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Accuracy of digital templating in uncemented primary total hip arthroplasty: which factors are associated with accuracy of preoperative planning?

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Abstract

Background: Preoperative planning is a fundamental step for successful total hip arthroplasty (THA). Studies have highlighted the accuracy of preoperative digital templating for estimating acetabular cup and stem size. Stem design such as single-wedge metadiaphyseal (Type 1 stem) versus mid-short stem (microplasty) and surgical approach (anterior, direct lateral or posterior) have not been well investigated as predictors of THA templating accuracy.

Methods: 204 patients (220 hips) who had undergone elective THA between November 2016 and December 2019 and presented a saved preoperative template were retrospectively reviewed. Templates from 5 different surgeons were involved in the analysis. 3 different approaches were used: direct lateral (DL), posterior (PA), direct anterior (DAA). 2 different stem designs were used: single-wedge metadiaphyseal and single-wedge mid-short (Biomet Taperloc Microplasty), while the acetabular component remained the same. Bivariate and multivariate regression analyses were performed to determine predictors of accuracy.

Results: Femoral component size templating accuracy was significantly improved when using the single-wedge mid-short stem (Taperloc Microplasty) design when performing bivariate analysis. Although accuracy of cup sizing was not affected by approach, precision was significantly better in the PA group ($p < 0.05$). Accuracy of templating was found to be independent of BMI and gender but dependent on presence of calibration marker and stem design ($p < 0.05$).

Conclusions: When striving for improved templating accuracy, acetabular and femoral component accuracy were best achieved using a calibration marker and a metaphyseal short femoral stem design.

Keywords

Accuracy, digital templating, preoperative planning, stem design, surgical approach, THA

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Introduction

Preoperative planning is a fundamental step for successful total hip arthroplasty (THA).[1] The surgeon is able to assess patient anatomy prior to surgery and determine appropriate implant size and position, as well as plan and anticipate intraoperative challenges. Templating also enables surgeons to prevent both intraoperative and postoperative complications, such as instability, leg-length discrepancy, periprosthetic fracture, implant loosening and loss of bone.[2–6] Digital templating has been shown to help accurately predict appropriate sized implants in 50% to 98% of cases within 1 size for the femoral stem, and between 52% and 91% to within 2 mm (1 size) for the acetabular component.[7–12]

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Table 1. Comparison of patient demographic characteristics between DAA, PA and DL.

	Cohort (n = 220)	DAA (n = 124)	PA (n = 79)	DL (n = 17)	p-Value
Age in years	65 ± 8.6	66.5 ± 8.5	61.7 ± 7.8	70.2 ± 7.6	<0.001*
Gender (% male)	110 (50%)	73 (59%)	33 (42%)	4 (24%)	0.005*
BMI in kg/m^2	30.5 ± 8.3	28.7 ± 5.8	33 ± 11	31.5 ± 6	0.009*
Size cup, mean	53 ± 4	53 ± 3	53 ± 5	52 ± 2.7	0.3
Size stem, mean	13 ± 3	13 ± 3	12 ± 4	11.1 ± 2.5	0.03*
Calibration ball, n (%)	143 (65%)	74 (60%)	59 (75%)	10 (59%)	0.08
Stem (% Micro)	127 (55.7%)	117 (94%)	5 (6.3%)	5 (29%)	<0.001*

BMI, body mass index.
*Significance at $p < 0.05$.

During the past decade, the direct anterior approach (DAA) has gained significant popularity due to sparing of muscle and improved early postoperative function compared to the posterior (PA) and direct lateral (DL) approaches.[13–15] The DAA also allows for easy use of intraoperative fluoroscopy, allowing for enhanced accuracy of cup placement and restoration of leg length and offset compared to standard techniques.[13–15] However, the DAA does present some challenges due to the associated learning curve, especially for surgeons who are new to the approach.[16,17] When the DAA and PA were compared by Rivera et al.,[18] in the context of assessing templating accuracy, they found that the femoral stem was 6 times more likely to be 2 sizes smaller with the DAA compared to the PA. This was attributed to the increased difficulty in femoral preparation and exposure, as well as the knowledge of increased risk of intraoperative fractures associated with the DAA. Such observations have led to the increased popularity of using a short metaphyseal filling stem with a DAA.[19] However, whether the use of such stem design is associated with improved template accuracy is unknown.

The study's primary aim was to establish whether the accuracy of digital templating for preoperative planning of THA differed for surgical approach: DAA, PA and DL or stem designs single-wedge metadiaphyseal versus single-wedge mid-short stem. The secondary aim was to determine whether there were any other pre- or intraoperative factors that impacted templating accuracy. We hypothesised that the calibration ball and single-wedge mid-short stem would have the greatest impact on templating accuracy.

Methods

This is a retrospective, institutional review board approved study. We reviewed charts, surgical records, and radiographs of patients who demonstrated a saved preoperative template report and x-ray, as per Bono 2004,[20] for primary uncemented THA at a single arthroplasty centre between November 2016 to December 2019. 5 surgeons' templates were included in the study. Of the 5 surgeons involved, only surgeon 1 (<5 years of practice) used solely the posterior approach in their practice. All other surgeons (2–5) involved were experienced in all 3 approaches with 3 of the 4 presenting >20 years experience respectively.

Our study included 204 patients who underwent 220 primary uncemented THA surgeries. We included patient who were operated on for either end-stage osteoarthritis (n = 218) or end-stage avascular necrosis (AVN) of the femoral head (n = 2). Exclusion criteria, as per a previous study by Shemesh et al.,[10] included prior surgery on the affected hip, THA for femoral neck fracture, post traumatic osteoarthritis, as well as complex deformities. Complex deformities such as severe hip dysplasia and Legg-Calvé-Perthes were excluded due to their possible negative effect on templating accuracy. All x-rays and operative notes were reviewed prior to inclusion in order to ensure that there were no intraoperative complications that may have affected the size of the prosthesis implanted. If this was the case, the patient was excluded.

The mean age at THA was 65 ± 8.6 years, 50% were males (n = 110) and the mean body mass index (BMI) was 30.5 ± 8.3 kg/m^2. 5 surgeons contributed to the patients involved in the study: Surgeon 1, 40 (18.2%); Surgeon 2, 89 (40.5%); Surgeon 3, 24 (10.9%); Surgeon 4, 40 (18.2%); and Surgeon 5, 27 (12.3%). One hundred and forty-three (65%) x-rays presented a calibration marker. Of the stems implanted, 127 (55.7%) had a mid-short stem design and the other 93 stems had a single-wedge metadiaphyseal design. The characteristics of the patients in the DAA, PA and DL approach are summarised in Table 1. There were significantly more mid-short stems used in the DAA group 117 (94%), compared to the 5 (6.3%) in the PA group and 5 (29%) in the DL group (Table 1) ($p < 0.001$).

All patients received a G7 Titanium cup (Zimmer Biomet Warsaw, IN, USA) for the acetabular component and either a single-wedge metadiaphyseal press fit stem[21] (Taperloc Complete, Zimmer Biomet Warsaw, IN, USA) or the single-wedge mid-short press fit stem (Taperloc Microplasty, Zimmer/Biomet Warsaw, IN, USA) for the femoral component, based on surgeon preference.[21,22] The G7 cup is a cementless hemispherical acetabular design with plasma spray finish and increases by 2 mm with each size. Both the single-wedge metadiaphyseal and mid-short stem are both proximally plasma spray-coated stem designs which increase in size by 1 for each sequential stem.

Preoperative templating

Prior to undergoing surgery, a standard anterior-posterior (AP) digital plain radiograph with film focus distance 1.15 metres was obtained in a supine position with both feet internally rotated 10–15° using a previously described radiographic protocol.[23] For magnification purposes, a spherical metallic calibration marker (25 mm) was ideally placed between the patient's legs, approximately at the great trochanter level. This was, however, not present on all study patients. For those who did not present a calibration marker, magnification of 115% was used prior to templating. Each radiograph was centred, which was confirmed by ensuring that the symphysis pubis was positioned directly below the coccyx and that both obturator foramina were symmetric.[23] Preoperative digital templating was performed by either the surgeon himself or his orthopaedic fellow using the "OrthoView" software by Materialise (Jacksonville, FL, USA). All templates were reviewed by a staff physician. Templating technique followed standard templating steps as described by Bono.[20]

Pre- and postoperative data collection

Templated cup and stem sizes, as well as offset of the stem used (standard or high) were recorded. The actual acetabular and femoral implant sizes were retrieved from each patient's respective operative report and compared to the templated implant sizes recovered from the "Orthoview" software report. Chosen implant sizes of the cup and stem were based on best fit and reconstruction assessments intraoperatively.

Radiographic analysis

Pre- and postoperative (from the 6-week clinical review) radiographs were reviewed in order to assess postoperative reconstruction. Total offset (TO femoral offset + acetabular offset) was measured on the anteroposterior (AP) radiograph as described by Dastane et al.;[27] this is the sum of femoral (FO) and acetabular offset (AO). In addition, acetabular component abduction angle and stem axis were measured from the postoperative radiographs. When assessing stem axis, a threshold of ±3° was used to describe neutral alignment (varus $\geqslant +3°$ vs. valgus $\leqslant -3°$), as described in previous published literature.[24,25]

Statistical analysis

Preoperative digital templating accuracy and precision were determined via 2 methods. First, precision was calculated as the difference between the templated implant sizes and those implanted in surgery (mean absolute error ± standard deviation [SD]), as documented in the operative report and implant records. Secondly, accuracy was determined by analysing the number of perfect matches (templated = implanted), and those within 1 (Stem:1 size; Cup: 2 mm) or 2 (Stem: 1; Cup: 4 mm) sizes from the respective template. We classified a template within ±2 sizes of those implanted as accurate as this seemed to be the acceptable range based on what has been previously reported in the literature.[7,10,26,27] The effect of accuracy of templating on accuracy of reconstruction was assessed. Patient and surgical variables included in our analysis were patient gender, sex, BMI, approach, stem design and presence or not of calibration marker. Descriptive statistics were applied to patient age, gender, BMI, implant design and surgical approach. A *t*-test and ANOVA were used for investigating quantitative variables. Chi-square test was used for qualitative variable analysis.

We conducted a multivariate logistic regression analysis to assess which factors were most effective in predicting implant size within 2 sizes. Factors having a significance with a $p < 0.2$ in the univariate analysis were included in the model. All variables were assessed for confounding and interaction where appropriate. A *p*-value of <0.05 was regarded as significant. Statistical analysis was performed using SPSS software version 27 by IBM SPSS statistics for windows 10.

Results

Preoperative templating accuracy for entire cohort

When assessing precision of cup sizing, the average deviation from templated was −0.2 ± 1.3 sizes. Stem precision was found to be more variable with average deviation from templated of 1.1 ± 2.2 sizes. 75% of cups implanted were within ±1 size (2 mm) of templated and 91.4% were within ±2 sizes (4 mm) of templated (Figure 1) (Table 2). On the femoral side, 48.6% of stems were templated within ±1 size and 71.4% were templated within ±2 sizes (Figure 2) (Table 2). When assessing stem offset, 63.6% ($n = 140$) and 36.4% ($n = 80$) had been templated as standard and high offset respectively. Of these, 83.2% ($n = 183$) of offset type used intraoperatively matched that of the template. Total offset was reconstructed within 5 mm between pre- and postoperative x-rays in 63.8% of cases. When templated and used offset-type of stem matched, there was a significant increase in probability (odds ratio [OR] 1.93; 95% confidence interval [CI], 1.17–3.2; $p = 0.04$) of achieving reconstruction of native offset within 5 mm. Restoration of offset was, however, not associated with perfect match stem size (OR 0.87; 95% CI, 0.36–2.1; $p = 0.76$) or when matched within 2 sizes (OR 0.96; 95% CI, 0.46–2; $p = 0.91$).

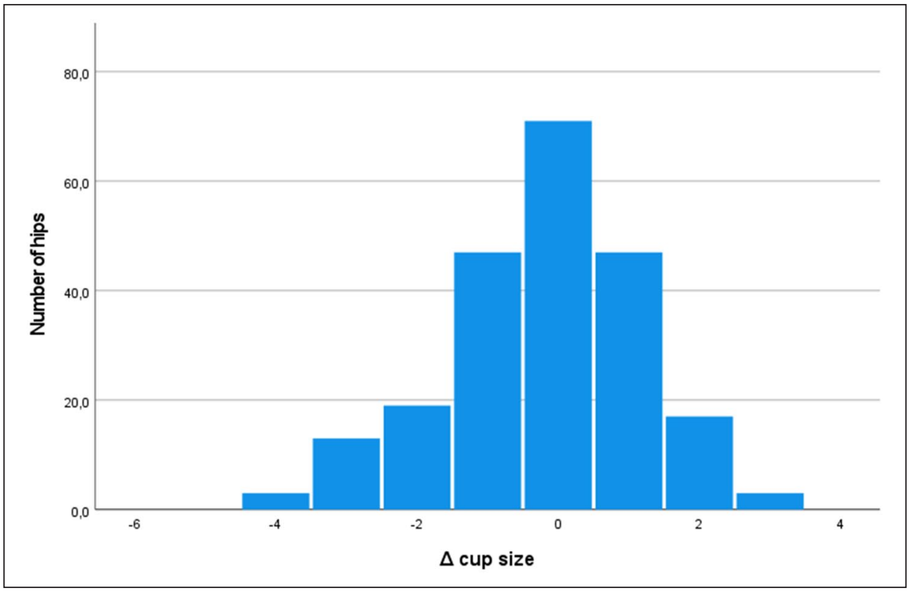

Figure 1. Differences between templated and implanted cups. Positive values indicate that the cup that was implanted was larger than the one that was on the pre-operative template (1 = 2 mm, 2 = 4 mm).

Table 2. Digital templating accuracy for all THA patients.

	All cohort (220 hips)
100% accuracy cup size	32.3% (71)
Accuracy within 1 cup size	75% (165)
Accuracy within 2 cup sizes	91.4% (201)
Δ implanted – Templated cup	−0.2 ± 1.3
100% accuracy stem size	19.1% (42)
Accuracy within 1 stem size	48.6% (107)
Accuracy within 2 stem sizes	71.4% (157)
Δ implanted – Templated stem	1.1 ± 2.2

There was also no difference in cup abduction angle or coronal stem alignment whether sizes were a perfect match or within 2 sizes of the template ($p > 0.05$), with an average cup abduction angle of 42.3° ± 6° (26–62°) angle and coronal alignment of 1.2° ± 2.5° (−6–10°), with 179 (81.4%) stems placed in neutral alignment.

Preoperative templating relative to surgical approach

Significant differences were observed in both precision and accuracy when comparing approaches as detailed in Supplemental Material: eTable 1. The posterior approach demonstrated the best precision (PA: 0 ± 1.4 sizes), and similar accuracy to the anterior approach (PA: 94% (114/124); DAA: 92% (74/79) within 2 sizes) when assessing cup sizing. When stem sizing was analysed, however, significant differences ($p < 0.01$) were observed between groups when assessing both precision and accuracy, with the DAA and DL approach demonstrating better precision (DAA: 0.67 ± 1.9 sizes; DL: 0.5 ± 2) and accuracy (DAA: 79% (98/124); DL: 71% (12/17) within 2 sizes) compared to the PA (Supplemental Material: eTable 1). There was no significant difference between approaches in reliably restoring total offset (Supplemental Material: eTable 2). There were also no significant differences in cup abduction angle or coronal stem alignment between approaches (Supplemental Material: eTable 2).

Preoperative digital templating accuracy relative to stem design

The mid-short stem design demonstrated significantly better accuracy when assessing cases of perfect match ($p < 0.05$), and within 2 sizes ($p < 0.05$) from the digital template (Table 3). The mid-short stem also demonstrated greater precision (0.58 ± 1.9 vs. 1.72 ± 1.9; $p < 0.001$).

Surgeon-specific accuracy

Significant differences in templating between surgeons were observed when assessing accuracy of the cup within 2 sizes (4 mm), as well as precision of both the cup ($p < 0.001$) and stem size ($p < 0.001$) relative to the template (Supplemental Material: eTable 3).

Impact of calibration ball on templating accuracy

The presence of a calibration ball was associated with greater accuracy and precision in acetabular component sizing (absolute error, ±1 and ±2 sizes of template,

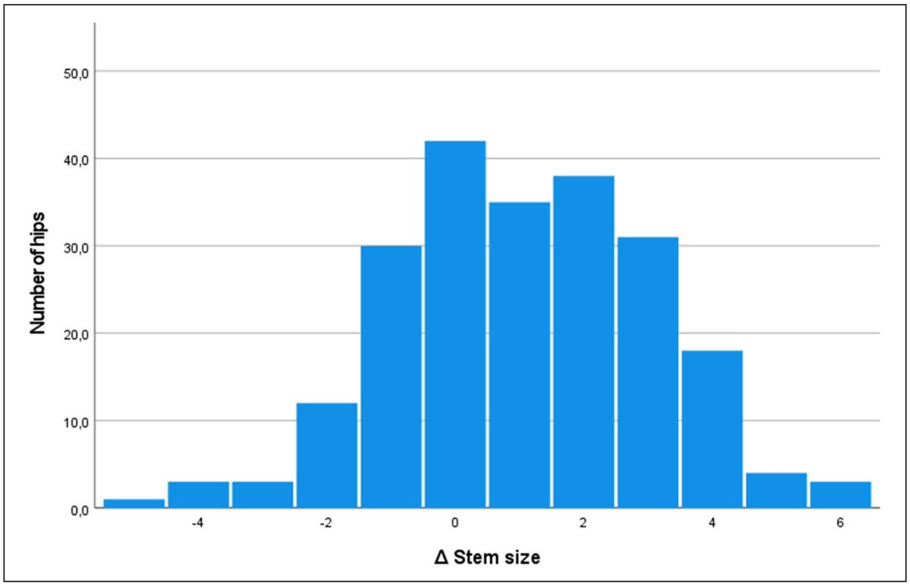

Figure 2. Difference between templated and implanted stems. Positive values indicate that the stem that was implanted was larger than the one that was on the pre-operative template.

Table 3. Bivariate analysis comparing digital templating accuracy of the femoral component relative to stem design.

	Taperloc ($n=93$ hips)	Microplasty ($n=127$ hips)	p-Value
100% accuracy stem size	11/93 (12%)	31/127 (24%)	0.02*
Accuracy within 1 size	37/93 (39%)	70/127 (55%)	0.025*
Accuracy within 2 sizes	56/93 (60%)	101/127 (79%)	0.002*
Δ implanted – templated	1.72 ± 1.9	0.58 ± 1.9	<0.001*

*Significance at $p<0.05$.

Table 4. Multivariate analysis of factors associated with increased digital templating accuracy.

Risk factor	Cup size accuracy ±2 sizes	Stem size accuracy ±2 sizes
	Odds ratio (95% CI) – p-value	Odds ratio (95% CI) – p-value
BMI grade (according to WHO)		0.6 (0.3–1.6) – 0.3
Approach	1.7 (0.9–3.4) – 0.138	1.5 (0.6–3) – 0.4
Calibration ball	4.9 (1.8–13.8) – 0.002*	0.7 (0.3–1.6) – 0.4
Stem design		4.1 (1.3–12.9) – 0.02*

CI, confidence interval; BMI, body mass index.
*Significance at $p<0.05$.

$p<0.05$). However, the presence of a calibration ball was not associated with improved accuracy of stem sizing but did significantly impact precision ($p=0.04$) (Supplemental Material: eTable 4).

Multivariate regression

Only 2 factors resulted in improved templating accuracy. The presence of a calibration ball (OR 4.9; range 1.8–13.8; $p=0.002$) improved the prediction of accurate cup size (within ±2 sizes), and the presence of a mid-short stem design (OR 4.1; range 1.3–12.9; $p=0.02$) resulted in an improved ability to predict stem size (within ±2 sizes) (Table 4).

Discussion

This study retrospectively analysed 220 digital templates used for preoperative planning during elective THA. The primary goals were to establish the potential impacts of approach (DAA vs. PA vs. DL) and stem design (single-wedge metadiaphyseal vs. single-wedge mid-short stem) on templating accuracy and precision, as well as to investigate whether certain pre- or intraoperative factors may have a significant influence. Our results show that the PA yields significantly better precision ($p < 0.05$) but is no different to the DAA or DL in accurately predicting cup size. The DAA approach; however, was significantly more accurate ($p < 0.01$) and precise ($p < 0.001$) when predicting stem sizing (within 2 sizes). This was most likely due to the stem design, as the majority (94%) (Table 1) of DAA THA cases utilised the mid-short stem design. When assessing the impact of stem design as a bivariate, the single-wedge mid-short stem exhibited superior precision (within 1 and 2 stems size) and accuracy (ability to perform a perfect match) compared to the single-wedge metadiaphyseal stem. We were able to demonstrate that the ability of the template to predict accurate and precise acetabular and femoral component sizing was independent of patient sex and BMI. Both calibration marker, for cup accuracy, and stem design for femoral component accuracy, were significant factors when performing multivariate regression analysis.

When assessing all 221 hips, the femoral component was predicted within ±1 size in 48.6% and acetabular component in 75% of cases. This is similar to results seen in studies by Petretta et al.[26] and Crooijmans et al.[12] Petretta et al.[26] demonstrated accuracy between 27% and 75%; however, this was dependant on the individual templating (resident, fellow or staff); whereas Crooijmans et al.[12] demonstrated accuracy of 50%, despite others demonstrating much better accuracy with numbers as high as 85%.[10] The acetabular component template accuracy was within ±1 size (2 mm) in 75% of cases, which is similar to previous studies.[7,26,27] Percentage accuracy increased to 91.4% and 71.4% for both the cup and stem respectively when within ±2 sizes (4 mm) of template. Contrary to others, who have demonstrated no significant difference between the DAA and PA with regards to accuracy of the template to predict stem size, the DAA demonstrated significantly improved accuracy ($p < 0.001$) when predicting within 2 stem sizes.[10,18] This is most likely due to the mid-short stem design primarily used with this approach, yielding it less likely to pot distally prior to achieving metaphyseal fit, which can be seen in a femur with an elevated canal flare index (CFI).[29]

When analysing femoral offset, cup abduction and coronal stem alignment, we were able to demonstrate that offset was appropriately restored regardless of the approach used, which is similar to what has been observed previously in the literature.[10,30]

However, when templated offset (high or standard) matched that of offset use intraoperatively, the likelihood of reconstructing native offset within 5 mm was significantly improved (OR 1.93; 95% CI, 1.17–3.2; $p = 0.04$). This is an important observation as the restoration of native offset is an important factor in maintaining hip stability and improving function postoperatively.[31,32] Coronal reconstruction was not impacted by the precision or accuracy of the template, with no differences observed in offset or coronal alignment whether stem size used was a perfect match or within 2 sizes ($p > 0.05$). This is likely to have occurred because surgeons used visual and tactile cues (e.g. soft tissue tension, canal fill) intraoperatively to appropriately reconstruct the hip, instead of strictly following the preoperative plan, which might have otherwise led to adversity. Coronal reconstruction was not different between approaches; these findings are contrary to work published by Abe et al.,[25] which demonstrated a significant difference in coronal stem alignment between the DAA and PA, with DAA trending more towards valgus alignment. However, similar results were observed by Vaughan et al.,[33] which demonstrate no difference between the anterolateral and PA when assessing coronal alignment.

When we specifically examined the impact of stem design (single-wedge metadiaphyseal versus mid-short stem) on the accuracy of preoperative digital templating, significant differences were observed, with improved accuracy when using the mid-short stem (i.e. Taperloc Microplasty). This finding is in contradiction to others, such as Schmidutz et al.,[28] who demonstrated no significant difference in accuracy of templating the correct stem within 1 size when comparing short stem (89%) and standard-length stem (88.5%). Brenneis et al.[34] also looked at accuracy of preoperative templating and the impact of stem morphology (short vs. standard) and found no significant differences when using 2D digital templating. However, when comparing 2D and 3D digital templating techniques, a significant difference was found with short stems only ($p = 0.03$).

In our multivariate analysis, neither BMI nor surgical approach was associated with increased accuracy of the template (Table 4). This partly contradicts a recent study by Shemesh et al.[10] which had demonstrated male gender to be associated with a 2.74 times odds of inaccurately selecting the stem size compared with female patients. Holzer et al.[35] demonstrated significantly greater inaccurate planning in overweight individuals compared to those with normal BMI. Design of prosthesis and patient gender had no influence on predicting component size, but the study's conclusions were not drawn from a multivariate analysis. Our analysis demonstrated an association with improved templating accuracy of the cup within 2 sizes (4 mm) with the presence of calibration ball (OR 4.9 [1.8–13.8]; $p = 0.002$) as well as improved templating accuracy within ±2 sizes of the stem based on stem design (OR 4.1 [1.3–12.9]; $p = 0.02$), with the mid-short stem yielding better results.

With a proper AP pelvis radiograph, as described by Clohisy et al.,[23] presence of a calibration marker and appropriate stem design, we have shown the ability to achieve accurate templating. We hypothesise that the reason for implantation of larger stems than templated (1.72 ± 1.9 sizes) in the Taperloc Complete group may be attributed to the effect of CFI, particularly with standard length stem design.[29,36] Work by Merle et al.[37] has also demonstrated that greater error is present when defining proximal femur canal shape using an AP pelvis radiograph, as the beam is centred further away from the hip, suggesting that an AP radiograph of the hip provides a more accurate and reliable representation of native anatomy. We believe that good templating practice should include the following when looking to achieve accuracy and precision in THA: appropriate AP radiograph of the pelvis and hip; presence of a calibration marker; evaluation of the CFI; and consideration of mid-short stem design when performing the DAA.

The strengths of this study are that it is the first study, to our knowledge, that has completed a comprehensive review on the accuracy of 2D digital templating looking at both approach and stem design as primary predictors of accuracy. We believe that our data is more generalisable to everyday practice due to the subtle minutia that each individual surgeon presents in their day-to-day practice, as multiple surgeons were involved. The retrospective design of the study eliminates the possibility of the Hawthorne effect, as surgeons were unaware that their templates would be analysed at the time of completion. The main limitation of the study was that the groups (DAA vs. PA vs. DL) presented significant heterogeneity when comparing age, sex, BMI, presence of calibration marker and the respective use of each stem design, with the majority of the mid-short stems used during the DAA. Lastly, we did not assess for intra- and inter-observer reliability, as each template had only been performed by a single surgeon; this could be perceived as a weakness as we did not verify reproducibility.

We have demonstrated that digital templating for primary cementless THA can accurately predict appropriately sized implants. The presence of a calibration marker and stem design have been identified through multivariate regression, as the 2 most important factors when looking to achieve an accurate template for both the acetabular and femoral component respectively. We believe that the CFI may also play an important role in preoperative preparation, as the proximal femoral anatomy seems to predominantly impact the accuracy of stem sizing in standard length stems due to the potential mismatch that can occur between the metaphyseal and diaphyseal anatomy.[33] If good templating practices are followed, we believe that this may provide an opportunity to decrease instrumentation in the operating room by including only what is necessary to perform the procedure This would account for expected variability, potentially creating increased efficiency and cost savings in elective THA.

Although templating is important in achieving restoration of native anatomy and hip stability, we were able to demonstrate the particular importance of templated offset in achieving this goal, as it was the only parameter to demonstrate significance in doing so with appropriate reconstruction being achieved even in the setting where sizing of the stem or cup were not a perfect match. This highlights the continued importance of intraoperative cues and surgical judgement in achieving restored hip biomechanics and that one should not "blindly" follow the template as this might lead to reconstruction error and adverse outcomes.

Declaration of conflicting interests

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Supplemental material

Supplemental material for this article is available online.

References

1. Eggli S, Pisan M and Müller ME. The value of preoperative planning for total hip arthroplasty. *J Bone Joint Surg Br* 1998; 80: 382–390.
2. Bourne RB and Rorabeck CH. Soft tissue balancing: the hip. *J Arthroplasty* 2002; 17: 17–22.
3. Carter LW, Stovall DO and Young TR. Determination of accuracy of preoperative templating of noncemented femoral prostheses. *J Arthroplasty* 1995; 10: 507–513.
4. Della Valle AG, Padgett DE and Salvati EA. Preoperative planning for primary total hip arthroplasty. *J Am Acad Orthop Surg* 2005; 13: 455–462.
5. Haddad FS, Masri BA, Garbuz DS, et al. The prevention of periprosthetic fractures in total hip and knee arthroplasty. *Orthop Clin North Am* 1999; 30: 191–207.
6. McAuley JP and Ridgeway SR. Preoperative planning to prevent dislocation of the hip. *Orthop Clin North Am* 2001; 32: 579–586, viii.
7. Gamble P, de Beer J, Petruccelli D, et al. The accuracy of digital templating in uncemented total hip arthroplasty. *J Arthroplasty* 2010; 25: 529–532.
8. Kumar PG, Kirmani SJ, Humberg H, et al. Reproducibility and accuracy of templating uncemented THA with digital radiographic and digital TraumaCad templating software. *Orthopedics* 2012; 32: e815–e819.
9. Shaarani SR, McHugh G and Collins DA. Accuracy of digital preoperative templating in 100 consecutive uncemented total hip arthroplasties: a single surgeon series. *J Arthroplasty* 2013; 28: 331–337.

10. Shemesh SS, Robinson J, Keswani A, et al. The accuracy of digital templating for primary total hip arthroplasty: is there a difference between direct anterior and posterior approaches? *J Arthroplasty* 2017; 32: 1884–1889.
11. The B, Diercks RL, van Ooijen PM, et al. Comparison of analog and digital preoperative planning in total hip and knee arthroplasties. A prospective study of 173 hips and 65 total knees. *Acta Orthop* 2005; 76: 78–84.
12. Crooijmans HJ, Laumen AM, van Pul C, et al. A new digital preoperative planning method for total hip arthroplasties. *Clin Orthop Relat Res* 2009; 467: 909–916.
13. Anterior Total Hip Arthroplasty Collaborative Investigators, Bhandari M, Matta JM, Dodgin D, et al. Outcomes following the single-incision anterior approach to total hip arthroplasty: a multicenter observational study. *Orthop Clin North Am* 2009; 40: 329–342.
14. Matta JM and Ferguson TA. The anterior approach for hip replacement. *Orthopedics* 2005; 28: 927–928.
15. Matta JM, Shahrdar C and Ferguson T. Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. *Clin Orthop Relat Res* 2005; 441: 115–124.
16. Hartford JM and Bellino MJ. The learning curve for the direct anterior approach for total hip arthroplasty: a single surgeon's first 500 cases. *Hip Int* 2017; 27: 483–488.
17. Dall'Oca C, Ceccato A, Cresceri M, et al. Facing complications of direct anterior approach in total hip arthroplasty during the learning curve. *Acta Biomed* 2020; 91: 103–109.
18. Rivera F, Leonardi F, Evangelista A, et al. Risk of stem undersizing with direct anterior approach for total hip arthroplasty. *Hip Int* 2016; 26: 249–253.
19. Stulberg SD and Patel RM. The short stem: promises and pitfalls. *Bone Joint J* 2013; 95-B(Suppl. A): 57–62.
20. Bono JV. Digital templating in total hip arthroplasty. *J Bone Joint Surg Am* 2004; 86-A(Suppl. 2): 118–122.
21. Kim JT and Yoo JJ. Implant design in cementless hip arthroplasty. *Hip Pelvis* 2016; 28: 65–75.
22. Khanuja HS, Vakil JJ, Goddard MS, et al. Cementless femoral fixation in total hip arthroplasty. *J Bone Joint Surg Am* 2011; 93: 500–509.
23. Clohisy JC, Carlisle JC, Beaulé PE, et al. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am* 2008; 90(Suppl. 4): 47–66.
24. Wang H, Gu J, Liu X, et al. Variation in greater trochanteric lateroversion: a risk factor for femoral stem varus in total hip arthroplasty. *Hip Int* 2020; 30: 33–39.
25. Abe H, Sakai T, Takao M, et al. Difference in stem alignment between the direct anterior approach and the posterolateral approach in total hip arthroplasty. *J Arthroplasty* 2015; 30: 1761–1766.
26. Petretta R, Strelzow J, Ohly NE, et al. Acetate templating on digital images is more accurate than computer-based templating for total hip arthroplasty. *Clin Orthop Relat Res* 2015; 473: 3752–3759.
27. Dastane M, Door LD, Tarwala R, et al. Hip offset in total hip arthroplasty: quantitative measurement with navigation. *COOR* 2011; 469: 429–436.
28. Schmidutz F, Steinbruck A, Wanke-Jellinek L, et al. The accuracy of digital templating: a comparison of short-stem total hip arthroplasty and conventional total hip arthroplasty. *Int Orthop* 2012; 36: 1767–1772.
29. Brumat P, Pompe B, Antolič V, et al. The impact of canal flare index on leg length discrepancy after total hip arthroplasty. *Arch Orthop Trauma Surg* 2018; 138: 123–129.
30. Innmann MM, Streit MR, Kolb J, et al. Influence of surgical approach on component positioning in primary total hip arthroplasty. *BMC Musculoskelet Disord* 2015; 16: 180.
31. Forde B, Engeln K, Bedair H, et al. Restoring femoral offset is the most important technical factor in preventing total hip arthroplasty dislocation. *J Orthop* 2018; 15: 131–133.
32. Innmann MM, Maier MW, Streit MR, et al. Additive influence of hip offset and leg length reconstruction on postoperative improvement in clinical outcome after total hip arthroplasty. *J Arthroplasty* 2018; 33: 156–161.
33. Vaughan PD, Singh PJ, Teare R, et al. Femoral stem tip orientation and surgical approach in total hip arthroplasty. *Hip Int* 2007; 17: 212–217.
34. Brenneis M, Braun S, van Drongelen S, et al. Accuracy of preoperative templating in total hip arthroplasty with special focus on stem morphology: a randomized comparison between common digital and three-dimensional planning using biplanar radiographs. *J Arthroplasty* 2021; 36: 1149–1151.
35. Holzer LA, Scholler G, Wagner S, et al. The accuracy of digital templating in uncemented total hip arthroplasty. *Arch Orthop Trauma Surg* 2019; 139: 263–268.
36. Mavčič B and Antolič V. Cementless femoral stem fixation and leg-length discrepancy after total hip arthroplasty in different proximal femoral morphological types. *Int Orthop* 2021; 45: 891–896.
37. Merle C, Waldstein W, Gregory JS, et al. Proximal femoral canal shape is more accurately assessed on AP hip radiographs than AP pelvis radiographs in primary hip osteoarthritis. *Hip Int* 2013; 23: 484–491.