Cloud-based Preoperative Planning for Total Hip Arthroplasty: A Study of Accuracy, Efficiency, and Compliance

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Abstract: As digital radiography becomes more prevalent, several systems for digital preoperative planning have become available. The purpose of this study was to evaluate the accuracy and efficiency of an inexpensive, cloud-based digital templating system, which is comparable with acetate templating. However, cloud-based templating is substantially faster and more convenient than acetate templating or locally installed software. Although this is a practical solution for this particular medical application, regulatory changes are necessary before the tremendous advantages of cloud-based storage and computing can be realized in medical research and clinical practice.

Total hip arthroplasty (THA) is a reliable treatment for hip arthritis. Successful THA consistently relieves pain, improves function, and restores biomechanics of the hip. However, improper component selection or malposition causing excessive wear, limb-length discrepancy, fracture, or dislocation can lead to early failure or patient dissatisfaction. Therefore, preoperative planning is an important step for achieving a successful outcome after THA.1-4

Prior studies examining the accuracy of templating have shown more than 90% accuracy to within 2 sizes of the implant. However, the exact size of the component was predicted in only 42% to 50% of cases for the acetabular component and 68% for the femoral component.4,5

As digital radiography has become more prevalent, tools for digital preoperative planning have become available for use by the treating surgeon. On-screen evaluation of digital imaging does not affect the accuracy of interpretation.6-8 However, when printed digital radiographs are combined with acetate overlay templating, correct component size is predicted accurately only 69% of the time.9

Studies investigating the accuracy of digital templating have produced varied results. Gonzalez Della Valle et al.10 showed consistently better accuracy with conventional templating compared with digital templating in a study of 69 patients undergoing cemented THA. In contrast, Iorio et al.11 reported that the mean errors did not differ significantly and concluded that both acetate and digital templating can accurately predict the size of THA implants. For these studies, digital templating was performed using software packages installed on site.10,11

In the current study, the authors used cloud-based software for digital templating (HipCAT; University of Michigan, Ann Arbor, Michigan). Cloud computing is a relatively new model in information technology that provides fee-for-service access to computing resources via the Internet.12 It avoids the high costs associated with traditional in-house computing infrastructure deployment and expansion. Instead, computing is provided as a metered service and resembles the service provided by a public utility company that supplies gas or electricity.12-14 Advocates of this model highlight its low cost, ease of adoption, scalability, and performance.14,15 However, the model continues to be challenged by concerns over privacy and security.12,16-18

Many of the advantages of cloud computing are applicable to digital templating...
systems. This digital templating system did not require the purchase of additional hardware or software or software deployment. It also avoided the expense associated with systems integration by providing a utility to import images into the cloud saved from a picture archiving and communication systems (PACS) viewer (McKesson Corp, San Francisco, California). All functions required for templating, reviewing, and uploading images are accessible through a Web browser. Privacy and security concerns were addressed with Health Insurance Portability and Accountability (HIPAA)-compliant encryption implemented on the Web browser–based client and the cloud-based service.

The purpose of this study was to measure the accuracy and efficiency of cloud-based digital and acetate templating for preoperative planning of THA. The authors also address the regulatory compliance issues related to cloud computing.

**Materials and Methods**
A retrospective review of 20 primary uncemented THAs performed between September and December 2010 under the direction of 1 adult reconstruction fellowship-trained surgeon (A.G.U.) was performed. Patients who underwent prior THA on the contralateral hip, had metal implants on the operative side, or had nonstandard imaging were excluded from the study.

Standardized techniques were applied when preoperative radiography was obtained. Anteroposterior pelvis radiographs were downloaded from the PACS system. The downloaded images were deidentified and then printed on analog film or uploaded as an encrypted file into the cloud-based templating software. The images were then calibrated in the templating system based on the scaling overlay used by the PACS system and a magnification marker when present. In a separate session, the operative report was reviewed to determine the actual implanted acetabular and femoral components for later statistical comparison.

**Measurement of Templating Accuracy**
One attending (A.G.U.) and 2 senior orthopedic surgical residents (R.C.S., W.J.D) performed preimplant assessments of hip implant sizing on the 20 cases with traditional acetate templates and with digital templating software. This was done in 2 sessions spaced 2 weeks apart. Acetate templating was performed according to a previously described standardized method.\(^3,17\) Digital templating was performed according to the digital templating software protocol, allowing marking and measurement similar to acetate templating (Figure).

The template results for both methods were compared with the actual acetabular and femoral components implanted.

**Measurement of Templating Timing**
The preparation of each preoperative plan by both methods was individually timed by an observer (J.D.M.) and recorded. The timer began when each film was hung on the lightbox or the image was loaded. The timer was stopped when the participant indicated satisfaction with the templating.

**Statistical Analysis**
PASW Statistics version 19 software (IBM, Armonk, New York) was used for statistical analysis. Interrater reliability was measured with intraclass correlation coefficients. Two-tailed 1-sample \(t\) tests were used to assess the accuracy of templating by both of these methods for each participant. The time required to template by each method was also recorded. Differences in time for each method of templating were analyzed using paired \(t\) tests.

**Results**

**Measurement of Templating Accuracy**
Digital templating predicted correct acetabular component size within 2 sizes in 96% of cases and within 1 size in 73% of cases. Acetate overlay templating was similarly accurate to 2 sizes in 86% of cases and to 1 size in 63% of cases. Digital templating predicted correct femoral component size within 2 sizes in 93% of cases and 1 size in 75% of cases. Acetate templating was accurate to 2 sizes in 98% of cases and 1 size in 93% of cases. Table 1 shows the distribution of error by size for each component.

Moderate and comparable interrater reliability was found with digital and acetate templating of the acetabular component (Table 2). However, slightly lower interrater reliability was found with acetate templating of the femoral component compared with the digital method.

Analysis of pooled measurement data showed significant underprediction of femoral and acetabular component size with digital and acetate
TABLE 1
Distribution of Acetabular and Femoral Component Error

<table>
<thead>
<tr>
<th>Error (sizes)*</th>
<th>Acetabular Component, %</th>
<th>Femoral Component, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Digital</td>
<td>Acetate</td>
</tr>
<tr>
<td>−3+</td>
<td>3.33</td>
<td>11.67</td>
</tr>
<tr>
<td>−2</td>
<td>18.33</td>
<td>20.00</td>
</tr>
<tr>
<td>−1</td>
<td>15.00</td>
<td>16.67</td>
</tr>
<tr>
<td>0</td>
<td>38.33</td>
<td>30.00</td>
</tr>
<tr>
<td>1</td>
<td>20.00</td>
<td>11.67</td>
</tr>
<tr>
<td>2</td>
<td>5.00</td>
<td>8.33</td>
</tr>
<tr>
<td>3+</td>
<td>0.00</td>
<td>1.67</td>
</tr>
</tbody>
</table>

*Negative error is underprediction of size.

TABLE 2
Interrater Reliability as Assessed With Intraclass Correlation Coefficients*

<table>
<thead>
<tr>
<th>Method</th>
<th>Acetabular Component</th>
<th>Femoral Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital</td>
<td>0.52</td>
<td>0.42</td>
</tr>
<tr>
<td>Acetate</td>
<td>0.52</td>
<td>0.34</td>
</tr>
</tbody>
</table>

P < .001.

TABLE 3
Acetabular Component Size Accuracy

<table>
<thead>
<tr>
<th>Participant</th>
<th>Digital Error*</th>
<th>P</th>
<th>Acetate Error*</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−0.65±1.35</td>
<td>&lt;.05</td>
<td>−0.90±1.92</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>2</td>
<td>−0.05±1.05</td>
<td>.83</td>
<td>−0.25±1.33</td>
<td>.41</td>
</tr>
<tr>
<td>3</td>
<td>−0.25±1.25</td>
<td>.38</td>
<td>−0.70±1.45</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Combined</td>
<td>−0.31±1.23</td>
<td>&lt;.05</td>
<td>−0.61±1.58</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

*Negative error is underprediction of size.

TABLE 4
Femoral Component Size Accuracy

<table>
<thead>
<tr>
<th>Participant</th>
<th>Digital Error*</th>
<th>P</th>
<th>Acetate Error*</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−1.10±1.25</td>
<td>&lt;.005</td>
<td>−0.65±0.81</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>2</td>
<td>0.25±0.78</td>
<td>.17</td>
<td>0.10±0.55</td>
<td>.42</td>
</tr>
<tr>
<td>3</td>
<td>−0.55±1.23</td>
<td>.06</td>
<td>−0.40±0.83</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Combined</td>
<td>−0.46±1.22</td>
<td>&lt;.005</td>
<td>−0.31±0.79</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

*Negative error is underprediction of size.

TABLE 5
Time Required for Completion of Templating

<table>
<thead>
<tr>
<th>Participant</th>
<th>Digital Time, sec</th>
<th>Acetate Time, sec</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63.45±17.66</td>
<td>93.00±18.02</td>
<td>&lt;.005</td>
</tr>
<tr>
<td>2</td>
<td>66.65±13.12</td>
<td>168.80±79.03</td>
<td>&lt;.005</td>
</tr>
<tr>
<td>3</td>
<td>82.95±28.10</td>
<td>157.80±27.38</td>
<td>&lt;.005</td>
</tr>
<tr>
<td>Combined</td>
<td>64.35±15.47</td>
<td>133.25±71.27</td>
<td>&lt;.005</td>
</tr>
</tbody>
</table>

Measurement of Templating Timing

Analysis of the time required to complete the tasks revealed that acetate templating on average took 2.07 times longer than digital templating. Although some variation existed in the amount of time required for completion of the task by each participant, acetate templating was consistently slower (1.47 to 2.53 times longer to complete the task depending on the participant). On average, digital templating required 64 seconds per case and acetate templating required 133 seconds per case (P < .005). Results for each participant are shown in Table 5.

Discussion

In the current study, digital and acetate templating were comparably accurate for planning THA. Digital and acetate templating predicted components to within 2 sizes in the vast majority of cases (>90% of the time). Digital and acetate templating also showed comparable interrater reliability for the selection of each component.

The results are comparable with prior studies of the accuracy of digital and acetate preoperative templating with uncemented THA. Iorio et al11 reported that components could be predicted within 1 size in 60% to 74% of cases with digital templating and in 77% to 78% of cases with acetate templating. The current authors’ results showed prediction of components within 1 size in 73% to 75% of cases with digital templating and 58% to 93% of cases with acetate templating. These results are also comparable with prior

overlay templating (Tables 3, 4). Digital measurements resulted in greater underprediction of femoral component size (negative error values, P < .05). Acetate measurements resulted in greater underprediction of acetabular component size (negative error values, P < .05). However, the standard deviation of the estimation error with both digital and acetate templating is reflective of the number of cases in which the components were oversized.
studies examining the accuracy of acetate templating in planning uncemented THA; these studies reported exact prediction of component size 42% to 68% of the time and within 2 sizes greater than 90% of the time.4,5

In contrast, Gonzalez Della Valle et al10 reported that analog templating was more predictable and precise than digital templating. In their study, analog templating predicted components within 1 size in 97% to 98% of cases, whereas digital templating from scanned analog radiographs predicted components within 1 size in 81% to 94% of cases. However, in their study, a cemented technique was used for placement of the femoral stem.10 Multiple investigators have reported that prediction of cemented components is more reliable in preoperative planning than prediction of uncemented components.10,18-20 Thus, if a cemented technique for the femoral stem is used, analog templating may be more accurate than digital templating.

To the authors’ knowledge, no other studies to date have examined the efficiency of analog and digital templating. This study showed that surgeons needed approximately half the time to prepare a preoperative plan with digital templating when compared with analog templating.

With the increasing prevalence of digital radiography and use of PACS in the hospital and office setting, digital templating may be a more efficient and cost-effective method for preoperative planning. Potential benefits to surgeon and hospital include reduced expense from film production, secure storage, improved access, and increased efficiency of templating. Another advantage of digital templating is the ease of error correction. As a result, digital templating is a valuable tool for teaching and discussion of cases, especially in a teaching hospital setting.

A cloud-based system confers additional benefits beyond traditional on-site PACS and digital templating systems. Cloud-based systems for electronic health records and medical imaging software may lower financial barriers and promote acquisition.12 However, questions remain regarding the security and privacy of information stored on these systems.

Use of these systems in medical applications must comply with the privacy and security rules of the HIPAA Act and of the Health Information Technology for Economic and Clinical Health Act. Federal law requires that third parties handling protected health information enter into a Business Associate Contract with the client that stipulates adherence to privacy guidelines. Liability now extends to the business associates for violations of the security provisions.12,21 Development of these systems with a focus on enhanced security is sensible when storing sensitive medical data.

The digital templating system used in this study encrypts all medical data on the local computer prior to transmission and storage. With this approach, in the event of a security breach of the cloud, the data remain unintelligible without each user’s encryption key.15,22 These approaches to security and legislative policy make the use of cloud computing feasible in the medical industry.

CONCLUSION
Preoperative planning for THA with cloud-based digital templating is comparable with acetate templating in accuracy but offers the additional benefits of efficiency, cost savings, and workflow improvement. Cloud-based medical software can be safely implemented in compliance with federal privacy and security regulations. However, individual physicians and institutions should be judicious consumers of nascent technology with potential security and privacy pitfalls.

REFERENCES


