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Acetate Templating on Digital Images Is More Accurate Than Computer-based Templating for Total Hip Arthroplasty

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Abstract

Background Templating is an important aspect of preoperative planning for total hip arthroplasty and can help determine the size and positioning of the prosthesis. Historically, templating has been performed using acetate templates over printed radiographs. As a result of the increasing use of digital imaging, surgeons now either obtain additional printed radiographs solely for templating purposes or use specialized digital templating software, both of which carry additional cost.

Questions/purposes The purposes of this study was to compare acetate templating of digitally calibrated images on an LCD monitor to digital templating in terms of (1) accuracy; (2) reproducibility; and (3) time efficiency.

Methods Acetate onlay templating was performed directly over digital radiographs on an LCD monitor and was compared with digital templating. Five separate observers participated in this study templating on 52 total hip arthroplasties. For the acetate templating, the digital images were magnified to the scaled reference on the templates provided by the manufacturer (ratio 1.2:1) before templating using a 25-mm marker as a reference. Both the acetate and digital templating results were then compared with the actual implanted components to determine accuracy. Interobserver and intraobserver variability was determined by an intraclass correlation coefficient. Observers recorded time to complete templating from the time of complete upload of patients' imaging onto the system to completion of templating.

Results Both acetate and digital templates demonstrated moderate accuracy in predicting within one size of the eventual implanted acetabular cup (77% [199 of 260]; 70% [181 of 260], respectively; $p = 0.050$; 95% confidence interval [CI], 0.058–0.32), whereas acetate templating was better at predicting the femoral stem compared to digital templating (75% [195 of 260]; 60% [155 of 260], respectively; $p < 0.001$; 95% CI, 0.084–0.32). Acetate templating showed moderate to substantial interobserver agreement (cup intraclass correlation coefficient [ICC] = 0.55; 95% CI, 0.14–0.86; femoral ICC = 0.75; 95% CI, 0.39–0.95) and both methods showed almost perfect intraobserver agreement in reproducibility (acetate cup ICC = 0.82; 95% CI, 0.66–0.97; acetate femoral ICC = 0.86; 95% CI, 0.74–0.97; digital cup ICC = 0.82; 95% CI, 0.68–0.97; digital femoral ICC = 0.88; 95% CI, 0.77–1.0). Acetate templating could be performed more quickly (acetate mean 119 seconds; range, 37–220 seconds versus 154 seconds; range, 73–343 seconds; $p < 0.001$).

Conclusions Acetate onlay templating on digitally calibrated images can be a reliable substitute for digital templating using specialized software. It is quicker to

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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perform and much less expensive. Hospitals and practices need not purchase expensive software, particularly at lower volume centers.

Level of Evidence Level III, diagnostic study.

Introduction

Templating is an important aspect of preoperative planning for THA and can minimize both intraoperative and postoperative complications related to THA such as instability, leg length discrepancy, periprosthetic fracture, prosthetic loosening, and loss of bone stock [4, 5, 8, 13, 14, 19, 21, 22]. Many surgeons use either standard radiographs with acetate templates or digital templating for preoperative planning for THA. The use of hard-copy (analog) radiographs with onlay acetate templates has been well studied [5, 13, 24] but has inherent potential flaws resulting from actual variations in radiographic magnification [23]. The development of digital radiography and Picture Archiving and Communication Systems has in turn led to the development of digital templating software. Several studies have looked at the validity and reliability of digital templating compared with analog templating [6, 10, 12, 15, 18, 25]. Digital templating has been shown to have good reliability and validity [2, 6, 10, 12, 15, 18, 25]. However, digital templating requires the availability of digital templating software on numerous workstations and assumes that hospital IT departments will provide timely updates of the built-in templates within the software. In addition, specialized implant systems may be required that do not necessarily have templates built into the digital software, whereas acetate templates are generally readily available from manufacturers. Acetate templating over hard-copy radiographs requires the additional cost of printing digital radiographs, which incurs an additional expense. We have begun using a hybrid templating technique for THA, which involves templating directly over digital images on the liquid crystal display (LCD) monitor using acetate templates. This method has been described previously for use in templating for hybrid THA [21], but to our knowledge, its validity and reliability have yet to be studied in press-fit THA nor has it been compared with digital templating.

We therefore sought to evaluate: (1) the accuracy of acetate templating on digitally calibrated images and compare it with digital templating for preoperative planning of uncemented primary THA; (2) the inter- and intraobserver reliability of both approaches; and (3) the time each method takes to perform.

Patients and Methods

This is a prospective clinical study assessing the reliability and validity of acetate templating on digital images and was compared with digital templating. Approval to conduct this study was obtained from our University and Hospital Clinical Research Ethics Board.

Between July 2012 and July 2013, 52 patients who underwent uncemented primary THA for osteoarthritis were identified for inclusion in this study. Patients with bony deformity on preoperative radiographs such as previous osteotomy or fracture, bilateral hip dysplasia, those with nonstandardized preoperative radiographs, or who were undergoing revision surgery were excluded from the study. All THAs were performed by a single fellowship-trained arthroplasty surgeon (BAM) using the same surgical technique with a posterior approach with a standardized press-fit technique and posterior soft tissue repair. Acetate templating on the digital images was the technique used for all operations. These preoperative acetate templated sizes, however, were not used for data during the study to minimize bias. None of the radiographs reviewed had any markers related to any previous templating. The final implant size was uses based on the best fit intraoperatively and not based necessarily on the results of templating, which was only used as a guide.

Templating was based on the AP pelvic radiographs for both the acetate and digital templating guides. This was performed in a standard manner with the patient supine and both legs internally rotated 15° with a 25-mm magnification marker at the level of the hip. In patients with a lower body mass index (BMI), it was placed at the level of the greater trochanter and in patients with an elevated BMI, it was placed in the groin at the level of the coronal plane of the greater trochanter. The images were reviewed to ensure the 25-mm marker was visible and appropriately positioned.

Two forms of templating were performed for this study. The first consisted of a hybrid technique using acetate templates on digital images displayed on a standard LCD monitor. The radiographs were first magnified such that the 25-mm marker disc corresponded to the magnification scale of the acetate templates as provided by each manufacturing company. Once the image was magnified, acetate templating was completed directly over the digital images on the LCD monitor in a standard fashion as described by González Della Valle et al. [13]. To mark the center of rotation of the template acetabular component, a small circle was drawn using the circle annotation tool on the digital imaging system. The remaining templating was then referenced from this mark. The second method consisted of digital templating using the Orthoview software (Version 5.3.3; Orthoview LCC, Jackonsonville, FL, USA) and performed as described by Bono [3]. The images were first calibrated to match the 25-mm magnification marker followed by standard digital templating.

Five separate observers were used for this study: one orthopaedic arthroplasty staff surgeon (BAM), two arthroplasty fellows (NEO, PM), and two senior orthopaedic surgical residents (RP, JS). Each observer templated for 52 THAs during four separate sessions using each templating method twice. Variables recorded included acetabular cup size, femoral stem size, neck offset, and neck length. To avoid recollection bias, each of the four templating sessions was performed at least 1 week apart, and all sessions were a minimum 6 months after the date of surgery. Furthermore, each case was randomized for each session with patient-identifiable information obscured at the time of templating.

The templated results were compared with the actual implanted acetabular and femoral components. Component sizes used at the time of surgery were obtained from the operative reports in the electronic medical record. Each observer performed templating using each method twice, separated by at least 1 week. Inter- and intraobserver reliability was based on these observations. A secondary objective was to assess the time to perform each templating method. Observers recorded the time to complete templating from the time of complete upload of patients' imaging onto the system to completion of templating.

In every case, the acetabular component consisted of a hemispherical cementless Trilogy IT (n = 24), Continuum (n = 6) (Zimmer, Warsaw, IN, USA) or Pinnacle Porocoat (n = 22) cup (DePuy, Warsaw, IN, USA) and was implanted using a press-fit technique. Supplementary screw fixation was not ordinarily used unless it was deemed necessary by the surgeon intraoperatively for further fixation. Uncemented M/L Taper (n = 30) (Zimmer) or Tri-Lock BPS (n = 22) (DePuy) components were implanted for the femoral components, both of which are metaphyseal-coated tapered designs. The reason for the use of the two systems at our hospital is related to cost. By having two competing systems, we were able to drive the cost down by creating competition. The agreement with our hospital administration was that half of the hips would be performed using Zimmer-supplied implants and the other half using implants supplied by DePuy. The choice of implants used was more or less random at the time of booking to maintain the 50–50 ratio.

The templating results were considered correct if they were either exactly correct or within ± 1 size to the implanted components. A McNemar test was used to assess for statistical significance between groups. Mean errors were used to assess for bias and mean absolute error was used to assess for precision. To account for multiple ratings on the same subjects, generalized estimating equations (GEE) were used to compare the precision of acetate versus the precision of digital templating (which compares absolute errors). Both intraobserver and interobserver reliability were calculated using the intraclass correlation coefficient (ICC). Individual intraobserver reliability based on each observer was measured using kappa values. We used the following convention to interpret the ICC and kappa values: 0 to 0.20 indicates slight agreement, 0.21 to 0.40 indicates fair agreement, 0.41 to 0.60 indicates moderate agreement, 0.61 to 0.80 indicates substantial agreement, and greater than 0.80 indicates almost perfect agreement [20, 27].

Results

With the numbers available, acetate showed similar or better accuracy than digital templating in terms of predicting the sizes of the acetabular and femoral components implanted at the time of surgery. The acetabular implant size was predicted exactly using the acetate onlay on digital images technique in 28% (73 of 260) of cases, whereas digital templating accurately predicted the acetabular size in 28% (74 of 260) of cases ($p = 0.914$; 95% confidence interval [CI], 0.067–0.32). When defining accuracy to be within one size above or below the final implant size, the acetabular size was accurately predicted using the acetate onlay technique in 77% (199 of 260) of cases and 70% (181 of 260) of cases using digital templating ($p = 0.05$; 95% CI, 0.058–0.32). The femoral component size was accurately predicted using the acetate onlay on digital images technique in 33% (86 of 260) of cases compared with 25% (64 of 260) of cases using digital templating ($p = 0.023$; 95% CI, 0.004–0.25). When looking at the accuracy within one size, acetate templating demonstrated 75% (195 of 260) accuracy compared with 60% (155 of 260) with digital templating ($p < 0.001$; 95% CI, 0.084–0.32). Neck length within one size was 87% (221 of 255) using the acetate onlay and 87% (221 of 255) using digital templating ($p = 1.0$; 95% CI, 0.27–0.51). The neck offset was accurately predicted using the acetate onlay technique in 66% (172 of 260) of cases compared with 67% (174 of 260) using digital templating ($p = 0.777$; 95% CI, 0.46–0.67). Experience level did not appear to have a negative effect on accuracy (Table 1). Using a GEE, acetate templating was found to be more precise ($p < 0.001$) in predicting the femoral component than digital templating (Table 2). No difference was noted between methods when predicting the acetabular cup component size ($p = 0.16$) or the neck length ($p = 0.42$). Acetate templating tended to underpredict (negative error value) both acetabular cup size and femoral stem size, whereas the digital templating tended to overpredict (positive error value) cup size (Figs. 1, 2). Neither the acetate templating method ($p = 0.85$) nor the digital templating method ($p = 0.08$) showed a bias in predicting cup size, but both demonstrated a bias to undersize the femoral stem ($p < 0.001$) (Table 3). Digital templating did show a bias to overpredict neck length ($p = 0.007$).

We found substantial agreement (ICC values 0.61–0.8) in terms of interobserver reproducibility in predicting the

Table 1. Templating results by observer

Templating method	Observer	Acetabular component		Femoral component	
		Number of exact cases	Number of ± 1 size cases	Number of exact cases	Number of ± 1 size cases
Acetate	BAM	23%	71%	17%	64%
	JS	21%	67%	40%	73%
	NEO	33%	75%	31%	73%
	PM	25%	73%	40%	85%
	RP	39%	96%	37%	81%
	Total	28%	77%	33%	75%
Digital	BAM	38%	75%	15%	50%
	JS	25%	65%	27%	67%
	NEO	29%	79%	33%	75%
	PM	19%	60%	10%	27%
	RP	31%	69%	39%	79%
	Total	28%	70%	25%	60%

Table 2. Acetate and digital templating mean absolute error measurements between the planned and implanted component sizes for the acetabular cup, femoral stem, and neck length components

	Acetate mean absolute error	Digital mean absolute error	Absolute error difference	Generalized estimating equation p value
Cup	1.04	1.14	0.10	0.16
Stem	1.02	1.42	0.40	< 0.001
Neck length	0.73	0.77	0.04	0.42

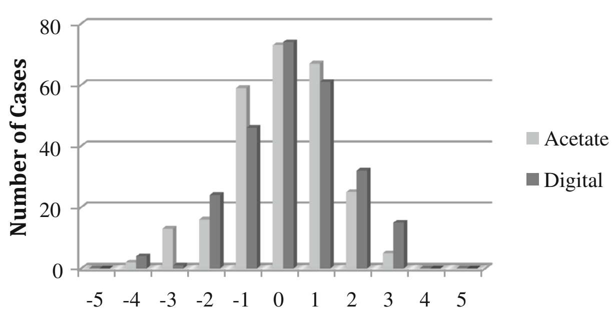

Fig. 1 Histograms depicting size difference between the templated and implanted acetabular cup component, which shows the accuracy difference between the acetate and digital methods.

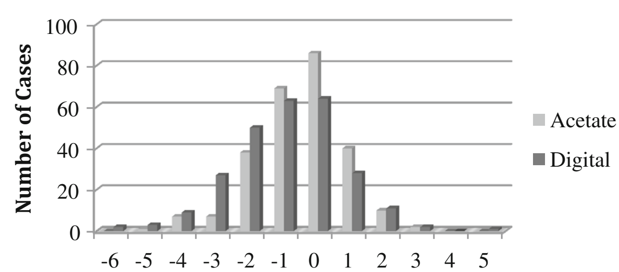

Fig. 2 Histograms depicting the size difference between the templated and implanted femoral stem component, which shows the accuracy difference between the acetate and digital methods.

acetabular and femoral component in the digital templating technique and the femoral component with the acetate technique (Table 4). We found moderate agreement in predicting the acetabular component using the acetate technique. Fair agreement was noted for reproducing the neck length in both methods. Both the acetabular and femoral sizes had almost perfect (ICC values > 0.8) reproducibility using both methods when assessed for intraobserver reliability (Table 4). Moderate agreement was noted in intraobserver reproducibility for the neck length. Experience level did not appear to have a negative effect on intraobserver variability (Table 5).

The mean time for templating was 119 seconds (range, 37–220 seconds) using the acetate templating method compared with 154 seconds (range, 73–343 seconds) using the digital templating method with a mean difference of 35 seconds ($p < 0.001$).

Table 3. Acetate and digital templating mean error measurements between the planned and implanted component for the cup, stem, and neck length sizes

Component	Mean	SE	Minimum	Maximum	p value
Acetate cup error	−0.02	0.09	−4	3	0.85
Digital cup error	0.27	0.09	−4	5	0.08
Acetate stem error	−0.51	0.08	−5	3	< 0.001
Digital stem error	−0.95	0.10	−6	5	< 0.001
Acetate neck length error	0.21	0.06	−3	3	0.07
Digital neck length error	0.31	0.06	−2	3	0.01

Table 4. ICC values for interobserver and intraobserver variability

Interobserver variability	ICC value	95% confidence interval	
Component	Method Acetate	Lower	Upper
Acetabular	0.55	0.14	0.86
Femoral	0.75	0.39	0.95
Neck length	0.35	0.05	0.81
	Digital		
Acetabular	0.62	0.20	0.89
Femoral	0.64	0.09	0.78
Neck length	0.24	−0.01	0.80
Intraobserver variability			
Component	Acetate		
Acetabular	0.82	0.66	0.97
Femoral	0.86	0.74	0.97
Neck length	0.56	0.34	0.78
	Digital		
Acetabular	0.82	0.68	0.97
Femoral	0.88	0.77	1.0
Neck length	0.59	0.25	0.93

ICC = intraclass correlation coefficient.

Table 5. Kappa values for intraobserver variability by observer

Templating method	Observer	Kappa	95% confidence interval	
			Lower	Upper
Acetate cup	BAM	0.50	0.34	0.66
	JS	0.68	0.56	0.80
	NEO	0.66	0.55	0.77
	PM	0.78	0.69	0.86
	RP	0.77	0.68	0.86
Digital cup	BAM	0.49	0.36	0.61
	JS	0.90	0.84	0.96
	NEO	0.68	0.57	0.79
	PM	0.46	0.33	0.58
	RP	0.75	0.64	0.85
Acetate femur	BAM	0.68	0.55	0.80
	JS	0.82	0.73	0.90
	NEO	0.46	0.33	0.59
	PM	0.83	0.76	0.91
	RP	0.83	0.72	0.93
Digital femur	BAM	0.64	0.52	0.77
	JS	0.98	0.95	1.0
	NEO	0.72	0.65	0.80
	PM	0.54	0.41	0.66
	RP	0.85	0.76	0.91

Discussion

Templating is an integral part of preoperative planning for THA and can help determine the size and positioning of the prosthesis [4, 5, 9, 11, 14]. Accurate templating can help minimize both intraoperative and postoperative complications related to THA such as instability, leg length discrepancy, periprosthetic fracture, prosthetic loosening, and loss of bone stock [4, 5, 8, 13, 14, 19, 22]. The development of digital imaging has resulted in either a costly reproduction of printed films or the creation and use of expensive digital templating programs for the purposes of preoperative planning. In addition, specialized implant systems may be required that do not necessarily have templates built into the digital software, whereas acetate templates are generally readily available from manufacturers. Given the importance of preoperative templating and the added costs of either templating using printed acetate images or digital templating programs, we sought to determine the accuracy and reliability of a technique that consists of the use of acetate templates directly over magnified digital images. This technique was compared with the well-validated technique of digital templating. Our study sought to answer the following questions: (1) How does the accuracy of our method compare with digital templating? (2) Are these methods reproducible?

Table 6. Previously published templating results which used cementless components

Templating method	Study	Percentage of cases ± 1 size		
		Acetabular cup	Femoral stem	Offset
Analog	Iorio et al. [15]	78.0%	77.0%	
	Crooijmans et al. [6]	82.8%	84.4%	
	Viceconti et al. [26]	69.0%	82.8%	
	The et al. [25]	64.0%	52.0%	
	Goldstein et al. [11]	99.2%	99.2%	
	Knight and Atwater [17]	96.0%	85.0%	
	Gamble et al. [10]	60.0%	85.0%	
	Kearney et al. [16]*	75.0%	91.0%	91.0%
	González Della Valle et al. [12]*	97.0%	98.0%	86.0%
Digital	Iorio et al. [15]	60.0%	74.0%	
	Crooijmans et al. [6]	62.5%	50.0%	
	The et al. [25]	52.0%	66.0%	
	Davila et al. [7]	86.0%	72.0%	
	Gamble et al. [10]	80.0%	85.0%	
	González Della Valle et al. [12]*	81.0%	94.0%	75.0%
	Anil Kumar et al. [1]	91.0%	78.0%	93.0%

* Used cemented femoral stem prosthesis.

(3) Is there a difference in the time required to template using either method?

There were some limitations to our study. First, a potential bias may have existed in case selection for this study. Second, there may be higher familiarity with our method of templating as opposed to digital templating. Although this is not a standardized technique used by staff surgeons at our institution, it is the method used by the staff surgeon involved in the study and taught to his fellows and residents, and our results may not be reflective of other surgeons attempting to use this technique. Third, a potential source of bias may have existed as a result of the variation in implants used. Our study did not look at whether this bias existed between differing components. Fourth, the hybrid technique, using acetate templating over magnified digital images, was used at the time of surgery and involved the senior investigator (BAM) for all cases. Although the templated components at the time of surgery were not used as data for this study (because the templating was performed a minimum of 6 months after surgery), there may be a bias toward the acetate templating as a result. Additionally, the templated component sizes were compared with the actual implanted components. This assumes the implanted prostheses were the optimal size, which may not always be the case. However, both methods were compared with the actual implanted prosthesis, which inevitably compared both techniques with potentially suboptimal component sizes. Finally, there was noted variability among observers in terms of accuracy and reliability. However, experience level did not appear to have a negative effect on either outcome.

Our study has shown that the use of acetate templating directly over magnified digital images is a reliable technique when compared with digital templating. In fact, in our study, this technique was as accurate at predicting neck length and offset and more accurate at predicting femoral stem sizes when compared with digital templating. This technique met statistical significance in having less error in predicting the femoral stem size as compared with digital templating. Our acetate method had a fairly similar accuracy in predicting both the acetabular cup and femoral stem sizes but was not as accurate at predicting offset when compared with previously published studies (Table 6). To improve the validity of our comparison, we included mainly those studies that used cementless components (with the exception of Kearney et al. [16] and González Della Valle et al. [12]). The digital method in our study was in the middle to lower end in its accuracy in predicting component sizes when compared with previous studies. This difference may be accounted for the fact that in our study each observer at the time of templating was blinded to the actual implants used at the time of surgery. Furthermore, we did not use the templated sizes (at the time of surgery) as data for our study, avoiding potential bias during the time of prosthesis implantation, which may not have been the case in other studies. Other sources of difference include the difficulty in comparing directly with other studies as a result of the differences in prostheses used between studies. Finally, there may be a difference in accuracy of templating with varying prosthetic types or digital templating programs used, which may account for some of the differences between studies including our own. More recently with the creation of digital imaging systems, several studies have assessed the validity of digital templating and have shown good results when compared with analog templating [10, 12, 15]. This has added to the literature and may potentially be cost-saving by allowing the use of valid and reliable digital templating and avoiding the cost of creating printed images for templating. Preoperative templating has been shown to lead to fewer complications [4, 5, 8, 14, 19]. However, to the best of our knowledge, no study has shown that errors in templating at the time of surgery directly leads to inferior clinical outcomes.

Our study found substantial interobserver ICC value agreement for acetate templating for the femoral component and digital templating for the acetabular and femoral components, which is similar to several studies using the analog or digital templating methods [6, 15]. However, values were lower than that quoted by Gamble et al. [10], which found ICC values ranging from 0.8 to 0.94. We found moderate interobserver ICC value agreement for the acetate templating for the acetabular component, similar to the findings of Oddy et al. (ICC, 0.43–0.47) [21]. Intraobserver ICC values showed almost perfect agreement (ICC > 0.8) for both acetabular and femoral components when using both templating methods, suggesting both methods are highly reproducible. Our ICC values correspond well to previous studies, which found ICC values ranging from 0.7 to 0.97 [6, 10, 15, 21]. Our study showed that experience level did not have an effect on accuracy nor intraobserver variability.

We found that acetate templating was a faster templating method when compared with digital templating. On average, acetate templating was 35 seconds quicker per case. To our knowledge, ours is the first study to evaluate time as an outcome measure in this way. Although we do not believe the 35-second difference to be in any sense clinically meaningful, we include it to demonstrate that surgeons who opt to use this approach should not expect it to take longer than digital templating once they are familiar with the acetate-based approach.

Acetate onlay templating on digitally calibrated images can accurately predict the size of THA implants. The technique we have described is reliable and valid to use for preoperative planning when compared with digital templating. This method is efficient and offers a less expensive alternative for preoperative templating by avoiding the purchase of digital templating software or the creation of printed (analog) radiographs.

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References

1. Anil Kumar PG, Kirmani SJ, Humberg H, Kavarthapu V, Li P. Reproducibility and accuracy of templating uncemented THA with digital radiographic and digital TraumaCad templating software. *Orthopedics*. 2009;32:815.
2. Bertz A, Indrekvam K, Ahmed M, Englund E, Sayed-Noor AS. Validity and reliability of preoperative templating in total hip arthroplasty using a digital templating system. *Skeletal Radiol*. 2012;41:1245–1249.
3. Bono JV. Digital templating in total hip arthroplasty. *J Bone Joint Surg Am*. 2004;86(Suppl 2):118–122.
4. Bourne RB, Rorabeck CH. Soft tissue balancing: the hip. *J Arthroplasty*. 2002;17:17–22.
5. Carter LW, Stovall DO, Young TR. Determination of accuracy of preoperative templating of noncemented femoral prostheses. *J Arthroplasty*. 1995;10:507–513.
6. Crooijmans HJA, Laumen AMRP, Pul C, Mourik JBA. A New digital preoperative planning method for total hip arthroplasties. *Clin Orthop Relat Res*. 2008;467:909–916.
7. Davila JA, Kransdorf MJ, Duffy GP. Surgical planning of total hip arthroplasty: accuracy of computer-assisted EndoMap software in predicting component size. *Skeletal Radiol*. 2006;35:390–393.
8. Eckrich SG, Noble PC, Tullos HS. Effect of rotation on the radiographic appearance of the femoral canal. *J Arthroplasty*. 1994;9:419–426.
9. Eggli S, Pisan M, Müller ME. The value of preoperative planning for total hip arthroplasty. *J Bone Joint Surg Br*. 1998;80:382–390.
10. Gamble P, de Beer J, Petruccelli D, Winemaker M. The accuracy of digital templating in uncemented total hip arthroplasty. *J Arthroplasty*. 2010;25:529–532.
11. Goldstein WM, Gordon A, Branson JJ. Leg length inequality in total hip arthroplasty. *Orthopedics*. 2005;28:s1037–40.
12. González Della Valle A, Comba F, Taveras N, Salvati EA. The utility and precision of analogue and digital preoperative planning for total hip arthroplasty. *Int Orthop*. 2008;32:289–294.
13. González Della Valle A, Padgett DE, Salvati EA. Preoperative planning for primary total hip arthroplasty. *J Am Acad Orthop Surg*. 2005;13:455–462.
14. Haddad FS, Masri BA, Garbuz DS, Duncan CP. The prevention of periprosthetic fractures in total hip and knee arthroplasty. *Orthop Clin North Am*. 1999;30:191–207.
15. Iorio R, Siegel J, Specht LM, Tilzey JF, Hartman A, Healy WL. A comparison of acetate vs digital templating for preoperative planning of total hip arthroplasty: is digital templating accurate and safe? *J Arthroplasty*. 2009;24:175–179.
16. Kearney R, Shaikh AH, O'Byrne JM. The accuracy and interobserver reliability of acetate templating in total hip arthroplasty. *Ir J Med Sci*. 2013;182:409–414.
17. Knight JL, Atwater RD. Preoperative planning for total hip arthroplasty: quantitating its utility and precision. *J Arthroplasty*. 1992;7:403–409.
18. Kosashvili Y, Shasha N, Olschewski E, Safir O, White L, Gross A, Backstein D. Digital versus conventional templating techniques in preoperative planning for total hip arthroplasty. *Can J Surg*. 2009;52:6–11.
19. McAuley JP, Ridgeway SR. Preoperative planning to prevent dislocation of the hip. *Orthop Clin North Am*. 2001;32:579–586, viii.
20. Montgomery AA, Graham A, Evans PH, Fahey T. Inter-rater agreement in the scoring of abstracts submitted to a primary care research conference. *BMC Health Serv Res*. 2002;2:8.
21. Oddy MJ, Jones MJ, Pendegrass CJ, Pilling JR, Wimhurst JA. Assessment of reproducibility and accuracy in templating hybrid

total hip arthroplasty using digital radiographs. *J Bone Joint Surg Br*. 2006;88:581–585.
22. Schmalzried TP. Preoperative templating and biomechanics in total hip arthroplasty. *Orthopedics*. 2005;28:s849–s851.
23. Sinclair VF, Wilson J, Jain NPM, Knowles D. Assessment of accuracy of marker ball placement in pre-operative templating for total hip arthroplasty. *J Arthroplasty*. 2014;29:1658–1660.
24. Suh KT, Cheon SJ, Kim DW. Comparison of preoperative templating with postoperative assessment in cementless total hip arthroplasty. *Acta Orthop Scand*. 2004;75:40–44.
25. The B, Diercks RL, van Ooijen PMA, van Horn JR. 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.
26. Viceconti M, Chiarini A, Testi D, Taddei F, Bordini B, Traina F, Toni A. New aspects and approaches in pre-operative planning of hip reconstruction: a computer simulation. *Langenbecks Arch Surg*. 2004;389:400–404.
27. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med*. 2005;37:360–363.