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Original research

Variance in predicted cup size by 2-dimensional vs 3-dimensional computerized tomography–based templating in primary total hip arthroplasty

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ABSTRACT

Background: Preoperative total hip arthroplasty templating can be performed with radiographs using acetate prints, digital viewing software, or with computed tomography (CT) images. Our hypothesis is that 3D templating is more precise and accurate with cup size prediction as compared to 2D templating with acetate prints and digital templating software.

Methods: Data collected from 45 patients undergoing robotic-assisted total hip arthroplasty compared cup sizes templated on acetate prints and OrthoView software to MAKOplasty software that uses CT scan. Kappa analysis determined strength of agreement between each templating modality and the final size used. *t* tests compared mean cup-size variance from the final size for each templating technique. Interclass correlation coefficient (ICC) determined reliability of digital and acetate planning by comparing predictions of the operating surgeon and a blinded adult reconstructive fellow.

Results: The Kappa values for CT-guided, digital, and acetate templating with the final size was 0.974, 0.233, and 0.262, respectively. Both digital and acetate templating significantly overpredicted cup size, compared to CT-guided methods ($P < .001$). There was no significant difference between digital and acetate templating ($P = .117$). Interclass correlation coefficient value for digital and acetate templating was 0.928 and 0.931, respectively.

Conclusions: CT-guided planning more accurately predicts hip implant cup size when compared to the significant overpredictions of digital and acetate templating. CT-guided templating may also lead to better outcomes due to bone stock preservation from a smaller and more accurate cup size predicted than that of digital and acetate predictions.

Introduction

Total hip arthroplasty (THA) is one of the most successful orthopaedic procedures [1]. It offers reliable pain relief and considerable improvement of function in patients suffering with arthritic conditions of the hip [1]. Preoperative planning is of paramount importance in obtaining reproducible results in THA [2]. An integral aspect of preoperative planning is templating which is important for several reasons—it allows the surgeon to restore biomechanics, it helps with implant selection, and it allows the surgeon to consider osseous anatomy for appropriate implant placement [3]. Templating can be performed using radiographs or computed tomography (CT) images. Radiographic templating can be performed using acetate prints with a known magnification factor, which is usually 115%, or it can be performed using digital templating software after calibration for size. Digital templating software also enables the surgeon to select from a library of templates and electronically overlay them onto a digital radiograph [2]. Both acetate and digital templating allow 2-dimensional (2D) preoperative planning.

In contrast to digital templating, CT images are used by surgical robotic systems for preoperative templating. CT-based templating enables the surgeon to assess the 3-dimensional (3D) anatomy and

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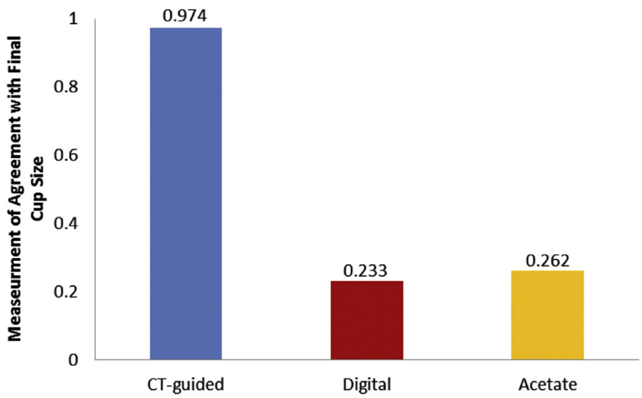

Figure 1. Kappa analysis of CT-guided, digital, and acetate templating.

place components appropriately. CT guidance is utilized to plan the optimal prosthesis size and fit to restore center of hip rotation, limb-length inequality, and optimize soft-tissue balance. Recent studies have shown that CT-based 3D templating is more accurate at predicting implant sizes and positioning than 2D radiograph-based templating, in nondysplastic and dysplasia-related THA [4-7].

To our knowledge, studies have compared 3D templating to only one form of 2D templating—acetate prints or digital templating software. Our study aims to compare the variability in cup sizes between acetate prints, a digital templating software, and CT-based 3D templating for robotic-assisted cementless primary THA. Our hypothesis is that 3D templating is more precise and accurate with cup-size prediction as compared to 2D templating with acetate prints and digital templating software and that reliably, a smaller acetabular cup size will be implanted due to the robotic accuracy.

Material and methods

This study received institutional review board approval at our urban, orthopaedic-specialty hospital. The inclusion criteria consisted of adults patients >18 years old, who had been indicated for a THA and had undergone robotic-assisted surgery. The exclusion criteria were patients <18 years old and contraindicated for robotic-assisted surgery. From January to August 2015, we identified 45 patients at our institution that underwent a robotic-assisted THA performed by a single surgeon. For each patient, we obtained a preoperative anteroposterior radiograph of the pelvis along with a limited nonintraveneous contrast CT scan of the pelvis and the operative hip. This CT scan was obtained as per the guidelines of the MAKOplasty robotic surgical system (MAKOplasty, Ft. Lauderdale, FL).

The MAKO templating software currently only allows templating with Stryker implants, and we solely focused on acetabular cup templating using radiographs and CT scans. The senior surgeon performed templating on acetate prints, the digital templating software, and on the CT-based MAKO templating software. The cup sizes determined from these various modes of templating were then compared to the actual cup size implanted. An adult reconstruction fellow independently templated the cup sizes using acetate prints and the digital templating software. The fellow was blinded to the actual cup size placed intraoperatively.

Acetate prints were obtained with standard 115% magnification. The radiographs were also reviewed with the OrthoView digital templating software (Plymouth, MI). The robotic-assisted procedures were performed by a single surgeon using a minimally invasive posterior approach in the lateral position using rigid pelvic fixation.

We performed a Cohen's Kappa analysis to determine the interrater agreement between CT-guided prediction and the final cup size used, digital templating and the final cup size used, and acetate templating and the final cup size used in order to see which modality carried a higher measurement of agreement with the final cup size used. The mean cup size difference from the final cup size was calculated for the 3 different templating modalities and compared to one another via 3 *t*-test analyses. We tested the reliability of digital templating and acetate templating with an interclass correlation coefficient (ICC) analysis of the predicted cup size as determined by the operating orthopaedic surgeon and a third-party blinded orthopaedic adult reconstructive fellow. All statistical tests were conducted using SPSS for Windows. Statistical significance for all tests was set to a $P < .05$.

Results

With regard to demographics, the mean age and standard deviation of the 45 patients were 54.0 ± 10.8 years, with 44.4% of patients being male and 55.6% of patients being female. THAs (53.3%) were performed on the right hip, 44.4% of THA were performed on the left hip, and 2.2% were bilateral. The primary diagnosis was osteoarthritis in 53.3% patients, hip dysplasia—related arthritis in 26.7% patients, osteonecrosis in 17.8% patients, and rheumatoid arthritis in 2.2% patients.

To determine the strength of association between the predicted cup size using CT-guided templating and the final cup size used, we performed a kappa analysis (Fig. 1). The kappa measurement of agreement was 0.974 with a standardized error of 0.026. This association was stronger than both digital templating and acetate templating predictive capability. Digital templating and the final cup size used shared a measurement of agreement of 0.233 with a standardized error of 0.079. Acetate templating and the final cup size used shared a measurement of agreement slightly higher than

Table 1
Kappa—measurement of agreement with final cup size.

Templating modality	n	Kappa—measurement of agreement
CT guided and final	45	0.974
Digital and final	45	0.233
Acetate and final	45	0.262

Table 2
t test—cup size difference from final: CT vs digital.

Templating modality	n	Mean	SD	SEM	95% Confidence interval		Sig. (2 tailed)
					Lower	Upper	
CT guided	45	−0.022	0.149	0.022	−1.391	−0.787	<0.001
Digital	45	1.067	1.009	0.150			

SD, standard deviation; SEM, standard error of the mean.

Table 3
t test—cup size difference from final: CT vs acetate.

Templating modality	n	Mean	SD	SEM	95% Confidence interval		Sig. (2 tailed)
					Lower	Upper	
CT guided	45	−0.022	0.149	0.022	−1.068	−0.398	<0.001
Acetate	45	0.711	1.120	0.167			

SD, standard deviation; SEM, standard error of the mean.

Table 4
t test—cup size difference from final: digital vs acetate.

Templating modality	n	Mean	SD	SEM	95% Confidence interval		Sig. (2 tailed)
					Lower	Upper	
Digital	45	1.067	1.009	0.150	−0.091	0.802	0.117
Acetate	45	0.711	1.121	0.167			

that of digital templating of 0.262 with a standardized error of 0.080. Hence, CT-guided templating was more predictive of the final cup size used as compared to digital templating and acetate templating (Table 1).

Three different *t* tests were used to compare the mean differences between the CT-guided predictions vs final, digital predictions vs final, and acetate predictions vs final (Tables 2-4). Figure 2 illustrates the mean cup size differences between the three templating modalities and the final cup size placed. A mean of −0.02 cup-size difference existed in CT-guided cup-size prediction from the actual cup sized used. CT-guided templating predicted the final cup size in 44 of the 45 cases, the one being underpredicted by 1 cup size. In contrast, a mean of +1.07 cup size difference existed in digital cup-size predictions from the actual size used. Digital templating predicted the final cup size in 15 cases, underpredicted in 1 case, and overpredicted in 29 cases. It was found that digital templating significantly overpredicted the cup size, when compared to CT-guided methods ($P < .001$). Acetate templating had a mean of +0.711 cup size difference from the final size used. It correctly predicted in 16 cases, underpredicted in 5 cases, and overpredicted in 24 cases. Acetate templating was also found to significantly overpredict the cup size when compared to CT-guided templating ($P < .001$). The final *t*-test analysis was performed to compare whether a difference existed in the predicive capabilities of digital and acetate methods. With a $P = .117$, there was no significant difference between the 2 templating modalities.

An ICC analysis was performed in order to determine the precision of digital templating. Cup sizes predicted as determined by the senior surgeon and the fellow were compared. The single-measure interclass correlation value was 0.928, indicating a fairly strong reliability.

The reliability of acetate templating was then tested via ICC analysis as demonstrated in Tables 5 and 6. The same senior surgeon and fellow were compared. The single-measure interclass correlation value was 0.931, indicating a fairly strong reliability.

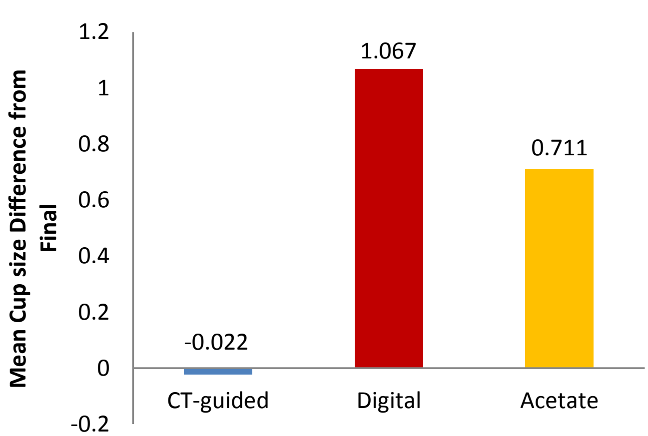

Figure 2. Mean cup size difference from final: CT-guided vs digital vs acetate templating.

Table 5
Intraclass correlation coefficient—blinded vs unblinded digital templating.

	Intraclass correlation	95% Confidence interval		Significance
		Lower	Upper	
Single measures	0.928	0.817	0.967	<0.001
Average measures	0.963	0.899	0.983	<0.001

Discussion

Our data showed an *Almost perfect agreement* ($\kappa = 0.81$-0.99) of 0.974 for the CT-guided templating relative to the *Fair agreement* ($\kappa = 0.21$-0.40) of 0.233 for the digital templating and 0.262 for acetate templating. This strong association is indicative of more accurate cup size prediction by the CT-guided templating modality. The differences in the cup sizes predicted were statistically significant, with a $P < .001$. Both digital and acetate templating significantly overestimates the cup size when compared to CT-guided templating, with a $P < .001$. When compared to each other, there was no difference found between digital and acetate templating ($P < .001$). Figure 3 demonstrates that the digital templating modality overestimated cup sizes in 29 cases, underestimated in 1 case, and correctly predicted the final cup sizes in 15 cases, of the 45 total cases. Acetate templating overpredicted in 24 cases, underpredicted in 5 cases, and correctly predicted 16 cases. CT-guided templating correctly predicted the final cup size in all but one instance. After investigating the precision of digital templating and acetate templating, we found an ICC of 0.963 and 0.964 average measures, respectively. Although the 2 modalities were precise, they were not as accurate as CT-guided templating in predicting the final cup size used for the THA. With more accurate template planning, surgical error may effectively be limited. CT-guided templating has demonstrated that it provides a more accurate starting point for the surgeon, as compared to 2D methods.

Previous studies have shown that digital templating may be an effective alternative templating modality to acetate templating. However, according to Iorio et al. [8], digital templating was not more accurate than acetate templating. The study found that acetate templating predicted cup size within one size in 196 (78%) of 250 cases, whereas digital templating predicted cup size within one size in 30 (60%) of 50 cases. Digital templating significantly overpredicted cup size ($P < .001$), but the mean absolute errors between the 2 templating modalities differ significantly for hip cup size ($P = .090$) [8]. Digital preoperative templating in a digital radiology environment enables the hip reconstruction surgeon to perform preoperative planning and implant sizing in a fast, reproducible, and cost-efficient manner [4]. A prospective study analyzing 173 knees by The et al. showed that digital templating using preoperative planning software was less frequently correct than analog planning [3].

More recent studies have shown the effectiveness of CT-guided templating and the high predictive value of this modality. CT-guided planning was more accurate than the conventional templating regarding the component size prediction and accuracy

Table 6
Intraclass correlation coefficient—blinded vs unblinded acetate templating.

	Intraclass correlation	95% Confidence interval		Significance
		Lower	Upper	
Single measures	0.931	0.874	0.962	<0.001
Average measures	0.964	0.933	0.981	<0.001

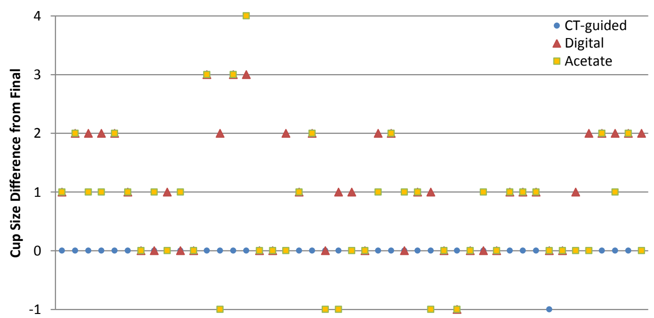

Figure 3. CT-guided vs digital vs acetate templating predicted cup size difference from final size used in 45 cases.

of the hip reconstruction planning [4]. Computer simulation of preoperative planning using 3D recreations of prosthetic fit can be combined with surgical navigation to more accurately place implants in the optimal position [4]. The lack of accuracy for the digital templating is probably related to the fact that the hip anatomy is not accurately analyzed on radiographs, especially the femur, as reported by Eckritch et al. [9] We found that the incorrect positioning of the scaling objects due to technical error is the major reason for incorrect predictions by digital templating.

At our institution, a 25-mm metallic sphere is placed in all preoperative x-rays to allow for accurate scaling of the x-rays by accounting for magnification based on patient body habitus and distance from the x-ray source and detector. Ideally, the scaling sphere is placed as close to the hip joint as possible (ie, lateral or medial to the hip). In the anterior-posterior direction, the scaling sphere should be placed at the level of the center of the femoral head. To avoid parallax distortion, the scaling sphere should be placed as close to the center of the x-ray plate as possible. Ideal positioning of the scaling sphere provides accurate estimation of implant sizes by digital templating; however, we have found that for every 4-cm discrepancy in the anterior-posterior direction, digital templating will be inaccurate by one cup size [10]. The scaling spheres must be consistently placed in the correct location in order to have an accurate measurement scale. This becomes challenging in obese patients where anatomic landmarks are difficult to identify. If the scaling spheres are not consistent in their placement, the digital template will have an unreliable and inaccurate estimate [10]. There has yet to be a study analyzing the reliability and precision of digital templating if the error due to scaling sphere placement can be overcome.

CT-guided templating is 3D in nature, and recently, Sariali et al. performed an interesting study comparing the accuracy of cup placement using 3D planning-assistance vs conventional freehand techniques [11]. They found that 3D planning and cup templates to assist the surgeon with component placement improved the accuracy of cup position especially with regard to anteversion and reduced the percentage of outliers while having no effect on operative time [11]. Cup abduction was also restored with greater accuracy using 3D-guided methods; however, the number of outliers was comparable to the freehand insertion group. Hence, the authors demonstrated that 3D templating is a useful tool to accurately place a cup even without the use of robotic or computer-assisted surgery [11].

One concern of CT-guided templating is the exposure to harmful radiation, which would be prevented with other templating modalities. Using a specific low-dose radiation protocol, corresponding to 5 mSv, which is reasonably equivalent to a hip x-rays routine protocol (2.7 mSv), the gain in accuracy and safety justifies the use of a CT scan for THA planning, particularly as it is associated with a slight increase in radiation exposure in comparison to conventional radiographs and low per-patient costs [12].

An interesting finding was that the CT-guiding templating was nearly exact for all but one patient, and for that patient, the cup size was underpredicted due to the sclerosis of the acetabular bed after reaming the templated side. Also, the CT-guided templating was consistently at least 1 cup size smaller than both digital and acetate templating, which could possibly be explained by the increased accuracy and the ability to place the cup in the optimal position with minimal bone loss. There was no statistical difference between the CT-guided predicted cup size and the final size used. This precision and accuracy can lead to less operating room delays attributed to the time spent with excessive implant trials, reduced costs due to less required operating room inventory, and improved preoperative preparation. One the other hand, both digital and acetate templating significantly overpredicted cup size as demonstrated in Figure 2 ($P < .001$). The overprediction of cup sizes by digital templating may lead to an excess bone loss. Once a larger than required cup size is predicted, it could mislead the operating surgeon to overream the bone, which would force the application of a larger than initially required cup size.

In 2009, Bozic et al. found that hip instability and mechanical loosening are the most common indications for revision THA in the United States [6]. Revision surgery carries a significant risk burden and must be handled delicately. Generally, revision surgery is less successful than primary THA in relieving pain and functional status, and the risk of rerevision following THA revision is higher than that of primary THA [4,5]. With a more precise and accurate predictive value, CT-guided templating may preserve more bone than digital templating. A more accurate preoperative prediction leaves less room for subjective estimation intraoperatively, based on adequate press fit or reaming until bleeding bone is reached. The preservation of bone stock is clinically beneficial for revision surgery, and bone loss is the major challenge in acetabular reconstruction [11]. Preoperative assessment of acetabular bone stock is critical because the amount and location of pelvic osteolysis can determine the success of the procedure [11]. When excessive bone loss is present, bone grafting or placement of accessory acetabular hardware is indicated prior to revision hardware placement [10]. When performing THA, all efforts to prevent or delay revision should be explored, and preparation to achieve the best possible outcome, if revision surgery is necessary, must be taken. The preservation of bone stock and the prevention of bone-graft usage will lead to more promising outcomes in revision THA.

Conclusions

This study has shown that CT-guided planning can more accurately and precisely predict hip implant cup sizes for THA when compared to digital templating software and acetate prints. Digital templating has also been shown to be less accurate than acetate templating. The benefits of using a CT-guided modality outweigh the risks of radiation exposure. CT-guided templating may also lead to better postoperative outcomes due to bone stock preservation from a more accurate cup size predicted than that of a digital templating prediction, and improved preoperative planning may effectively limit surgical error.

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