impingement. We collected PT information from functional lateral radiographs (standing and sitting) and a supine CT scan, which was then input into the vROM tool. We developed a novel vROM scoring system, considering both seated flexion and standing extension manoeuvres, to quantify whether hips had limited ROM and then correlated the vROM score to component position.

Results

The vast majority of THA planned with standing combined anteversion between 30° to 50° and sitting combined anteversion between 45° to 65° had a vROM score > 99%, while the majority of vROM scores less than 99% were outside of this zone. The range of PT in supine, standing, and sitting positions varied widely between patients. Patients who had little change in PT from standing to sitting positions had decreased hip vROM.

Conclusion

It has been shown previously that an individual's unique spinopelvic alignment influences functional cup anteversion. But functional combined anteversion, which also considers stem position, should be used to identify an ideal THA position for impingement-free ROM. We found a functional combined anteversion zone for THA that may be used moving forward to place total hip components.

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Keywords: Total hip arthroplasty, implant position, range of motion, combined anteversion, safe zone

Introduction

Successful total hip arthroplasty (THA) has long been thought to require placement of the acetabular component in a "safe zone", such as the one defined by Lewinnek et al[1], in order to minimize dislocation after primary THA. However, components positioned in this safe zone can and do dislocate.[2] The reasons for this are multifactorial, including the fact that supine AP radiographs alone do not account for dynamic changes in pelvic tilt (PT).[3] More recent literature has described functional component position in THA, which is the concept that increasing posterior PT increases functional cup inclination and anteversion whereas anterior PT will result in decreased inclination and anteversion.[3-5] The magnitude of change in PT from standing and sitting has been associated with spine pathology, such as lumbar degenerative disc

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Table I. Clinical details of 100 patients in the study.

Variable	Total
Male:female, n	68:32
Men age, yrs (SD; range)	64 (13; 34 to 86)
Mean BMI, kg/m^2 (SD; range)	29 (4; 21 to 40)
Right side:left side, n	57:43

SD, standard deviation.

disease,[6] flatback deformity,[7] and lumbar spinal fusion.[8-10] Patients with reduced lumbar movement and fixed spinopelvic alignment from standing to sitting have been shown to be at higher risk of dislocation.[9,11,12]

The optimum THA component position algorithm should consider not only acetabular component orientation and the influence of dynamic PT, but also femoral stem position and the contribution of combined anteversion in functional positions of daily living to impingement-free range of motion (ROM). Even techniques that do incorporate combined anteversion (component plus stem), such as those described by Amuwa et al,[13] do not account for the dynamic changes in PT. In recent years, various experimental and computational models have sought to improve on the past biomechanical laboratory research that only evaluated geometrical ROM to impingement.[14] Despite a greater understanding of the dynamic performance of THA in the activities of daily living (ADL), an algorithm for determining the appropriate "target" or "safe zone" for component placement in each individual patient has not yet been validated.

In order to find the optimum THA position for each patient it is important to consider both the femoral and acetabular component design and orientation, the patient's bony anatomy and the effect ADLs have on an individual's lumbar-pelvic-femoral alignment and impingement-free range of component movement. Therefore, in this study we used a virtual hip ROM tool using the patient's own bony anatomy and functional imaging (supine calculated tomography scans, standing and sitting lateral radiographs) to investigate the relationship between the patient's range of spinopelvic motion and their corresponding impingement-free range of hip motion.

Methods

From May 2019 to May 2020, 100 patients undergoing primary THA were recruited to participate in this institutional review board-approved, cross-sectional study. Patients were mostly male (69 males; 31 females) with a mean age of 64 years (34 to 99) and mean BMI of 29 kg/m^2 (20 to 40; Table I). Patient history of previous lumbar disease or previous surgery was collected. All patients underwent standing and sitting biplanar frontal and lateral plane 2D head to ankle radiographs using a low-dose radiation imaging system (EOS Imaging System; EOS Imaging, France).[15,16] Patients were aligned consistently in a relaxed seated position on the stool so that their femora were aligned approximately parallel to the floor (to achieve 90° of apparent hip flexion). Preoperative supine CT scans were also collected in preparation for robotic-arm assisted surgery using the Mako Total Hip application (Mako THA 3.1 software; Stryker, USA). Implants were manufactured by Stryker (Trident Hemispherical Cup with an Accolade II tapered wedge cementless stem or an Exeter collarless cemented stem) and positioned as deemed appropriate by the surgeon. Supine component position for all patients were placed in 40° or 45° inclination and between 15° and 25° of anteversion. Femoral component anteversion was measured to the surgical transepicondylar axis and was planned to try and recreate the native femoral anatomy.

Following surgery, a virtual ROM (vROM) tool was used to reconstruct the preoperative CT scans and the surgically-implanted implant positions for simulation (Mako THA 4.0 software; Stryker, USA). Pelvic parameters, including PT and sacral slope, were inputted from preoperative standing and sitting lateral radiographs and used to align the pelvis in the vROM tool to calculate functional acetabular anteversion in standing and sitting poses (Figure 1). Stem version was measured as the angle between the neck and transepicondylar axes when both are projected on a plane orthogonal to the anatomical axis of the femur, and this value remains constant for each patient regardless of pose. For each patient, we then calculated functional combined anteversion as the average of standing combined version (standing component anteversion plus stem version) and sitting combined version (sitting component anteversion plus stem version).

We then simulated hip ROM to impingement (whether bony or prosthetic) in several manoeuvres, including maximum flexion with standing PT, maximum extension with standing PT, and maximum internal rotation at 90° flexion with sitting PT (Figure 2). Angles to impingement were calculated relative to an initial position of 0° flexion/extension, 0° abduction/adduction, and 0° internal/external rotation, in which the mechanical axis of the femur was set parallel to the coronal and sagittal planes and the transepicondylar axis was set parallel to the coronal plane. We calculated an overall vROM score to limit values to clinically relevant levels and to properly weight flexion and extension manoeuvres in the two poses. The vROM score was calculated making the assumptions that in sitting with 90° of femoral flexion the maximum internal rotation was not clinically relevant if greater than 50°, and in standing, the maximum extension should be 30° and the maximum flexion should be 110°, calculated as flexion past 90° (maximum 20°), to equally weight standing and sitting. As a result, the vROM score was calculated as a percentage of a maximum score of 100° for these three manoeuvres (50°

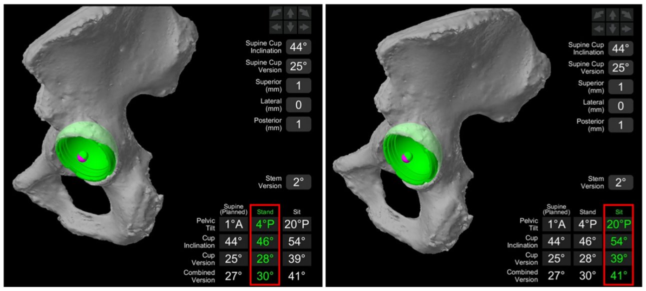


Fig. 1

An example of inputted pelvic tilt values and calculated combined versions in standing (left) and sitting (right) poses. Notice how the combined version increases in sitting as the pelvis rotates posteriorly.

+ 30° + 20°). Published values of acceptable or healthy ranges of motion of the hip vary greatly in the literature. The thresholds determined here (50° of internal rotation at 90° of flexion, 110° of standing flexion, and 30° of standing extension) were within published ranges, and deemed representative by the senior author (WD).[17-21]

Statistical analysis. An analysis of variance (ANOVA) test was used to compare vROM score between patient groups with stiff spines (change in PT from standing to sitting < 10°), normal spines (change in PT from 10 to 30°), and with hypermobile spines (change in PT from standing to sitting > 30°).[3] In the case of a significant one-way ANOVA result, a Tukey's honestly significant difference (HSD) post-hoc test was used if the data had equal variances. Statistical significance was taken at the 5% level ($p < 0.05$). All statistical analysis was performed using IBM SPSS Build 1.0.0.1447 (IBM, USA).

Results

The range of PT in supine, standing, and sitting positions varied widely between patients (Figures 3 and 4). Mean standing PT was 1° (standard deviation (SD) 9°; 28° to -16°), mean sitting PT was 21° (SD 12°; 44° to -13°), and mean lying PT was -4° (SD 6°; 14° to -16°). For each patient, the common trend was more posterior PT from standing to sitting, and more anterior PT from sitting to lying (Figure 3b). There werefive patients (5%) with "paradoxical" pelvic movement with more anterior PT from standing to sitting, shown in red in Figure 3b.

We found a significant difference in vROM score between stiff (mean vROM 91.6 (SD 8)), normal (mean vROM 95.8 (SD 6)) and hypermobile spine patients (mean vROM 96.6 (SD 6)); $p = 0.034$, ANOVA test), with stiff spine patients have a lower vROM score compared to the other two groups (Figure 5). In all, 48/100 of the patients (48%) had vROM scores ≥ 99% (excellent ROM). Overall, 34/48 (71%) of those were planned with standing combined anteversion between 30° to 50° and sitting combined anteversion between 45° to 65° while 28/52 (54%) of vROM scores less than 99% were outside of this

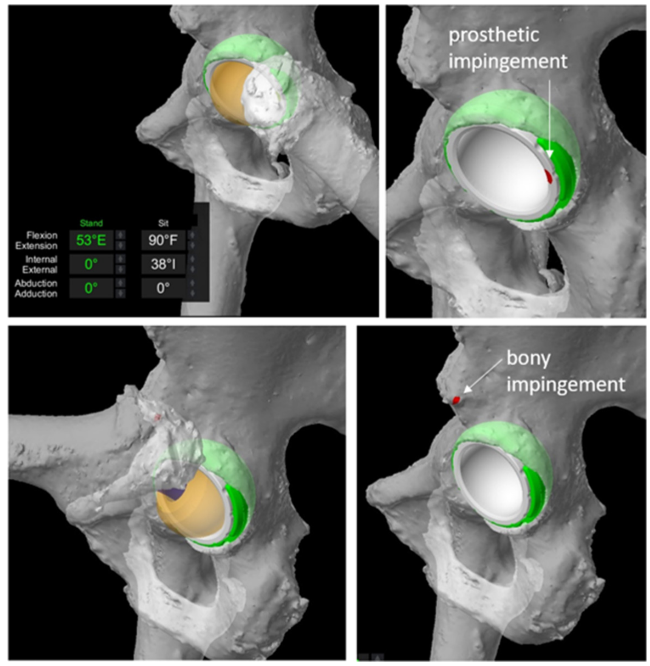


Fig. 2

An example where prosthetic impingement is detected in extension during standing (top) and bony impingement was detected during internal rotation at 90° of flexion in the sitting pose (bottom). The femur has been virtually removed in right images for better visualization of impingement.

zone, suggesting a new optimal combined anteversion zone for THA (Figure 6).

We found a parabolic correlation between functional combined anteversion and vROM score (Figure 7) suggesting that a functional combined anteversion between 35° and 55° is ideal for maximizing impingement-free hip ROM (Figure 8). Figure 7 shows that neither supine component anteversion (per Lewinnek)[1] nor supine combined anteversion (per Amuwa et al)[13] correlated nearly as well with the vROM score ($r^2 = 0.02$ and $r^2 = 0.15$, respectively) as functional combined anteversion did ($r^2 = 0.39$).

Discussion

We propose a novel model of functional combined version that takes into account both pelvic movement throughout functional activities and THA component positions and were able to demonstrate an increased impingement-free ROM for those cases that lie in target zone of 35° to 55°. In this study of 100 patients undergoing robotically-assisted THA, we demonstrated a large variation in both the pelvic position and hip ROM in patients with stiff, normal, and hypermobile spines. The CT-based simulation allowed us to evaluate the combined impact of a patient's spinopelvic mobility and bony morphology, to find an optimal implant position (component and stem) for impingement-free hip ROM.

The PT values we found in our patients are in keeping with published literature.[15,22,23] In our study, we found

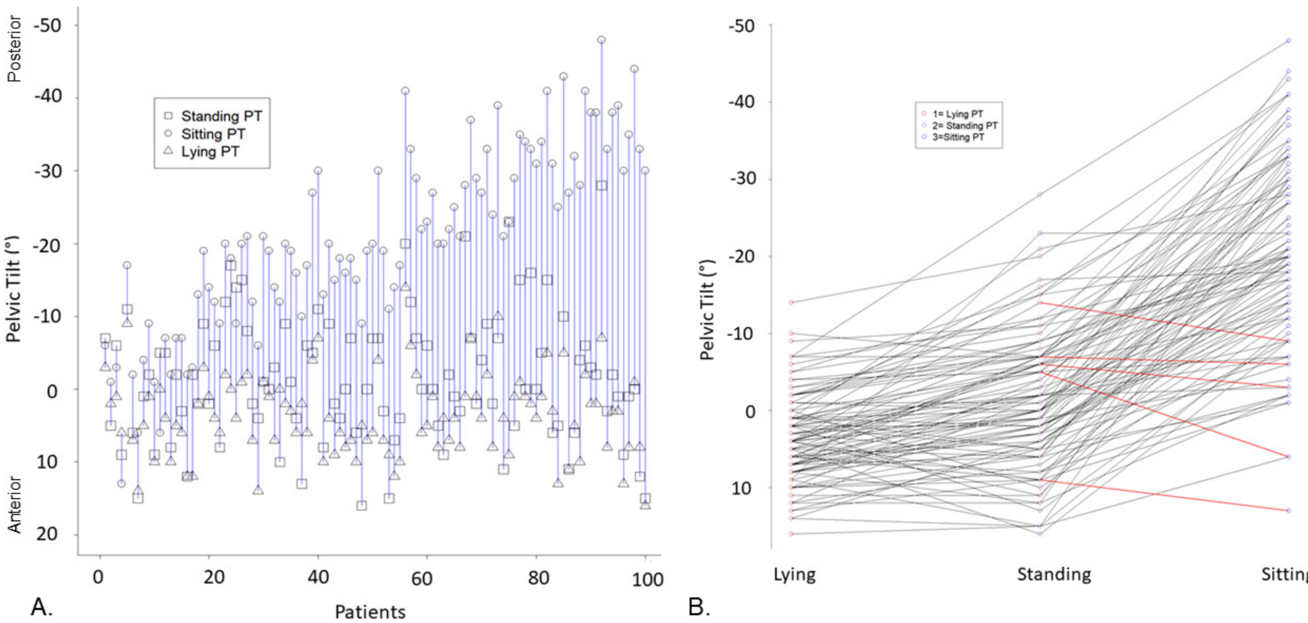


Fig. 3

a) A line graph showing pelvic tilt (PT) between standing, sitting and lying for each patient in order of increasing range of overall PT. b) A line graph showing how each patient's PT compares between standing, lying and sitting positions. Red lines indicate patients who had more anterior PT in sitting position than standing position. Anterior PT is negative.

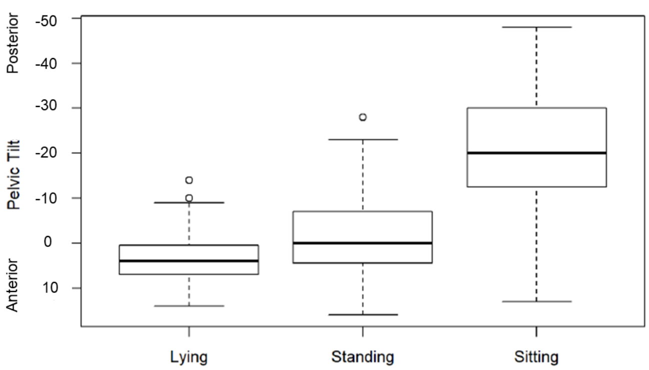


Fig. 4

Box plot showing the variability in preoperative lying, standing and sitting pelvic tilt (PT) in patients undergoing total hip arthroplasty. Positive PT indicates posterior PT, while negative indicates anterior PT.

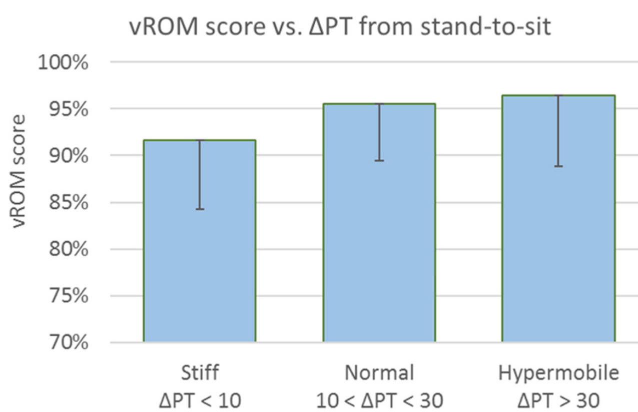


Fig. 5

Bar chart showing a lower virtual range of motion (vROM) score for patients with stiff spines compared to patients with normal or hypermobile spines.

a wide range in standing, sitting and lying PT values (Figures 3 and 4). We found a correlation between stiff spines and decreased virtual ROM (Figure 5). It has been previously shown that patients with stiff spines are at higher risk of dislocation.[7,9] Patients who had less than 10° change in PT from standing to sitting positions had significantly less virtual hip ROM before impingement than those who had more than 10° ($p = 0.034$, *t*-test). Normal spinopelvic motion dictates that when a patient moves from standing to sitting the pelvis will tilt posteriorly. This postural change has been shown to increase acetabular anteversion and inclination, subsequently increasing anterior clearance and improving impingement-free proximal femoral flexion.[22] Patient's with decreased physiological posterior PT will lose this adaptation and will have decreased impingement-free ROM. This provides biomechanical evidence to support the previous findings in the literature that have reported an increased risk of dislocation among patients with fixed spinopelvic alignment.[9,12] Interestingly, Figure 3b shows five patients (5%) who have a paradoxical anterior PT from the standing to sitting positions. This anterior PT could have significant ramifications in THA patients since the anterior tilt decreases hip flexion to impingement and therefore increases risk of posterior hip dislocation. Recognition of paradoxical anterior PT with sitting may allow the surgeon to make intraoperative adjustments in component position for this "abnormal" pelvic motion.

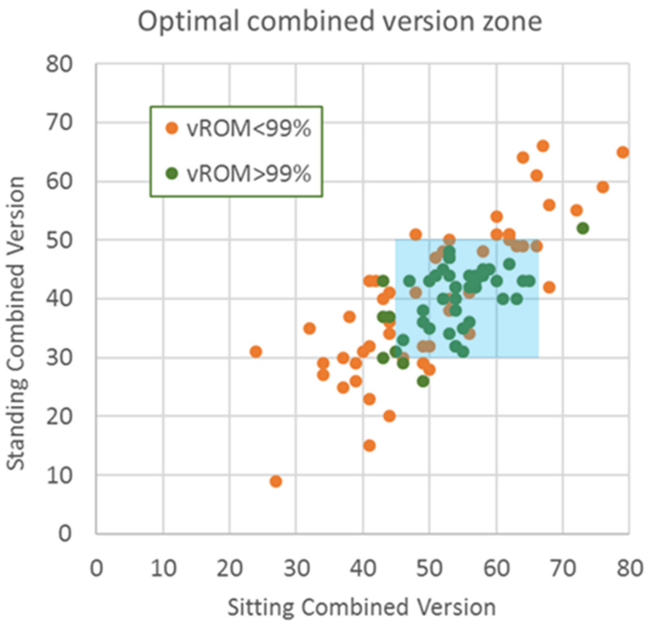


Fig. 6

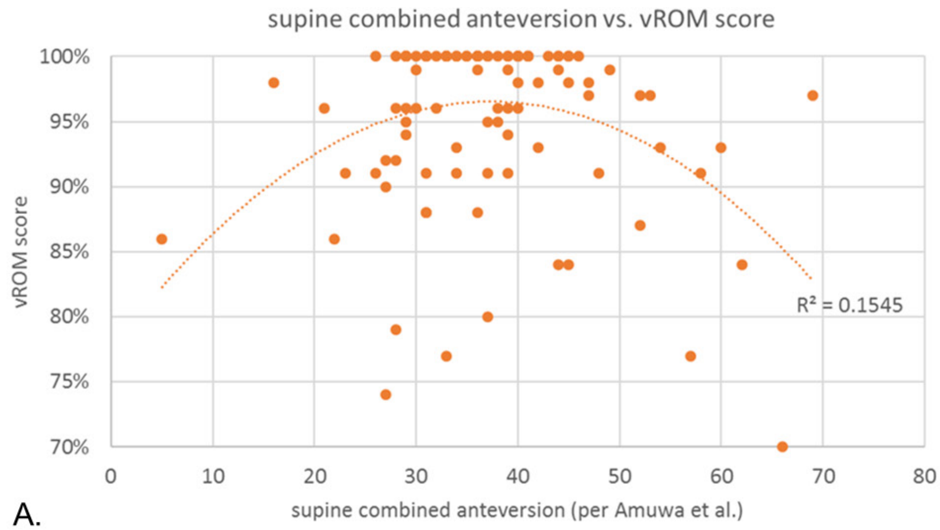
Scatterplot showing an optimal zone for standing and sitting combined anteversion, within which hips with high virtual range of motion (vROM) scores are located.

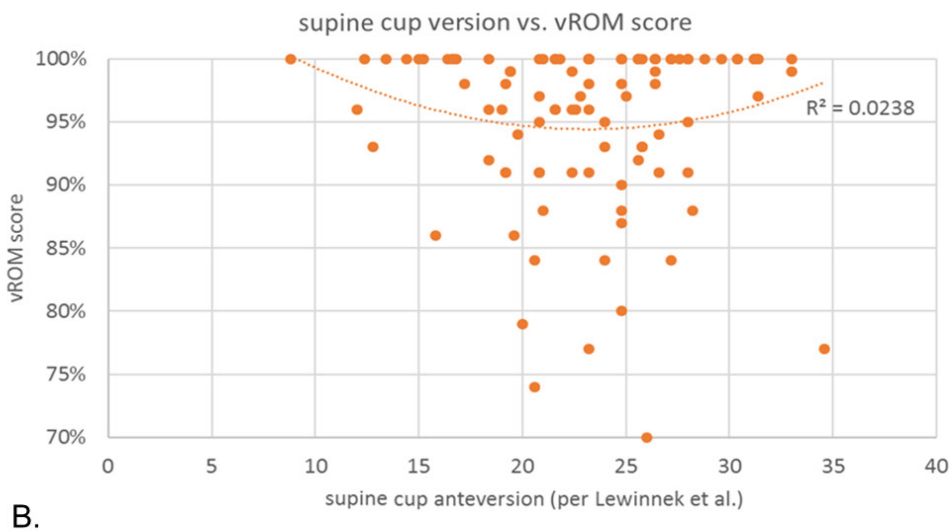
Based on our vROM algorithm we have identified a zone of optimal combined anteversion that maximises impingement-free ROM. Figure 6 shows that standing combined anteversion between 30° to 50° and sitting combined anteversion between 45° to 65° seems to provide maximum impingement-free ROM values. This algorithm considers the patient's stem version as well as their preoperative spinopelvic motion. Previous authors have used computer and mechanical based modelling to define an optimal acetabular component position. Hisatome et al[24] used a mathematical model to determine the optimum position of the prosthesis in total hip arthroplasty for reducing neck impingement during hip ROM. They determined that the acetabular component should be orientated with an inclination 45° combined with component anteversion and stem antetorsion determined by the formula: component anteversion + 0.7 x stem antetorsion = 42°. They also determined that the theoretical optimum position of the prosthesis is the same regardless of femoral head size used. While being a novel technique for determining an optimum component position it does not take into account the variations of the position of the pelvis in the lying and standing postures. Other authors have used finite element modelling and mechanical artificial joint simulators to define component designs and positions that are least likely to cause impingement throughout ROM; however, the recommendations vary, and again only consider the pelvis in a static position.[25-28]

To further simplify our novel optimum safe zone algorithm, we aimed to combine the standing combined anteversion (30° to 50°) and sitting combined anteversion (45° to 65°) values. Thus, we posited a functional combined anteversion (combined standing anteversion plus combined sitting anteversion/2). In Figure 7, we plotted each patient's functional combined anteversion against their vROM score. We found a parabolic relationship that suggested that vROM scores were optimised between combined functional anteversion values of 35° to 55°. We also evaluated vROM in Lewinnek's safe zone (supine relative to the anterior pelvic plane) and Amuwa et al's[13] combined anteversion zone and found superior impingement-free ROM with our new functional combined anteversion zone.[1,13] This could be attributed to the fact that these safe zones either do not account for femoral version and/or are based off of only static supine pelvic references (Anuwa et al[13] and Lewinnek et al[1]).

This study has limitations. Similar to previous imaging studies using EOS scans, it must be recognized that static imaging may not fully represent the patient's dynamic spinopelvic motion through ADL.[4] PT can go from relatively neutral or even anterior in supine with legs in full extension to extreme posterior tilt in a crouching position. Such extreme positions are difficult to examine with static imaging. Second, the images that were analyzed were dependent on the position of the patient in the imaging system. We aimed to have their femora aligned parallel to the floor to assume 90° of apparent hip flexion to measure spinopelvic flexion across the patient cohort. This may not replicate how patients sit comfortably during their ADL. However, previous studies used the same method.[6,12,29] Third, the computer model used did not account for soft tissue factors that may predispose to earlier impingement than what was recorded in our dataset. Such soft tissue factors may allow for subluxation or dislocation, even in with ideally positioned components. And finally, anatomical stem version may not equate to functional stem version. While functional femoral version is a logical concept, to date there is no validated method in the literature for measuring this in sitting position where radiographs have limited view of the femur.

The hip-spine relationship and its change through functional activities influences body kinematics and therefore THA stability.[30] Existing "safe zones" and combined femoral-acetabular anteversion recommendations have assumed that the pelvis remains static. But a target supine component version can be calculated that will optimize ROM in the more functional poses of standing and sitting. Use of enabling technologies such as navigation or robotics could facilitate the execution of accurate targeted component positions that have been calculated based on a patient's unique known or estimated stem version and PT values (i.e. supine, standing, and sitting). This would allow an acetabular component to be placed in the functional combined anteversion





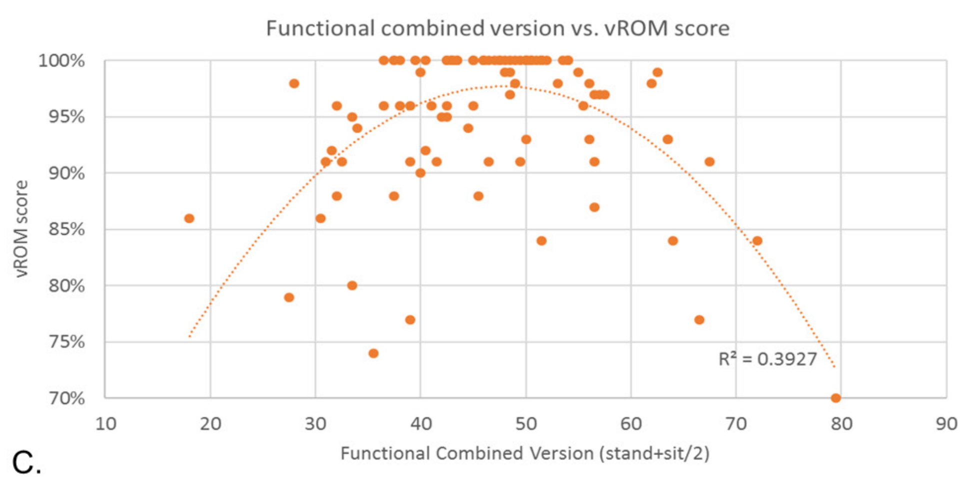


Fig. 7

Three scatterplots showing a) the correlation between supine combined anteversion per Amuwa et al[13] (r^2 =0 .15) and virtual range of motion (vROM) score, b) the correlation between anatomic supine component anteversion per Lewinnek et al ($r^2 = 0.02$), and c) the correlation between functional combined anteversion and vROM score ($r^2 = 0.39$).

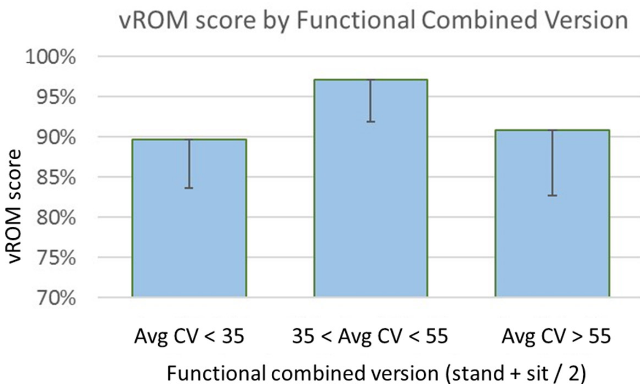


Fig. 8

Bar chart showing a higher virtual range of motion (vROM) score for those total hip arthroplasties with an average functional combined version (standing CV plus sitting CV/2) aged between 35 and 55 years.

zone outlined in this paper. To our knowledge, this is the first study to identify an optimal functional combined anteversion zone for maximum ROM to impingement in THA.[28] Further investigation of the efficacy of this zone is warranted, since dislocation remains the most common cause of revision surgery in the USA.[31]

Take home message

- We used a virtual hip range of motion (ROM) tool and functional imaging to investigate whether there is an ideal functional combined anteversion for reduced risk of impingement in 100 patients undergoing total hip arthroplasty. Our study suggests that a functional combined anteversion between 35° and 55° is ideal for maximizing hip ROM.

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- N. Poli: Formal analysis, Writing – review & editing.
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- T. Donnelly: Investigation, Writing – review & editing.
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