Scaling Marker Position Determines the Accuracy of Digital Templating for Total Hip Arthroplasty

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Abstract *Background:* Digital templating systems foster patient-specific measurements for preoperative planning. *Questions/Purposes:* We aim (1) to verify the accuracy of a templating system, (2) to describe the effects of scaling marker position on the accuracy of digital templating of the hip, and (3) to provide a practical guide for scaling marker position using patient body mass index (BMI). *Methods:* A scaling sphere was placed in five positions along the anterior-posterior axis of an acetabular implant and pelvis phantom, and x-rays were obtained. Each radiograph was templated for the acetabular component and recorded. A retrospective review identified CT scans of preoperative hip arthroplasty cases. The center of the greater trochanter was calculated from these CT scans as the percent distance from the anterior thigh and recorded with the patient's BMI. *Results:* By centering the scaling sphere on the acetabular component, an accurate cup size was achieved. A difference of 3.5 cm in sphere placement resulted in a full cup size magnification error. Positioning the scaling sphere at the level of the pubic symphysis resulted in a difference of four cup sizes. This patient population had an average BMI of

28.72 kg/m² (standard deviation 6.26 kg/m²) and an average position of the center of the greater trochanter of 51% (standard deviation of 6%) from the anterior surface of thigh. *Conclusions:* Digital templating relies on scaling marker position to accurately estimate implant size. Based on the findings in this study, scaling markers for hip imaging should be placed laterally, mid-thigh in the anterior-posterior direction for patients with a BMI between 25 and 40 kg/m². If abnormal hip anatomy or extremes of BMI are discovered, then scaling sphere positioning should be optimized on a case-by-case basis. Digital templating systems for total hip arthroplasty must use precisely placed scaling markers at the level of the hip joint to allow for accurate implant size estimation.

Keywords digital templating · total hip arthroplasty · radiographs · scaling · surgical planning

Introduction

Digital templating systems allow for measurement and sizing of patient anatomy for preoperative implant selection. Preoperative planning aims to reduce the risk of intraoperative fracture, decrease overall surgical time, plan for implant constructs, and decrease the total number of trays required for a given surgery [3–5]. Images that are used by digital templating systems must be accurately scaled to allow for accurate implant selection [1, 7, 8]. In the past, acetate templates have assumed a magnification between 110 and 120%, but this estimate relied on multiple factors including size of the patient and the distance from the x-ray detector [2]. To scale x-ray images, objects of known dimension are placed near the region of interest. These objects can be an implant of known dimension, ruler, scaling sphere, or coin [9]. To accurately scale the image, the scaling marker must be placed as close as possible to the anatomical region being imaged [6].

Work performed at the NYU Hospital for Joint Diseases.

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Fig. 1. A packaged acetabular implant and metallic scaling sphere. The metallic scaling sphere positioned at the center of the acetabular implant. The red dashed line represents the position of the acetabular implant in the packaging.

External anatomy (e.g., the olecranon, ulnar styloid, medial malleolus) is often used to precisely position scaling markers as close to the region of interest as possible. However, the placement of a scaling marker is difficult when the region of interest is deep within soft tissue. Clinically, the center of the hip joint cannot be palpated and its position is difficult to estimate by palpation. For these reasons, the center of the greater trochanter, which can be palpated by x-ray technicians, is often used as a surrogate for the center of the hip joint. However, the greater trochanter may be difficult to find in some or even many patients. In this study, we aim (1) to verify the accuracy of a templating system, (2) to describe the effects of scaling marker position on the accuracy of digital templating of the hip, and (3) to provide a practical guide for scaling marker position using patient body mass index (BMI). We hypothesize that small changes to scaling marker position greatly affect the accuracy of hip digital templating.

Fig. 3. An example case of the measurements that were used to determine the location of the center of the greater trochanter in the thigh.

Materials and Methods

A verification study of a digital templating system was performed. A packaged (Trident, Stryker®, Kalamazoo, MI) 52-mm acetabular shell was positioned vertically on a standard x-ray table as shown in Fig. 1. The packaging for the implant measured 14 cm in height. A 25-mm image scaling sphere (Akucal, J2 Medical, LP, Pittsburgh, PA) was positioned alongside the acetabular component at the center of the implant. A plain radiograph was obtained of both the implant and the scaling sphere in this position. Additionally, radiographs were obtained with the scaling sphere 7 cm below the center of the implant (flush with the table), at 3.5 cm below the center of the implant (half the distance between the center of the implant and the x-ray table), at 3.5 cm above the center of the implant (half the

Fig. 2. **a** Pelvis phantom and metallic scaling sphere placed on an x-ray table. **b** The clear plastic phantom allowed for easy alignment of the metallic scaling sphere at different predetermined anterior-posterior distances from the level of the hip joint. The image shown demonstrates the scaling sphere 4.5 cm above the center of the hip joint.

Table 1 Imaging magnification affects the digitally templated acetabular cup size based on the distance that the scaling sphere was from the center of the acetabular implant

Distance from center of implant (cm)	Digitally templated cup size
–7.0 (flush with table)	56
–3.5	54
0 (center of implant)	52
3.5	50
7.0 (top of implant package)	48

distance between the center of the implant and the x-ray table), and at 7 cm above the center of the implant (at the extreme of the implant packaging). All radiographs were obtained using standard beam to plate distance without changing the position of the x-ray source and detector. The plain radiographs were uploaded to the digital templating software (Orthoview™ v6.2.3.1, Jacksonville, FL), and the appropriate digital templates were selected. For each of the radiographs, the closest matching size template was selected and recorded by a fellowship-trained arthroplasty surgeon.

In order to study the effect of scaling marker position on magnification, a human pelvis x-ray phantom including the pelvis, bilateral hips, proximal femurs, and lumbar spine was positioned on a standard x-ray table as shown in Fig. 2a. The phantom's height measured 18 cm from its base to the anterior surface of the symphysis. A 25-mm image scaling sphere was positioned alongside the greater trochanter at the center of the hip, which was visualized through the clear plastic of the phantom. A plain anteroposterior x-ray was obtained of the pelvis and the scaling sphere in this position. Additionally, x-rays were obtained with the scaling sphere 9 cm below the hip center (flush with the table), 4.5 cm below the hip center (half the distance between the hip center and table), 9 cm above the hip center (at the level of the pubic symphysis), and 4.5 cm above the hip center half the distance between the hip center and the pubic symphysis (Fig. 2b). All AP hip radiographs were obtained with standard beam to plate distance without changing the position of the x-ray source and detector. The plain radiographs were uploaded to the same digital templating software, and the

Table 2 The hip phantom was used to investigate the difference in digitally templated cup size based on positioning of the scaling sphere

Distance from center of greater trochanter (cm)	Digitally templated cup size
–9.0 (level of the table top)	62
–4.5	58
0 (center of the hip)	54
4.5	50
9.0 (level of the pubic symphysis)	48

acetabular template was selected and recorded by a fellowship-trained arthroplasty surgeon.

In order to determine the optimal scaling marker position based on variable BMI, a retrospective chart review, approved by our institution's IRB, was used to identify all total hip arthroplasty cases that also underwent a preoperative CT scan of the bilateral hips performed by a single surgeon (JMV) at our institution between January 2013 and September 2015. Two measurements from each CT scan were performed on the operative hip in all cases: (1) the perpendicular distance from the center of the greater trochanter to the anterior skin surface and (2) the perpendicular distance from the center of the greater trochanter to the posterior skin surface. One example of these measurements is available in Fig. 3. The position of the center of the greater trochanter was calculated from these measurements as the percent distance from the anterior thigh. In addition, the body mass index (BMI), age, and sex of all patients were recorded.

Results

By centering the scaling sphere at the same level of the acetabular implant, an accurate cup size of 52 mm was achieved. Positioning the scaling sphere 3.5 cm closer to the x-ray detector resulted in magnification of one full cup size (Table 1, Fig. 4). Likewise, positioning the scaling sphere 3.5 cm further from the x-ray detector resulted in reduction of one full cup size. In the second part of this study, the pelvis phantom was found to have a cup size templated to be 54 mm (Table 2, Fig. 5). Positioning the

Fig. 4 X-ray imaging and digital templating of the packaged acetabular implant and metallic scaling sphere. The metallic scaling sphere was positioned flush with table—7.0 cm below the center of the implant (a), 3.5 cm below the center of the implant (b), center of the implant (c), 3.5 cm above the center of the implant (d), and at the top of the implant packaging—7.0 cm above the center of the implant (e). Templated cup sizes are shown in yellow text. The red text demonstrates the effect of magnification on the scaling sphere's diameter in each image.

Fig. 5. X-ray imaging and digital templating of the pelvis phantom and metallic scaling sphere. The metallic scaling sphere was positioned at the base of the table—9.0 cm below the center of the hip joint (a), 4.5 cm below the center of the hip joint (b), center of the hip joint (c), 4.5 cm above the center of the hip joint (d), and at the pubic symphysis—9.0 cm above the center of the hip joint (e). Templated cup sizes are shown in yellow text. The red text demonstrates the effect of magnification on the scaling sphere's diameter in each image.

scaling sphere at the level of the pubic symphysis resulted in a templated cup size of 48 mm, while placing the scaling sphere at the surface of the x-ray table resulted in a templated cup size of 62 mm.

With regards to using the center of the greater trochanter as a surrogate for scaling sphere positioning, a total of 65 patients (32 men, 33 women) were identified in this study ranging from 23 to 74 years of age with an average age of 54. Figure 6 demonstrates the distribution of the position of the center of the greater trochanter with respect to patient BMI for this series of 65 patients. This patient population had an average BMI of 28.72 kg/m^2 (standard deviation 6.26 kg/m^2) and an average position of the center of the greater trochanter of 51% (standard deviation of 6%) from the anterior surface of thigh. The position of center of the greater trochanter ranged from 46 to 53% from the anterior thigh surface. Table 3 shows the average position and standard deviation of the greater trochanter location based on BMI range.

Discussion

In this study, we have demonstrated the importance of proper scaling marker position for accurate digital templating for hip surgery. The first part of this study used a known

Fig. 6. This plot demonstrates location of the greater trochanter in the thigh with respect to each patient's body mass index.

acetabular cup size and varied the position of the scaling marker. This demonstrated that placing the scaling marker at the level of the center of the acetabular implant produces an accurate template. Four additional x-rays were obtained to show the effect of scaling marker position on templated implant size due to magnification. As the scaling marker was moved toward the x-ray detector, the templated implant size increased. Placing the scaling marker 3.5 cm more anterior or posterior than the center of an acetabular implant resulted in a one cup size difference from the known implant size.

The limitations of this study include (1) evaluation of a single hip pathology, (2) a limited number of samples for the BMI evaluation, and (3) variation in patient fat distributions (male vs female) affecting the BMI analysis. Given the large variation in patient anatomy and a lack of a priori knowledge, it is unlikely that a single estimation method will be applicable to all cases including the extremes; however, a practical guide of scaling sphere positioning for x-ray technologists that addresses most patient anatomy is highly desirable. In this study, we did not specifically evaluate hip dysplasia, Perthes disease, hip impingement, and variations in pelvic tilt. We recommend that after these conditions are discovered, scaling sphere position should be modified accordingly to plan for these cases. In the future, we plan to collect a larger number of patients to give recommendations based on specific disease state and also for patient-specific fat distributions. Furthermore, we plan to collect additional CT scans for a reliability study and to increase our sample

Table 3 Average location of the greater trochanter with respect to the anterior thigh based on BMI range

BMI (kg/m^2) range	Average percent from anterior thigh	Standard deviation
20–25	53%	6.2%
25.1–30	51%	5.5%
30.1–35	50%	5.4%
35.1–40	50%	5.7%
> 40	46%	3.7%

size for the extremes of BMI to provide recommendations for scaling sphere positioning in these patients.

An anatomic pelvis phantom was used in the second part of this study to demonstrate the effects of magnification based on anatomic landmarks. Clinically, x-ray technologists place scaling markers during image acquisition. The placement of the scaling spheres at the level of the center of the hip joint is difficult, especially given variations in body habitus, fat distribution, pelvic tilt, femoral anteversion, and hip dysplasia. Given a lack of a priori knowledge of patient specific anatomy, x-ray technologists use external palpable landmarks such as the center of the greater trochanter, pubic symphysis, or x-ray table for scaling marker placement. This large variation in scaling marker position is problematic for obvious reasons. In this portion of the study looking at specific anatomic landmarks, we have demonstrated a difference in two acetabular implant sizes when the scaling marker is placed at the level of the table and four sizes when positioned at the level of the pubic symphysis. These findings reinforce the need for a practical method for x-ray technologists to position scaling spheres for accurate hip imaging.

The third portion of this study aimed to establish a practical method for scaling marker positioning for x-ray technologists. The center of the greater trochanter is often a surrogate for the hip center given its ability to be palpated externally; we have demonstrated above that positioning the scaling sphere ± 3.5 cm from the actual hip center will result in a $\pm$ one cup size that is templated. This 7-cm window for scaling sphere position allows for some variation in patient-specific anatomy (e.g., variations in femoral version) when the greater trochanter is used as a surrogate for the hip center. However, the greater trochanter is not palpable in all patients, which was the motivation for the third part of this study; herein, we investigated patient BMI as a method to estimate the position of the greater trochanter. Overall, we found that scaling markers can be estimated to be placed mid-thigh in the anterior-posterior direction for patients with a BMI between 25.1 and 40. Patients with a BMI < 25 should have the scaling marker placed posterior to the mid-thigh (53% measured from the anterior thigh surface), and patients with a BMI > 40 should have the scaling marker placed anterior to the mid-thigh (46% measured from the anterior thigh surface).

In conclusion, digital templating relies on accurate scaling marker position to faithfully estimate implant size. We have shown that the most accurate digital templating is achieved when scaling markers are positioned as close as possible to the center of the hip joint. Deviation from this positioning results in inaccuracy in templated acetabular implant size. Based on the findings in this study, scaling markers for hip imaging should be placed laterally, mid-thigh in the anterior-posterior direction for patients with a BMI between 25 and 40 kg/m². If abnormal hip anatomy is

discovered, then scaling sphere positioning should be optimized on a case-by-case basis.

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Compliance with Ethical Standards

Conflict of Interest: Austin J. Ramme MD, PhD; Nina D. Fisher, BS; Jonathan Egol; Gregory Chang, MD; Jonathan M. Vigdorchik, MD have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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