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Original Research

Achieving Target Cemented Femoral Stem Anteversion Using a 3-Dimensional Model

Paul Rebgetz, MBBS, FRACS(Ortho), BPthy [a], Tom McCarthy, BS ME, MBA [b], Hamish McLaren, FRACS [a], Matthew J. Wilson, FRCS(Tr&Orth) [c], Sarah L. Whitehouse, PhD, BSc(Hons) [a, c], Ross W. Crawford, DPhil (Oxon), FRACS(Orth) [a, *]

[a] *Orthopaedic Research Unit, School of Mechanical, Medical & Process Engineering, Faculty of Engineering, Queensland University of Technology, The Prince Charles Hospital, Chermside, Queensland, Australia*
[b] *Stryker Corporation, Mahwah, NJ, USA*
[c] *Exeter Hip Unit, Princess Elizabeth Orthopaedic Centre, Royal Devon University Healthcare NHS Foundation Trust, Exeter, Devon, UK*

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ABSTRACT

Background: Total hip arthroplasty aims to provide patients with a pain-free and stable hip joint through optimization of biomechanics such as femoral anteversion. There are studies evaluating the limits of cementless stem version, however, none assessing the range of version achieved by a cemented collarless stem. A computed tomography (CT)–based study was performed, utilizing a contemporary robotic planning platform to assess the amount of rotation afforded by a cemented collarless stem, whilst maintaining native biomechanics.

Methods: The study utilized 36 cadaveric hips. All had CT scans of the pelvis and hip joints. The CT scans were then loaded into a contemporary robotic planning platform. A stem that restored the patients native femoral offset was selected and positioned in the virtual femur. The stem was rotated while checking for cortical contact at the level of the neck cut. Cortical contact was regarded as the rotation limit, assessed in both anteversion and retroversion. Target range for stem anteversion was 10°-20°. Failure to achieve target version triggered a sequence of adjustments to simulate surgical decisions.

Results: Native femoral offset and target version range was obtained in 29 of 36 (80.5%) cases. Following an adjustment sequence, 4 further stems achieved target anteversion with a compromise in offset of 2.3 mm. Overall 33 of 36 (91.7%) stems achieved the target anteversion range of 10°-20°.

Conclusions: Target femoral stem anteversion can be achieved using a cemented, collarless stem in a CT-based 3-dimensional model in 80.5% of hips. With a small compromise in offset (mean 2.3 mm), this can be increased to 91.7%.

Introduction

Total hip arthroplasty (THA) aims to provide the patient with a pain-free and stable hip joint throughout a functional range of motion [1–4]. Optimizing hip arthroplasty biomechanics through control of version, center of rotation, offset, and leg length is thought to address these aims [3,5,6].

Many authors have published on various combinations of component orientation to minimize instability in THA [4,7,8]. Widmer published work on combined anteversion of the acetabular and femoral components and calculated that this should equal 37.3° ± 10°. The mathematical model generated maximal movement prior to component impingement [9]. The calculation is achieved from adding the cup anteversion (goal of 20-28°) to 0.7 times the stem anteversion based on an inverse linear relationship between cup and stem anteversion [9]. More recently, a functional combined anteversion method has been described to reduce impingement in standing and seated positions, which accounts for the impact of an individual's pelvic tilt and spine mobility [10]. Regardless of the method, stem version is an important consideration in THA.

* Corresponding author. Queensland University of Technology, Orthopaedic Research Unit, Level 5, CSB, The Prince Charles Hospital, Rode Rd, Brisbane, Queensland 4032, Australia. Tel.: +61 07 3139 4481.

E-mail address: r.crawford@qut.edu.au

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An alternative to a modular cementless prosthesis in tackling version restoration is a cemented collarless stem. The combination of a cement mantle and the independence of the neck cut from the leg length with collarless cemented stems, results in increased flexibility regarding stem rotation. One of the most widely used cemented stems is the Exeter femoral stem (Stryker Orthopedics, Mahwah, NJ). First implanted in 1970, modified to the V40 taper in 2000 [11], the Exeter stem shows very low revision rates in multiple national joint registries [12–14]. With a selection of stem offsets from 30 mm up to 56 mm, the offset is independent of leg length and canal diameter. Short stems (125 mm) are available for those with smaller canal diameters in which standard length stems (150 mm) are unsuitable.

There have been several studies evaluating the limits of cementless stem version, however, no studies assessing the range of version achieved by a cemented collarless stem such as the Exeter. We have performed a computed tomography (CT)–based study, utilizing a contemporary robotic planning platform to assess the amount of rotation afforded by the Exeter stem, whilst maintaining native femoral offset and leg length. The hypothesis of this study is that a polished, tapered, collarless stem implanted in a cement mantle will restore femoral anteversion in the vast majority of cases.

Material and methods

The study utilized 36 cadaveric hips supplied by Stryker Corporation. Inclusion criteria included all cadavers having had CT scans of the pelvis and hip joints in keeping with a set protocol for MAKO THA (Stryker Orthopedics, Mahwah, NJ). All available femurs with appropriate scans were included. The CT scans were then loaded into the MAKO THA 4.0 software. The bone cortices of the pelvises and femurs were segmented by technicians creating a virtual 3-dimensional model of the hip joint.

Utilizing the robotic planning software, the native femoral version was measured. The software uses a line between the center of the femoral head and the center of the mid-femoral neck and compares this to the transepicondylar axis of the distal femur (Fig. 1). The software calculates the femoral offset by measuring the distance between the center of the native femoral head and the anatomical axis of the femoral canal.

An Exeter stem that restored the patients native femoral offset as accurately as possible was selected and positioned in the virtual femur (Fig. 2). The stem was inserted to a depth in the femur to restore hip length based on the stem insertion depth as described by Halai et al [15]. The position of the stem was checked in all 3 planes to ensure it was central within the canal and well aligned.

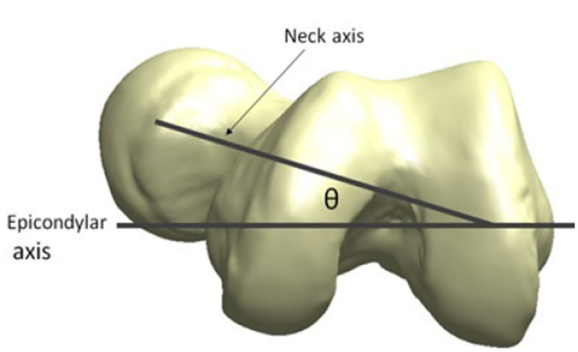

Figure 1. Native femoral neck anteversion is measured as the angle between the neck axis and epicondylar axis when these 2 axes are projected on a plane perpendicular to the anatomic axis of the femur.

To assess the degree of femoral stem rotation attainable with the selected stem, the stem was then rotated incrementally while checking for cortical contact at the level of the neck cut and the lesser trochanter. Once cortical contact was made, this was regarded as the limit of rotation. Rotation limits were assessed in both anteversion (Fig. 3) and retroversion (Fig. 4). A target range for stem anteversion was set at 10°-20°.

When the target anteversion within the range of 10°-20° could not be achieved, a set sequence was followed to rectify the issue. Firstly, the level of neck resection was lowered by 6mm from the original planned 12-mm cut (6 mm above the lesser trochanter – Fig. 5). The degrees of femoral stem rotation were measured once more.

If target anteversion was still not achieved (Fig. 6), the size number of the stem was reduced or if unable, a 125-mm stem was used. If this did not satisfy the anteversion criteria, the stem offset was reduced, and a +5 head was selected. This maintained the femoral offset while reducing the stem size, allowing increased version. Rotation was once again measured.

The final step if the stem failed to satisfy the target version was to introduce some valgus to the stem (Fig. 7), potentially shifting the stem from cortical contact points with minimal compromise in offset. Rotation was again assessed.

Outcomes measured included age, gender, laterality, native femoral offset, native femoral version, level of neck cut, stem sizing, and head length size, maximal anteversion, maximal retroversion, and total arc of version.

Results

Thirty-six femora were identified that satisfied the CT requirements. There were 16 bilateral hips and 4 individual hips included in the study. There were 20 left and 16 right sided femurs. There were 28 female and 8 male hips. The mean native femoral anteversion for the sample group was 3.8° (range −14° to 27°). The average difference of anteversion between the left and right hips in the 16 matching pairs was 5.5° (range 0°-26°).

The native femoral offset and the targeted version range of the stem could be obtained in 29 of 36 (80.5%) cases. Following a lower neck resection and sequence described in the methods, a further 4 stems achieved target anteversion with a compromise in offset of 2.3 mm. Overall 33 of 36 (91.7%) stems achieved the target anteversion range of 10°-20°.

These 4 (11.1%) cases required reduced offset stems with +5-mm heads. When small offset stems were used with the +5 heads, it did not perfectly recreate the native femoral offset. In terms of offset, a +5 femoral head with a neck shaft angle of 125° would change offset by 4.1 mm and length by 2.9 mm. Changing 44/0 to 37.5 with +5 equaled an offset of 41.6 mm, creating a 2.4-mm change in offset. Similarly, 50/1 to 44/1 or a 56/1 to 50/1 with +5 head both resulted in a 1.9-mm reduction in offset.

Overall, 33 of 36 (91.7%) stems produced the target anteversion and corrected offset to within a mean of 2.3 mm of the original offset. Three (8.3%) cases could not satisfy the study criteria despite lower neck cuts, smaller offset stems and addition of valgus. The anteversion achieved in these 3 cases was outside the target 10°-20°, and was 8°, 6°, and 28°, respectively. In the case in which the minimum anteversion achieved was 28°, the native femoral anteversion was 27°, which was the highest recorded within the cohort.

Seven (19.4%) cases required a 125-mm short Exeter stem due to femoral canal morphology.

The mean total arc of version of the stem was 50.8° (range 12°-115°). The mean maximal anteversion achievable was 27.3° (983 of 36). The mean maximal retroversion was −23.5° (−849/36).

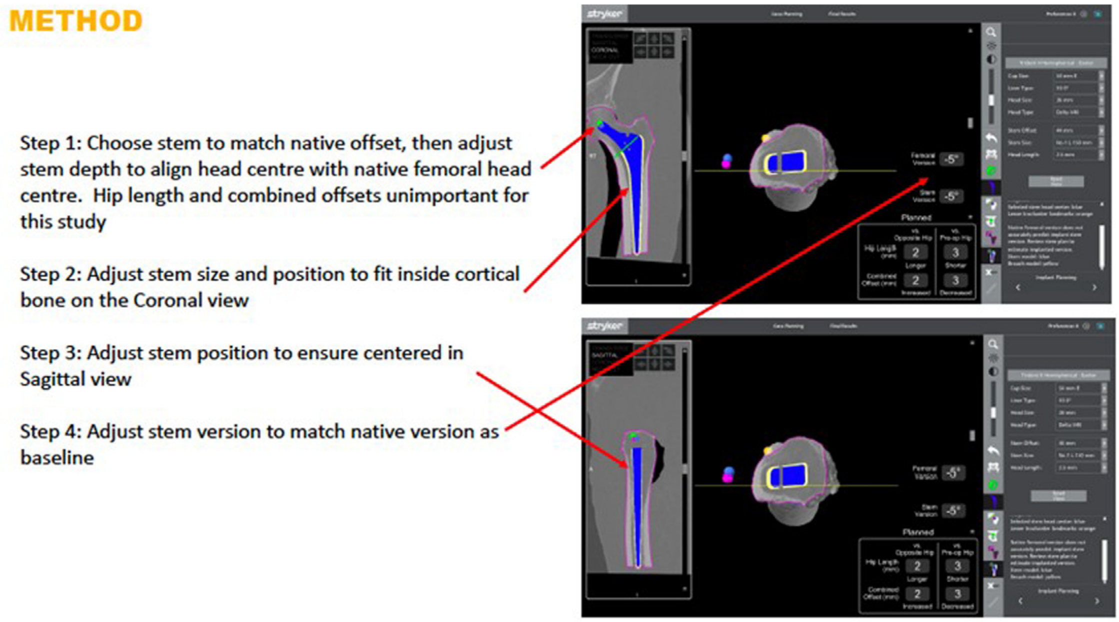

Figure 2. Sequence using software.

Discussion

This study found using CT modeling, the cemented, collarless stem could be placed within a 10°-20° arc of anteversion in 91.7% of the cases, while maintaining hip length and keeping femoral offset within 2.3 mm. It also found that in 80.5% of cases stem anteversion within a range of 10°-20° could be achieved while reproducing offset. For context, this compares favorably to previous studies assessing uncemented stems postoperatively via CT to satisfy the 10°-20° version target in 47%-65% of the cases [16,17].

As uncemented THA grew in popularity, difficulty to accurately achieve desired stem anteversion has been reported in the literature [18,19]. Wines and McNicol [19] showed 71% of uncemented femoral stems were placed between their desired 10°-30° of anteversion. Marcovigi et al [20] described native femoral anteversion and post-operative stem version for robotically implanted uncemented stems, showing large variability, with 30.1% of the 362 hips implanted showing a combined anteversion of under 25°. Sendtner et al [18] found 5 of 60 patients had normal stem anteversion post THA using a tighter 10°-15° definition of normal. Even with widening to a range of 0° to 25°, 35% of stems were outside the target. Moderate correlation was found between preoperative femoral neck version and stem version when using a single-wedge, straight cementless stem [20]. It is difficult to achieve target femoral stem anteversion using an uncemented stem when the native femoral anteversion is reduced.

In terms of the survivorship of cemented stems for patients undergoing THA, the Australian Orthopedic Association National Joint Replacement Registry shows patients aged under 55 years, there is no difference in the rate of revision when comparing cementless to hybrid fixation [13]. In patients aged 55-64 years, there is a higher rate of revision in the first month for cementless fixation compared to hybrid fixation. Cementless fixation has a higher rate of revision compared to hybrid fixation for all patients aged 65 years and over [13]. It would seem there are advantages to

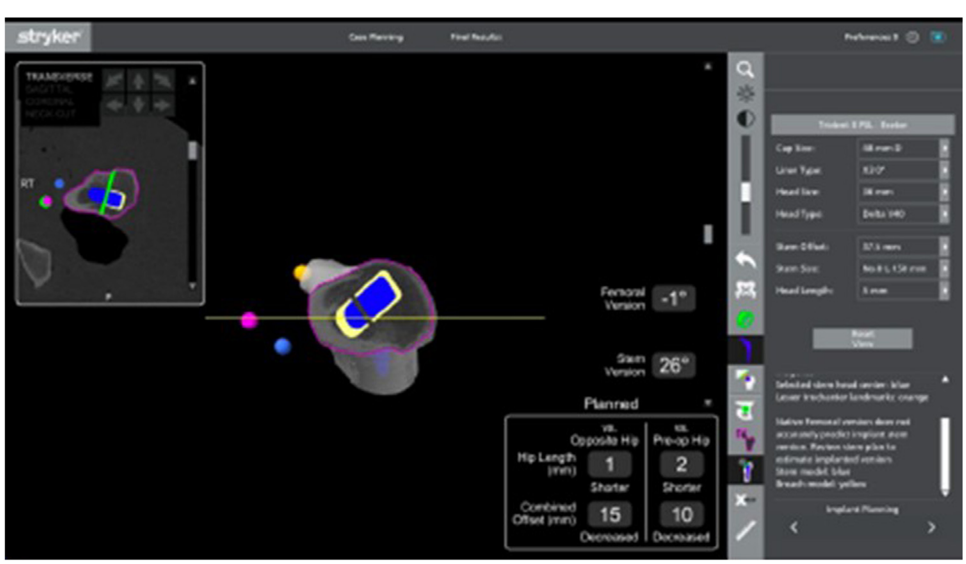

Figure 3. Anteversion of 26° achieved with 37.5 No. 0 stem, 125 mm length.

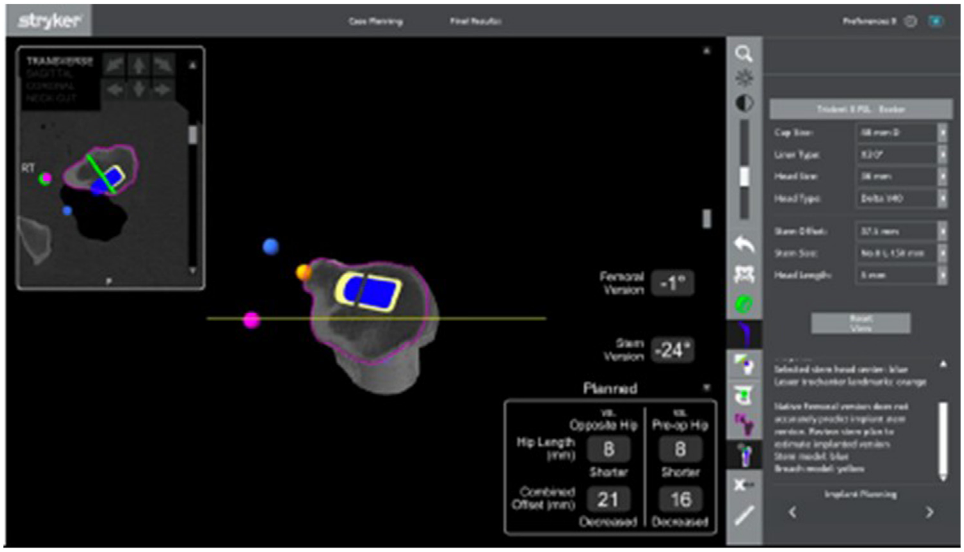

Figure 4. Retroversion of 24° achievable with stem 37.5 No.0, L 125 mm.

cemented collarless stems and is a legitimate choice for all age groups. A potential issue at maximal end points of rotation is that the cement mantle may be thinned, however, inferring from the evidence described as the French Paradox, particularly when using a taper-slip cemented stem as shown by Verdonschot et al [21], this is unlikely to affect long-term stem stability [22].

THA instability is still 1 of the major reasons for revision (24%), particularly in the first 4 years following surgery [8,13,23]. The causes for dislocation have been well studied and shown to be multifactorial [24]. Component positioning has been hypothesized as a possible cause, with the definitive, correct position of the components still appearing elusive [9]. In the study by Lewinnek et al, a series of 300 THA's showed a range of acetabular component position of 15 ± 10° of anteversion, and 40 ± 10° of lateral opening, as placement outside this range increased the dislocation rate from 1.5% to 6% [25]. Criticism of the safe zones and alternative concepts of combined anteversion and impingement free range of motion have led to more investigation of an individual's anatomy [9].

Often, subtle changes in component alignment can impact the stability of a THA [8]. With advancements in technology and robotic assistance, a surgeon has increased precision in executing a pre-operative plan [26,27]. When using the tibia as the method of estimating rotation intra-operatively, there is large variability in valgus force on the knee, which could lead the surgeon to under-estimate the amount of version on the femoral stem. CT has shown postoperative femoral component version ranged from −15° retroversion to 45° anteversion [19]. Similarly, Dorr et al [26] showed reduced anteversion of 10.2° in their series of 109 patients and concluded a surgeon's estimate of anteversion had poor precision, often outside the intended range of 10 to 20 of anteversion.

Dorr et al [7] proposed the "femur first" technique for uncemented components by preparing the femur first, assessing version

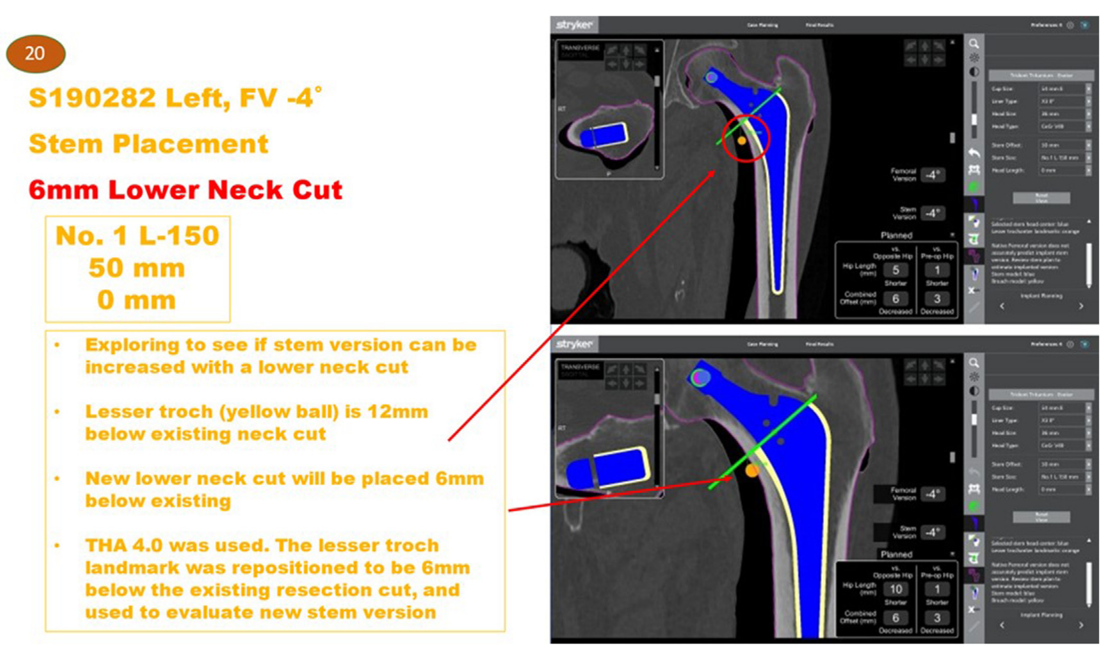

Figure 5. Process of lowering the neck cut.

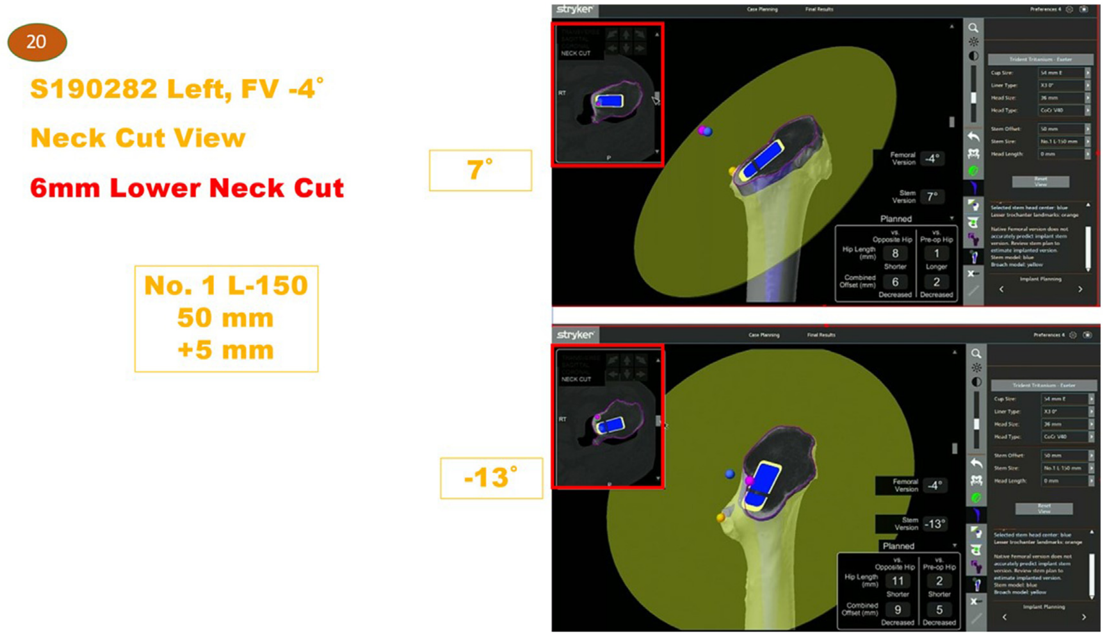

Figure 6. Stem that did not achieve target anteversion, despite lower neck cut.

and adjusting the socket position to achieve a desired combined version. This may mean placing the cup in a less-desirable position with increased risk of bony impingement anteriorly or posteriorly or excessive medialization of the center of rotation, to maximize bony coverage of the component.

One of the issues with cementless stems is use in individuals with outlier anteversion. Our study showed an anteversion range of −14 to +27 degrees. Pierrepont et al [28] also highlighted the variation in femoral anteversion, with the median among the 1215 patients of 14.4°, but range of −27.1 to +54.5°. Fourteen percent of patients had extremes of version (<0° or >30°). [28] Müller et al [5] showed a mean preoperative anteversion of +24.9° (+7.9° to +39.1°) reduced to +7.4° (−11.6° to +25.9°) using a cementless stem. These findings were supported by Kim et al [17], who showed great variability in stem anteversion with 28.9% outside of their safe zone of +5 to +25°. A modular cementless prosthesis is 1 option to tackle extremes of version, but this means using a prosthesis which the surgeon may not be as familiar with. Also, modular junctions have the potential for fretting, metal debris and metallosis [29].

In the cases which could not satisfy the required anteversion of 10°-20°, in 2 cases, the anteversion achievable was +6° and +8°, which would require an acetabular component anteversion of 23.1° and 21.7° to satisfy Widmer's combined anteversion target range of 37.3° ± 10 [9]. The robotic planning software would allow the surgeon to know this in advance and accommodate their acetabular version. The other stem to fall outside the target range had the highest native femoral neck anteversion of 27° and the achievable version was minimum of 28°. Again, knowing this in advance allows a surgeon to accommodate with either their choice of component, bearing or acetabular position. Also, potential use of

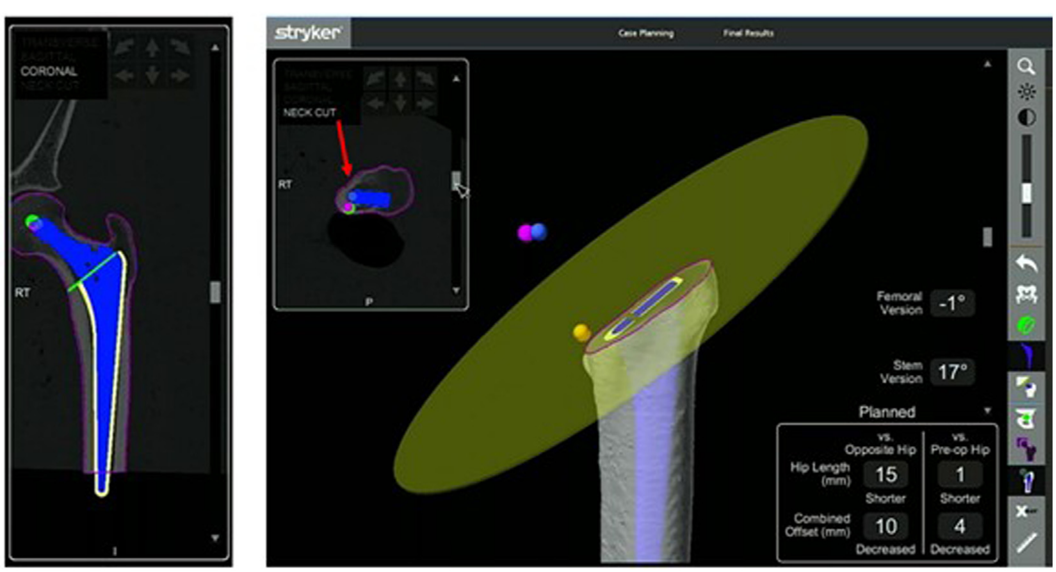

Figure 7. Addition of valgus to stem allowing stem to achieve target anteversion.

the enhanced robotic workflow in these cases would allow assessment of impingement positions.

This study showed that in more than 90% of cases, a cemented, collarless stem may be the optimal solution to achieve target anteversion, which is potentially a major advantage.

While this study is able to reliably recreate traditional goals of anteversion using a cemented collarless stem, it is unclear if this would make a clinical difference in terms of lowering dislocation rates. Further research is required to answer this question.

Limitations of the study include a small sample size which may make meaningful estimates about native anteversion and prevalence of asymmetry between sides inaccurate. It is certainly an area for further research and could have implications for templating and stem choice in the future. Gender differences are also difficult to ascertain when only 8 male hips were analyzed. A further limitation is the theoretical nature of a CT-based study rather than in vivo. A lack of analysis of femoral morphology and presence of osteoarthritis in the hips could also affect figures for native anteversion and explain difficulty in achieving anteversion in 3 of 36 cases. A larger sample size would potentially dilute these effects and allow analysis of population differences and gender effects. All cadavers were provided by Stryker, which is a potential source of bias, although no control over the anatomy of the specimens was conveyed. This technique is independent of surgical approach and level of femoral neck osteotomy; however, it does not take into account the soft tissue that may prevent or create problems when implanting the stem with extremes of version. Different approaches may make increased/decreased anteversion easier, but this is outside the scope of this study. Further research is required into the optimal version of components and whether this is affected by soft tissue approach, but this is also outside the scope of this study.

Future development into the use of robotics to navigate a cemented polished collarless stem into the desired version and leg length using haptic control, would further minimize surgeon error, and hopefully improve patient outcomes. This could also provide data to guide indications for dual mobility bearings and constrained prosthesis.

Conclusion

Target femoral stem anteversion can be achieved using a cemented, collarless stem in a CT-based 3D model in 80.5% of hips. With a small compromise in offset (mean 2.3 mm), this can be increased to 91.7%. Further research into the navigation of the cemented, collarless stem into the desired version may reduce surgeon error and potentially reduce the risk of instability post THA.

Conflicts of interest

Tom McCarthy is a paid employee of Stryker and has stock options for Stryker Corp. Sarah L. Whitehouse's position is partially supported via external institution by Stryker Australia and Stryker EU. Ross W. Crawford declares that Stryker Orthopedics support research projects of which they are Principal Investigator; declares they received royalties from Stryker Corporation in relation to products investigated in this paper; and is on the Editorial Board for the Journal of Arthroplasty. Matthew J. Wilson declares an Institutional Contract between Royal Devon and Exeter Hospital and Stryker to provide education courses, a long term database and research projects; declares they received royalties from Stryker Corporation; and is the Treasurer for the British Hip Society. The other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.101084.

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