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Basic Science

Calibration Marker Position in Digital Templating of Total Hip Arthroplasty

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ABSTRACT

Background: We report a mathematical method to assess the vertical and horizontal positions of spherical radiopaque objects of known size in conventional radiographs.
Methods: The reliability and validity of the method were tested in an experimental setting and applied to 100 anteroposterior pelvic radiographs with external calibration markers and unilateral total hip arthroplasty (THA).
Results: We found excellent reliabilities; intraclass correlation coefficients for interobserver and intra-observer reliabilities were 0.999-1.000 ($P = .000$). The mean normal height of THA was 198 mm (range: 142-243 mm, standard deviation: 18 mm) above the detector. Vertical and horizontal external marker positions differed significantly from the true hip center (THA; $P < .001$ and $P = .017$).
Conclusion: This method could enhance patient safety by enabling automated detection of malpositioned calibration markers by templating software.

Preoperative templating is the standard in planning of elective total hip arthroplasty (THA) [1,2]. Today, digital radiography has replaced conventional radiography and acetate templating, thus resulting in the necessity to use calibration markers [3,4]. The optimal position of these markers is at the same vertical and horizontal distance from the source of the X-ray beam as the hip joint center [5]. Calibration based on incorrectly placed markers is known to result in oversizing or undersizing of the planned prosthetic components [6,7]. However, in the clinical routine, neither the true height of the marker nor the hip center is known, and previous studies showed that the clinical localization of the supposed hip joint center before calibration marker placement is imprecise [8], thus leading to magnification errors of over 20% [3,6,7].

The present study aimed to dissect the effect of the position of the calibration marker during digital templating of THA and to develop a reliable method to calculate the true position of the marker in the radiograph. The first goal of this study was to assess the applicability and reliability of the presented mathematical method. The second goal was to validate the method in a clinical setting. Third, the study aimed to define the range of normal positions of the hip joint center in radiographs. Based on these findings, a plausibility check to identify misplaced external markers could be included in future templating software.

Patients and Methods

Experimental Setting

An object holder was designed to place a calibration marker of 16-mm radius on the X-ray table in a defined vertical (z_0) and horizontal (x_0) position above the cutting point of the central beam and the table (Fig. 1). The marker was placed in the predefined position on the table, and a radiograph was taken with a Philips DigitalDiagnost (Philips GmbH, Hamburg, Germany) with a tube-to-detector distance of 1100 mm and a table-detector distance of 75 mm; the pad was removed from the table before the experiment, and the height of the base of the object holder was 8 mm. Thus, the center of the marker could be placed between 99 and 399 mm above the detector.

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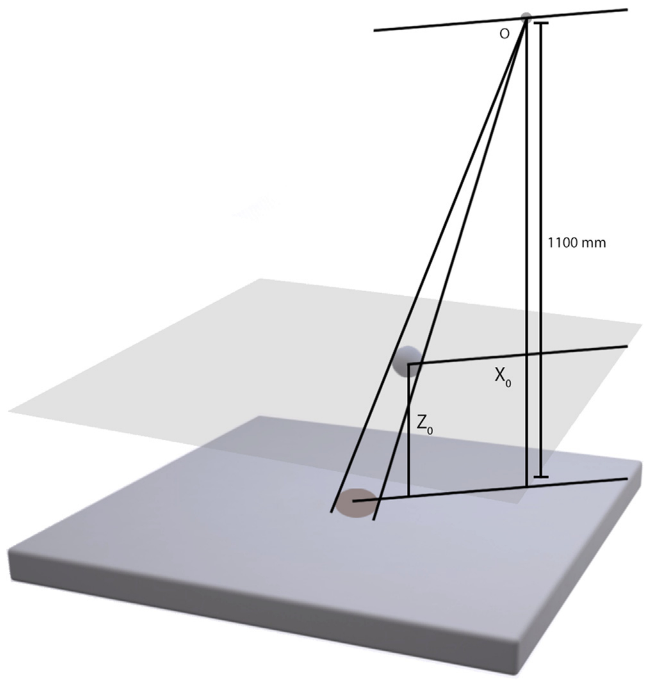

Fig. 1. Schematic figure of an object in the X-ray beam. The origin (O), central beam (vertical line), spherical object at a vertical distance (z_0) above the detector, and a horizontal distance (x_0) from the central beam are depicted. The projection of the sphere on the detector is shown.

First Experimental Setting

To test the applicability of the mathematical method, a series of 28 radiographs with positions for z_0 from 0-300 mm and for x_0 from 0-150 mm in 50-mm increments was taken; 5 radiographs did not depict the marker completely ($z_0 > 50$ and $x_0 = 150$ mm) and were excluded.

Second Experimental Setting

For validation, 25 radiographs with the marker ball were analyzed. To account for the possibility of incomplete depiction of the marker, fifty random values were generated using Microsoft Excel 2008 for Mac version 12.3.6 (Microsoft Corporation, Redmond) for x_0 (0-150 mm) and for z_0 (0-300 mm) and the corresponding radiographs were taken. The first 25 radiographs with complete depiction of the marker were stored in the picture archiving and communication system (PACS) and further analyzed.

Clinical Setting

A series of 100 standing anteroposterior radiographs of the pelvis of patients with unilateral THA of known implant size was retrospectively identified in the PACS. Radiographs were taken with the same X-ray apparatus as in the experimental setting. The feet were 15-20° internally rotated, and the X-ray beam was centered to the pubic symphysis. A spherical external calibration marker (ECM) of 28 mm diameter was attached to the patient medially between the legs at the laterally palpated height of the greater trochanter above the table.

Analysis of Radiographs

Radiographs were evaluated with a proprietary PACS client (IMPAX EE; AGFA HealthCare GmbH, Bonn, Germany). The center of the image, the diameter of the test marker or external and internal calibration markers (ICM; ie, THA head), and the distance of the center of the markers from the center beam were measured. Radiographs with incomplete depiction of the marker were excluded.

Two independent and blinded observers evaluated the experimental and clinical (JB, CKB) radiographs. One observer (JB), blinded to the previous results, performed repeated measures 3 months after the first measurement.

Geometric Principles of Radiographic Magnification Effects of Spheres

As previously described, formula 1 gives the projected size of a sphere at a vertical (z_0) and horizontal (x_0) position from the point where the central X-ray beam cuts the plane of projection (O, Fig. 2) [6]:

$$\left|P'Q'\right| = m = \frac{2rh\sqrt{x_0^2 + (h - z_0)^2 - r^2}}{(h - z_0)^2 - r^2}|PQ| \quad (1)$$

The major axis of the projected image is $A = 2a = |P'Q'|$. Solving equation 1 for x_0 or z_0, formulas 2 and 3 are derived:

$$x_0 = \sqrt{\frac{A^2\left[(h - z_0)^2 - r^2\right]^2}{4r^2h^2} - (h - z_0)^2 + r^2} \quad (2)$$

$$z_0 = h - \sqrt{r^2\left(1 + \frac{2h^2}{A^2}\right) + \frac{2rh}{A}\sqrt{\frac{r^2h^2}{A^2} + x_0^2}} \quad (3)$$

With these formulas, the vertical or horizontal distance can be calculated with the knowledge of either one of the variables. The vertical height can be assessed indirectly from the radiograph: after the identification of the center, projected x_0 and the projected diameter of the calibration marker, x_0, can be calibrated and, with formula 3, z_0 can be calculated.

The calibration factor (CF) is explained by formula 4:

$$CF = \text{Projected diameter/true diameter} \times 100 \quad (4)$$

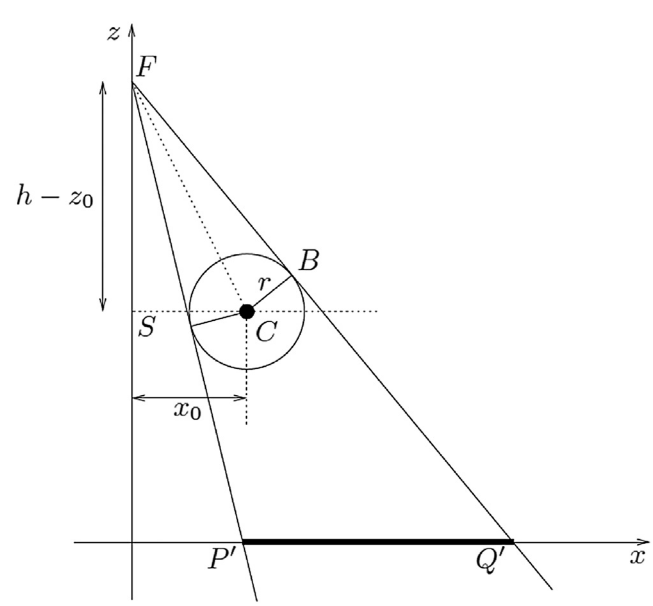

Fig. 2. Diagram of the projection of a sphere in radiographs. From Boese et al [6] under the Creative Commons Attribution (CC BY) license.