

A simple and convenient method guide to determine the magnification of digital X-rays for preoperative planning in total hip arthroplasty

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Abstract

Scaling of anteroposterior digital pelvic X-rays with variable magnification is the premise for accurate preoperative planning of total hip replacement with digital templating. Conn's method of placing a marker of known diameter beside the thigh at the level of the femur has been reproduced in many studies and confirmed as one of the most accurate methods. But in our experience, it is inconvenient for radiographers and is not well tolerated by some patients. We modified this method by placing a coin on the radiograph plate. One hundred patients who had undergone hip replacement were enrolled in the study and randomly divided into two groups. The actual diameter of the prosthesis head was taken as the gold standard for assessment of the magnification of the coin in Group A. The coin was within a mean of 117.95% (range 114.37-122.02%) of magnification for male, and 111.71% (range 114.37-120.93%) for female patients. The variation was small and limited, and had no correlation with body shape parameters (*i.e.* height, weight, BMI). Subsequently, the magnification of the coin was used to correct the measuring scale of the X-rays of the other 50 patients (Group B). Bias did not exceed 1.96 mm during measurement of the prosthesis with a diameter of less than 56 mm, and a range of absolute error of measurements of 56-66 mm (standard deviation, SD, 0.04-3.95 mm). Furthermore, in order to confirm the expressiveness of the modified method, CT scans of another 50 patients were randomly selected. The distance between the rotation center of the hip and the table, which is acknowledged to be a factor which influences magnification of the coin, changed little in response to body shape. Variation in magnification was caused by variation in distance between the rotation center of the hip and the table. The minimal change in distance for

patients with different body shape led to easier and more convenient examination, and increased the feasibility of our modified coin method, except in cases where implantation of a very large-sized prosthesis is necessary.

Introduction

Total hip arthroplasty (THA) is a reliable procedure for relieving pain and restoring function of the hip joint. To achieve optimal hip function, preoperative evaluation is a very important step for successful THA.^{1,2} Preoperative evaluation includes the analysis of X-rays. Besides confirming clinical diagnosis, these can also be used for operation planning with digital templating to assess the appropriate size of components, the level of osteotomy, and the required postoperative neck length and femoral offset. The purpose is to restore the biomechanics of the hip and minimize leg length discrepancy.

In order to obtain reliable data, the magnification of templates must correspond to the magnification of preoperative X-rays. An object of known size is used as a marker to determine magnification. There are many methods available, including Conn's method³ which uses a coin or ball of known diameter placed beside the patient's outer thigh at the level of the femur. Other studies have shown this method to be reproducible and accurate.^{4,5} However, it is not convenient or sufficiently feasible for radiographers and it has mostly only been used in experiments. Furthermore, the position of the marker (coin or ball) beside the outer thigh would not be included in anteroposterior X-rays of the pelvis of obese patients. The method was modified in our hospital by placing the marker between the patient's thighs and attaching it to the skin at the level of the femur. Patient feedback confirmed that this was not well tolerated. The marker was very small in diameter (23 mm) and the radiographers were unable to accurately estimate the level of the femur of obese patients.

In order to find a method which was better tolerated by patients and more convenient for radiographers, we modified the procedure by placing a coin as a point of reference directly on the plate. A study was performed to compare the accuracy of this modified method with that of Conn. Furthermore, according to the theory of magnification of X-rays, the greater the distance between the bone of the supine patient and the plate on the X-ray table, the greater the magnification.³ We hypothesized that the height, weight and BMI of each patient might be an influencing factor on distance and that, if this was correct, the correlation between them could be used to adjust the deviation of magnification and make it more accurate.

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Key words: total hip arthroplasty, X-ray, magnification, digital templating.

Acknowledgment: investigation carried out at the University of Duisburg, Essen, Germany. Head: Prof. Dr. Marcus Jäger.

Received for publication: 13 November 2011.
Accepted for publication: 11 January 2012.

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Orthopedic Reviews 2012; 4:e12
doi:10.4081/or.2012.e12

Therefore, all parameters relevant to body shape were recorded and use to calculate any required adjustment.

Materials and Methods

Local ethical approval was obtained for this study. The patients were randomly divided into two groups (A and B). Each group included 50 patients. The study was divided into three stages. In the first stage, the markers of the two methods were placed in position on the anterior-posterior X-rays of the pelvis of the 50 patients in Group A (Figure 1). The known diameters of the heads of the prostheses were used to calculate the magnification of the markers according to the following formula:

$$\text{magnification}_{(\text{marker})} = m_r / (h_r / h_i \times m_i)$$

where

m_r and m_i = diameters of the actual marker and the image of the marker, respectively and

h_r and h_i = diameters of the actual prosthetic femoral head and the image of the prosthetic femoral head, respectively.

Meanwhile, the data recorded at the same time as the X-ray examination concerning the body shape of the 50 patients were used to establish the correlation between them and the magnification of the markers. Subsequently, the assumed correcting factors of body shape for our modified new method were calculated and prepared for verification in the second stage of the study.

Stage 2 involved the 50 patients in Group B. The correlation established in Stage 1 was

used as a factor to eliminate the influence of body shape during procedures to examine the accuracy of the modified method. Coincidence between the measured and actual diameter of the prosthesis was used as the index by which the feasibility of our modified method was evaluated.

The question as to whether there are any body shape factors which could influence measurement was examined again by means of a CT scan in Stage 3. The distance between the femur and the plate was measured by CT to reassess the relationship with body shape. A retrospective chart review was made based on patient's height and weight, and the date on which these parameters were recorded. Patients without both height and weight recorded in their charts were excluded from the study. Patients whose CT scans showed abnormal features, such as skin defects, or deformity of the pelvis and hip that could influence determination of the rotation center of the hip were also excluded.

X-ray technique

Digital A/P view X-rays were taken according to a standard protocol with the patellae facing vertically if allowed by the internal rotation of the hip. The focus of the X-ray source was the pubic symphysis. The distance between the source and the patient was 900-1200 mm in order to include at least 8 inches of the proximal femur in all views.

Coin method

In our modified method, a coin of known diameter was placed on the plate on the same side of the hip to be operated. To ensure that the image of the coin would not be left out of the image of the prosthesis, the coin was placed a little more proximally to the body than the hip. X-rays were scaled by applying the known diameter of the prosthesis head. The diameter of the coin was then measured and compared with the known size, the result being the rate of magnification of all the patients for this method.

Ball method

Conn introduced a ten pence coin as reference. In his opinion, the maximum diameter of the coin could be measured on the X-ray, whether it was a side-on bar or an ellipse. The thickness of coin would only slightly influence the measurement. In order to exclude this potential interference, a ball was used instead of a coin in this part of the study. The ball of known diameter was attached to the skin between the patient's thighs as proximally as possible. It was placed at the same level as the femur as determined by the radiographer. The rate of magnification of all the patients was measured in the same way as with the coin.

Measurement of magnification

The MedCAD templating software (MediCAD Multimedia Co., Niederviehbach, Germany) was used to measure the radiological images. The images were scaled using the prosthesis head. The measurement tools measured the diameter of the ball and coin; these measurements were unknown to the operator. All measurements were carried out by the same operator.

The weight and height of the patients were measured at the same time as the X-rays were taken. From these data, body mass index (BMI) was calculated according to the formula:

$$\text{BMI} = \text{weight}/\text{height}^2$$

where

BMI was measured in kilograms per m²

weight was measured in kilograms

height was measured in meters.

Measurement of the distance between the hip rotation center and the table for patients with different body mass index

All 50 patients in Stage 3 underwent multi-section scanning (Siemens Somatom multi-slice-CT, Siemens AG, Munich, Germany); section thickness was 5 mm in all subjects. All the patients were positioned supine on the CT table. The distances between the rotation center of the hip and the CT plate were measured in the horizontal slice going through double rotation centers of hip, and the average of the two distances in each patient was used to correct the bias of the rotation of the pelvis. This

procedure was performed by 2 experienced operators who were familiar with the system.

Statistical analysis

Statistical analyses were performed with SPSS 12.0 software (SPSS Inc., Chicago, Illinois, USA), using Student's t-test to compare differences in magnification between the two methods. Levene's test was used to assess the significance of variations between the different methods. The strength of the correlation between physical characteristics and variety of magnification was evaluated by using linear regression analysis. $P < 0.05$ was considered significant.

Results

The mean, SD, ranges and comparisons between gender for the physical characteristics and magnifications of the marks of the 50 patients in the first stage of study are shown in Table 1.

There was a statistically significant difference between the magnification of the coin and the ball. However, using Levene's test ($P > 0.05$), there was no statistical difference in the variability of errors between the measurement of the coin and that of the ball, confirming similar accuracy for the two methods.

Linear regression analysis ($P > 0.05$) revealed no correlation between physical characteristics (*i.e.* height, weight, BMI) and the magnification of the coin. The relationship

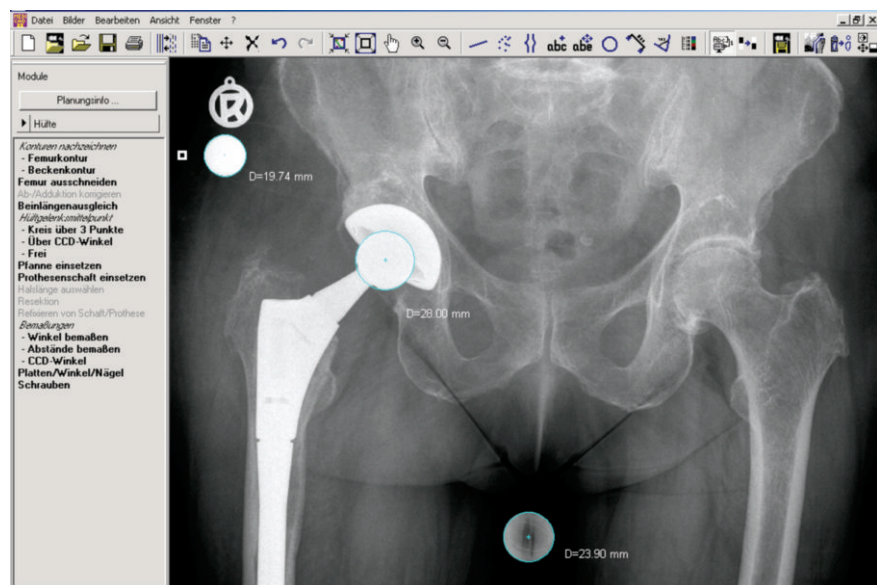


Figure 1. The known diameters of the prosthetic heads (28 mm) were used as the standard for the scale of the measuring ruler. In this case, the diameters of the images of the coin and ball were 19.74 and 23.90 mm, respectively. So magnifications calculated according to the formula: $\text{magnification} (\text{marker}) = m_r / (h_r / h_p \times m_p)$ were 116.5 and 104.6% for coin and ball, respectively.

between changes in height, weight and magnification was again analyzed using regression analysis. Any difference found was less than significant ($P > 0.05$). Independent analysis according to gender was performed for male and female patients (Figures 2 and 3).

No significant correlation was found between height, weight, BMI and position of the hip rotation center; however, the bias was small. The mean magnification of the coin established in the first stage of the study was used to scale the magnification of the X-rays of the other 50 patients (Group B). Figure 4 illustrates the relationship between the actual diameters of the component *versus* the diameters calculated using the coin method.

Data were divided into 3 ranges according to the size of implant. The diameter of prosthesis head was included in the small-size group which ranged from 28 to 44 mm. The middle-size-group ranged from 44 to 56 mm which included the diameter of most of the cups. The large-size-group included implant sizes over 56 mm. Levene's test was used to calculate and analyze mean error (Table 2).

The distribution of absolute error in the small-size group ranged from 0.35 to 0.48 mm, and in the middle- and large-size groups from 0.01 to 1.96 mm and from 0.04 to 3.95 mm, respectively.

Our hypothesis that an individual's height, weight and BMI are influencing factors on the distance between the femur and the examining table, and that these measurements could be used to correct the deviation of magnification, was not proved. Even so, we performed Stage 3 of our study to confirm our findings by means of measurement with a CT scan. The mean, SD, ranges and comparisons between genders for the physical characteristics and distances from the hip rotation center to the CT table of 50 patients after CT scan are shown in Table 3. The correlation between age, body-shape factors (including height, weight, BMI) and the distance from the hip rotation center to the CT table measured on the CT image was evaluated by stepwise linear regression analysis. For male patients, only body weight correlated significantly with the distance ($R^2=0.392$, $P < 0.05$). The formula of the linear regression was distance= $a+b \cdot \text{weight}$ ($a=8.441$, $b=0.026$).

For female patients, only age and body-weight correlated significantly with the distance ($R^2=0.576$, $P < 0.05$). The formula of the linear regression was

$$\text{distance} = a + b \cdot \text{weight} - c \cdot \text{age} \quad (a=9.251, b=0.055, c=0.028).$$

(Weight in kg; age in years).

However, the inclinations of the regression lines were very small for both male and female patients, which led to a narrow range of distance variation (Table 2).

Table 1. Physical characteristics and magnification of the marks in 50 patients.

Parameter	Men (n=26)		Women (n=24)	
	Mean±SD	Range	Mean±SD	Range
Age (years)	64.57±10.82	39-79	69.38±7.80	54-86
Height (cm)	175.38±7.57	157-189	166.79±5.24	156-176
Weight (kg)	86.62±13.59	60-115	73.79±14.84	59-102
body mass index (kg/m ²)	28.18±3.96	19.37-37.55	26.53±5.23	20.66-38.28
Magnification of coin (%)	117.95±1.95	114.37-122.02	111.71±2.08	114.37-120.93
Magnification of ball (%)	103.71±2.91	97.81-108.89	99.65±1.78	96.50-102.92

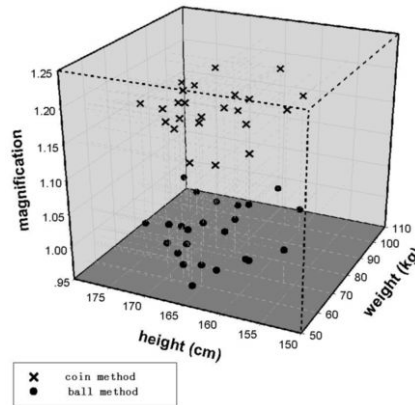


Figure 2. 3D-scatterplots showed no correlation between physical characteristics in female patients.

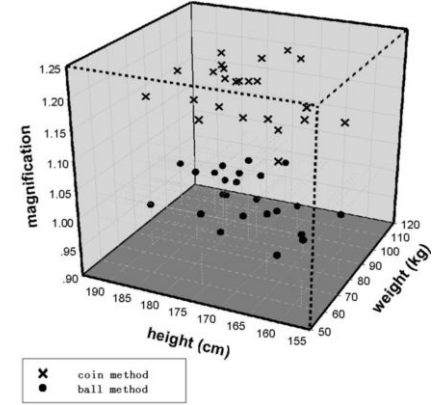


Figure 3. 3D-scatterplots showed no correlation between physical characteristics in male patients.

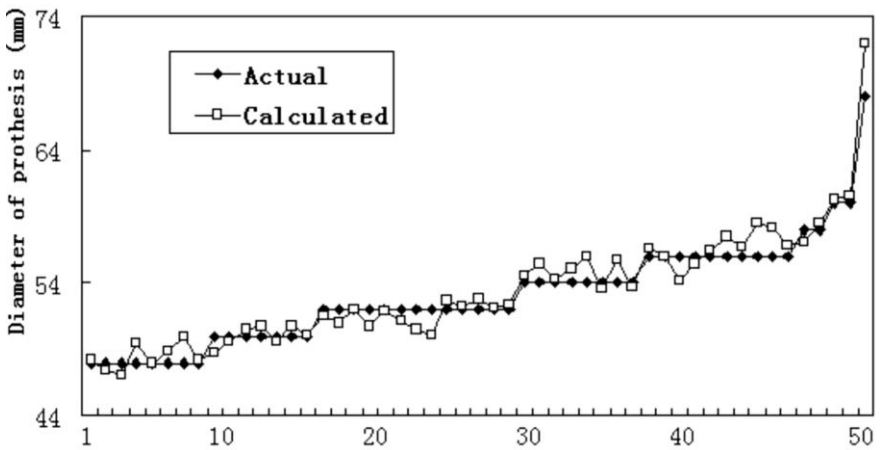


Figure 4. Scatterplots showed the relationship between the actual sizes of cups *versus* those calculated using the coin method. The larger the size, the greater the error. Only 28 mm prosthesis heads were used. Data concerning the actual heads and measurements are not shown.

Table 2. Mean error and significance (unit: mm).

Subject error	Small-size group	Middle-size group	Large-size group
Mean difference±SD	-0.0006±0.3846	-0.0623±0.9294	-0.7±1.1373
Mean absolute difference±SD	0.3006±0.2360	0.746±0.5433	1.3998±1.0408
P	P < 0.01	P < 0.01	P < 0.01

NB: the mean difference is derived from both positive and negative values when the measured values are subtracted from the calculated values. The mean absolute difference is calculated from absolute values in differences and is a more realistic indication of error. The P value indicates that the variability of errors is statistically distinguishable. In other words, the error of the small-size group was the smallest and that of the large-size group was the largest.

Discussion

The greater the distance of the bone from the plate, the greater the magnification. In order to eliminate the influence of variant distance and scale the magnification, Conn chose a point of reference on the greater trochanter. His study had an accuracy of 68.8%.³ However, it was a challenge for radiographers to find the correct position of the point of reference on the hip only by touching the greater trochanter. The outcome was especially inaccurate in cases where the legs were rotated or presented deformities of the proximal femur, or in cases in which the patients were obese. This was also a finding in our study.

No correlation was found between magnification and the normal parameters describing body shape, including height, weight and BMI. But the distance between the level of the femur and the examination table, which was the influencing factor for magnification, was found to correlate with body weight and age. We suspected that any minor change in distance according to weight and age identified by CT scan, would not be detected by the X-ray examination because of the acknowledged difference in reliability of the two technologies. Furthermore, the different sizes of patients' buttocks and the rotation of the legs and pelvis would lead to a change in magnification during X-ray examination. An unpublished pilot study at our institution revealed that, in the process of taking AP pelvic X-rays, the distance from the source to the plate ranged from 900 to 1200 mm, which was also an influencing, although not a major, factor. It was generally impractical for radiographers to attempt to monitor all these factors. Therefore, the contradictory results from CT and X-ray examinations were reasonable and acceptable.

Our study measurements with CT scan illustrated that there was not much variation in the distance between the bone and the plate in patients with different body shape. This result agrees with that of Wimsey *et al.*⁶ who measured

Table 3. Physical characteristics and distance from rotation center of hip to the computed tomography (CT) table of 50 patients following CT scan.

Parameter	Men (n=20)		Women (n=30)	
	Mean±SD	Range	Mean±SD	Range
Age (years)	68.40±10.38	37-83	66.7±14.88	35-95
Height (cm)	174.95±7.56	159-192	161.0±6.23	148-182
Weight (kg)	83.70±24.64	47-170	69.4±15.58	46-107
Body mass index (kg/m ²)	27.02±5.88	18.59-46.12	26.77±5.82	16.65-41.28
Distance from hip rotation center to the computed tomography table (cm)	10.66±1.04	8.60-12.55	11.23±1.35	8.25-3.55

the levels of the greater trochanter and found a narrow variant range between 6 and 12 cm from the examining plate. The accuracy and practicability of the coin method was, therefore, confirmed. Placing a coin on the plate was an easy and convenient method for radiographers which did not involve touching the patient's body. This was also more acceptable for patients. The maximum error margin of measurement of small and middle-size data was acceptable when on-screen measurement of prosthesis, leg length discrepancy and offset range was less than 54 mm. This was a little less precise than the outcome of Wimsey's research, in which the point of reference was placed between the thighs at the level of the greater trochanter and measured by a plastic rectangle.⁶ However, accuracy was sufficient to determine the best-fitting component and differentiate between each of the two sizes of acetabular cup in most of the cases. Nevertheless, in view of the increasing unacceptable error, the coin method cannot be recommended for scaling and measuring of data for cup dimensions over 56 mm.

This method is a practicable and convenient way of scaling magnification which can be applied in everyday X-ray procedures. The current results support the hypothesis that this method enables accurate templating with digital X-rays, except in cases in which implantation of a very large-sized prosthesis is necessary.

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