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Is There Any Difference Between a Spherical Marker and a Simple Coin for Hip Replacement Digital Planning?*

*Existe alguma diferença entre um marcador esférico e uma moeda simples para planejamento digital de substituição de quadril?**

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Abstract

Objective To evaluate the accuracy and differences between 2 types of metallic markers, sphere, and coin, for radiographic calibration in the preoperative planning of hip arthroplasty.

Methods Four spherical metallic markers and four coins, both 25 mm in diameter, were placed on the greater trochanter, pubic symphysis, between the thighs, and on the table of the exam, for radiographic examination of the hip in 33 patients with hip prosthesis. The prosthesis head was used for calibration and two examiners measured the markers' image diameters, and the results were analyzed statistically.

Results In the greater trochanter, the sphere and the coin were not visualized in 19 radiographs (57.6%). Between the thighs, the coin marker was not visualized in 13 radiographs (39.4%). In the greater trochanter, the 25-mm accuracy of the coin and the sphere was, respectively, between 57.1 and 63.3% and between 64.3 and 92.9%. The coin between the thighs reached 25-mm accuracy in between 50 and 60% of cases. Over the exam table, the coin and sphere markers reached, respectively, the mean diameters of 22.91 mm and 23 mm, the lowest coefficient of variation, the lowest confidence interval, and the easiest positioning. There was statistical difference between the evaluations of the markers (coin vs. sphere) in all positions ($p < 0.032$), except for the exam table position ($p = 0.083$).

Keywords

- arthroplasty, replacement, hip
- hip prosthesis
- radiography
- pelvis
- radiographic magnification

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Conclusions The coin between the thighs is the best marker for radiographic calibration in the preoperative planning of hip arthroplasty, and we suggest the use of another coin on the exam table for comparison, considering the 8% reduction in relation to its real size.

Resumo

Objetivo Avaliar a precisão e as diferenças entre 2 tipos de marcadores metálicos, esfera e moeda, para calibração radiográfica no planejamento pré-operatório da artroplastia de quadril.

Métodos Quatro marcadores metálicos esféricos e quatro moedas, ambas de 25 mm de diâmetro, foram colocadas em trocânter maior, sínfise púbica, entre as coxas e a mesa do exame, para exame radiográfico do quadril em 33 pacientes com prótese de quadril. A cabeça da prótese foi utilizada para calibração e dois examinadores mediram os diâmetros da imagem dos marcadores, e os resultados foram analisados estatisticamente.

Resultados No trocânter maior, a esfera e a moeda não foram visualizadas em 19 radiografias (57,6%). Entre as coxas, o marcador de moeda não foi visualizado em 13 radiografias (39,4%). No trocânter maior, a precisão de 25 mm da moeda e da esfera foi, respectivamente, entre 57,1 e 63,3% e entre 64,3 e 92,9%. A moeda entre as coxas atingiu 25 mm de precisão entre 50 e 60%. Sobre a mesa de exame, os marcadores de moeda e esfera atingiram, respectivamente, diâmetros médios de 22,91 mm e 23 mm, o menor coeficiente de variação, o menor intervalo de confiança e o posicionamento mais fácil. Houve diferença estatística entre as avaliações dos marcadores (moeda vs. esfera) em todas as posições ($p < 0,032$), com exceção da posição na mesa de exame ($p = 0,083$).

Conclusões A moeda entre as coxas é o melhor marcador para calibração radiográfica no planejamento pré-operatório da artroplastia de quadril, e sugerimos o uso de outra moeda na mesa de exame para comparação, considerando os 8% de redução em relação ao seu tamanho real.

Palavras-chave
- artroplastia de quadril
- prótese de quadril
- radiografia
- pelve
- ampliação radiográfica

Introduction

Preoperative surgical planning is fundamental to predict difficulties during the procedure, sizes of components, and positioning of implants in hip arthroplasty.[1–6] Adequate surgical planning reduces the number of complications associated with discrepancy between members, poor positioning, early implant loosening, instability, periprosthetic fracture, and loss of bone mass.[1–6] It was traditionally performed with printed radiographs and use of transparencies with magnification established by the prosthesis' manufacturer, with usual variations in the range of 100 to 130% of the real size.[5] However, with the development of digital radiographic imaging, computerized planning has become a practical alternative with proven reproducibility.[7]

To correct the magnification of digital radiography, radiopaque markers such as spheres,[8–10] disks (coins),[11] and plates[12,13] have been used in the past 10 years.[9,10,14–17] The nearer the position in relation to the joint studied, the smaller will be the variation in the marker's magnification,[17] decreasing the errors in calibration. For hip replacement, the markers are commonly positioned in the region around the joint, such as in the greater trochanter[9,11,12,14,15,17] and between the thighs.[9,10,12–14,16,17]

Calibration is an essential first step of the digital planning, performed by the examiner to identify a known distance between two points or by the diameter of a circle circumscribed around three peripheral points of the reference object. The gold standard calibration is calculated from the head of the prosthesis implanted in postoperative patients. There is no standardization either of the best position or the best type of marker for hip arthroplasty planning.

The objective of the present paper is to evaluate the precision and differences between two types of metal markers—sphere, and coin—for radiographic calibration in preoperative planning of hip arthroplasty. Our hypothesis was that the sphere positioned alongside the trochanter would be the best method for calibration due to the anatomical proximity to the hip joint and the facility of calibration, but the coin marker would have similar performance when keeping its largest diameter always visible in the radiograph.

Materials and Methods

This prospective transversal study was carried out by the Hip Surgery Group of the Department of Orthopedics and Traumatology of our institution.

The study was conducted with a convenience sample of 33 patients of both genders, with total and/or partial hip prosthesis, either primary or revision, who underwent pelvic radiography as part of the postoperative follow-up in April and May 2017. The radiographs in which the diameter of the head of the prosthesis was unknown from hospital records or that were outside of the radiographic standards were excluded from the study.[18]

Procedures

All the patients were submitted to pelvic radiography in anteroposterior incidence (AP), performed with the patient in dorsal decubitus, with internal rotation of the hips between 15 and 20° and incident radius at the midline, just above the pubic symphysis.[18] For standardization, the focus film distance was 100 cm, determined with a tape measure and Optimus 50 light indicator (Philips Medical Systems, Hamburg, Germany). To standardize analysis of the radiographs, the coccyx was aligned with the pubic symphysis (with distance between them of 2.5 cm for women and 1.5 cm for men), as well as symmetry of the obturator foramens.[18]

Before the radiography, a single physician positioned four spheres or four coins in four positions around the pelvis. The diameter of both markers was 25 mm, confirmed by a Mitutoyo p-06 analog pachymeter (Mitutoyo Sul Americana, Suzano, SP, Brazil) and a WesternPRO (Pasadena, CA, EUA) carbon fiber composite caliper (USA), both certified by Brazil's National Institute of Metrology (INMETRO, in the Portuguese acronym). The markers were held in place with adhesive tape or a clear polyvinyl chloride (PVC) tube with length of ¾ inch, as described in a previous study,[19] and a flexible PVC electrical conduit of the same length. The hose and conduit were sliced lengthwise to allow controlled slippage of the sphere to adjust the position. The markers were positioned at the following sites: 1–Right greater trochanter, on the skin, with the sphere in the electrical conduit and the coin attached with tape at the same level (►**Figs. 1A** and **1B**); 2 - Between the thighs, in the plane of the greater trochanter, with the sphere in the hose placed as proximate as possible and the coin at the same level (►**Figs. 2A** and **2B**); 3–At the level of the anterosuperior border of the pubic symphysis, both attached with adhesive tape (►**Fig. 3A**); 4–Between the exam table and proximal segment of the left thigh, 4 cm distal to the greater trochanter, both attached with adhesive tape (►**Fig. 3B**).

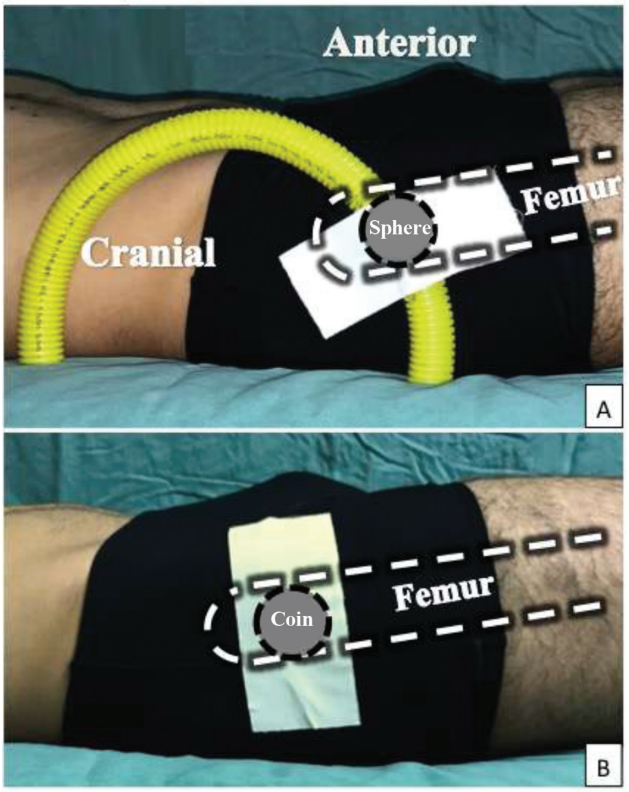

Fig. 1 Positioning of the sphere at the right greater trochanter (1A); Positioning of the coin at the right greater trochanter (1B).

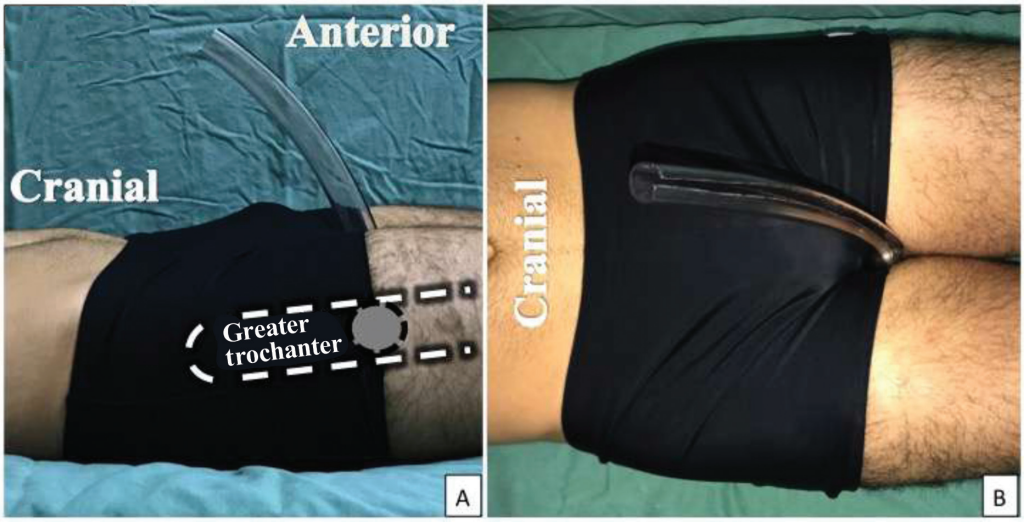

Fig. 2 Positioning of the sphere between the thighs, in the plane of the greater trochanter, side view (2A) and top view (2B).

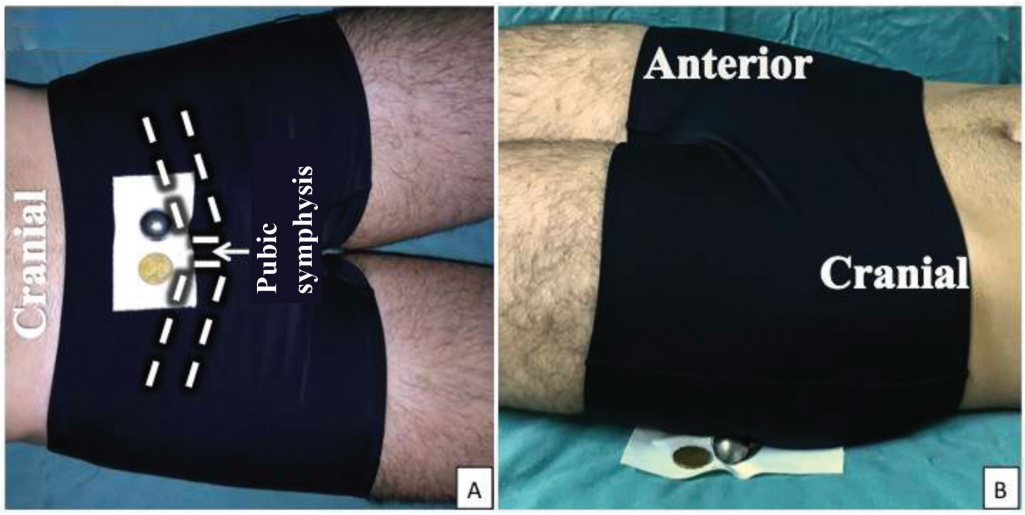

Fig. 3 Positioning of the sphere and coin in the pubic symphysis (3A); Positioning of the sphere and coin on the exam table, on the left side of the patient (3B).

Analysis of the Images

We only considered radiographs that enabled digital measurement of the head of the prosthetic component and at least two spherical markers and coins (►**Figs. 4A**, **4B**, **4C** and **4D**) in the same image. Markers not visualized in the radiograph were not analyzed.

The digital images were analyzed by two doctors who had received previous training for use of the AGFA HealthCare – IMPAX Orthopaedic Tools (AGFA Healthcare, Greenville, SC, EUA) planning software. The prosthesis head was used as a calibration parameter based on three marginal points and confirmed with a circle,[8–10,17] since the diameter is known and the location is centered in the joint.

The diameters of the markers after radiographic calibration were measured by the same technique of identifying three peripheral points and forming a circle to confirm the marker's diameter, both for the sphere[9] and the coin.[11] The diameter of the sphere was evaluated considering the whole circle filled, while for the coin, the largest diameter of the image was considered.

Each evaluator measured all the images of the coins and spheres visualized in each position for subsequent comparison between the measures. All the analyses were performed with a single HP Pavilion DV7 computer (The Hewlett-Packard Company, Palo Alto, CA, USA).

Statistical Analysis

The anthropometric characteristics of the sample were described by calculating the means and standard deviations as well as the absolute and relative frequencies.

The one-sample Student t-test was used to compare the mean at each position for each of the examiners' evaluation with the reference value of 25 mm. The paired Student t-test was used, and the mean, standard deviation, coefficient of variation, minimum and maximum of each of the examiners' evaluation were calculated at each position to judge the similarity between the markers.

The descriptive statistics in percentage of the real value (25 mm) were evaluated by the mean, median, standard deviation, minimum, maximum, and confidence interval. The accuracy of each marker at each position was also calculated. The equality of two proportions test was applied to characterize the relative frequency distribution of the qualitative variables. The results were compared by analysis of variance (ANOVA) and the Pearson and chi-squared tests.

All the analyses were performed with the programs IBM-SPSS for Windows version 20.0 (IBM Corp., Armonk, NY, USA), Minitab 16 (Minitab LLC, State College, PA, USA), and Microsoft Excel 2010 (Microsoft Corp., Redmond, WA, USA), with a 5% significance level, following the literature of reference.[20–22]

Results

The mean values of both markers at the greater trochanter and between the thighs were near the real value of 25 mm. There was no difference between the mean values at the greater trochanter position and the actual value, but in the position with the marker between the thighs, only the coin obtained a statistical difference and was considered more precise. ►**Table 1** reports the evaluations of the two examiners in comparison with the real size of 25 mm.

Comparison of the findings of the examiners for each marker at the different positions, as shown in ►**Table 2**, reveals similarity of the following measurements: coin at the greater trochanter, between thighs, and pubic symphysis positions; and sphere at the pubic symphysis and exam table positions.

►**Table 3** demonstrates a statistical difference of the measures between the markers (coin vs. sphere) at all positions except on the exam table (p-value = 0.083).

►**Table 4** identifies the percentage values in relation to the true size of 25 mm to allow understanding the range of variation measured at each position of the markers.

The accuracy calculated for each marker at the various positions by each examiner is shown in ►**Table 5**. With the coin on the exam table, utilizing a diameter of 23 mm as a

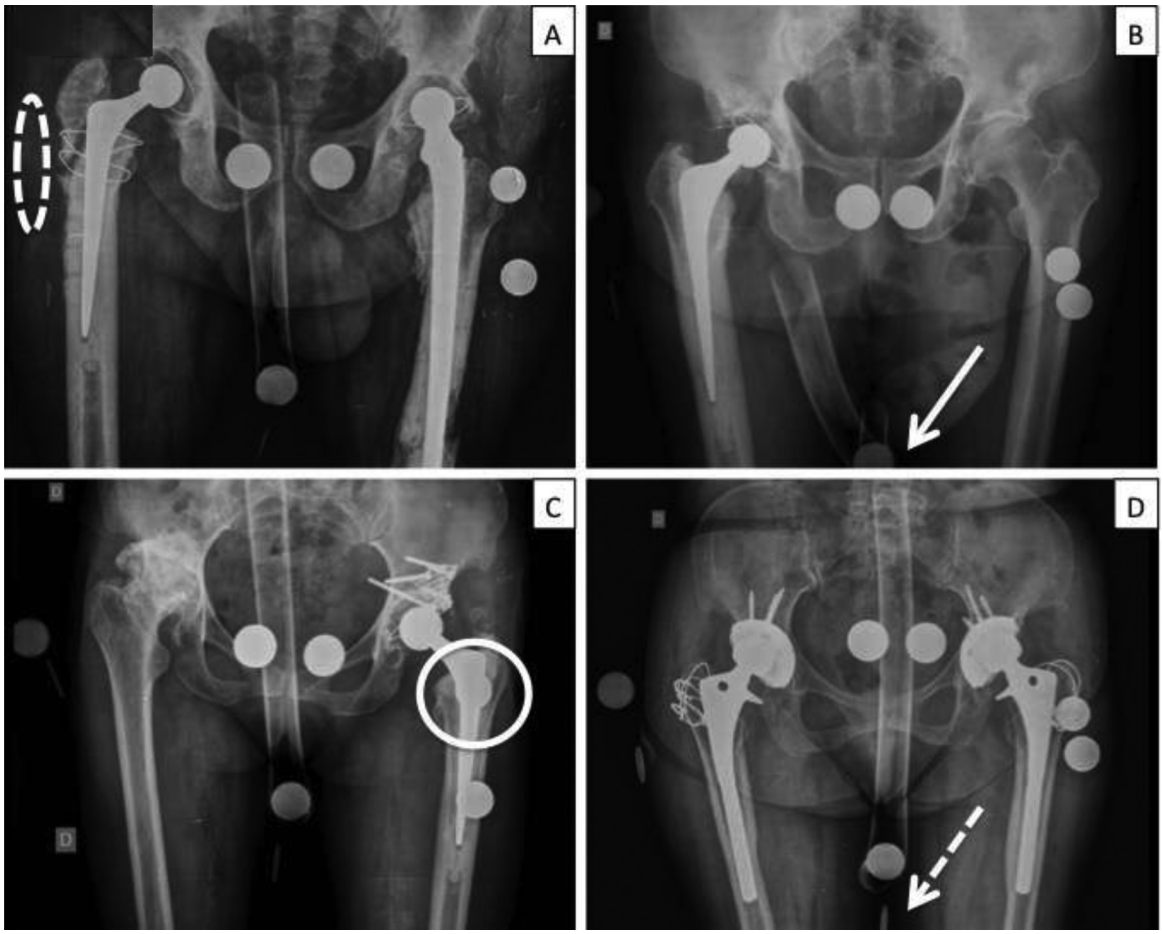

Fig. 4 Four radiographs of the sample analyzed. ►**Figure 4A**, note the absence of markers at the greater trochanter (broken line circle). In the male patients (►**Figs. 4A** and **4B**), the markers between the thighs are at the lower limit of the image, but the abdominal apron due to the large abdominal hernia in ►**Figure 4B** prevents the correct positioning of the markers, and the coin is hard to visualize between the thighs (white arrow). The overlap of the coin with the femoral shaft in ►**Figure 4C** (circle) does not prevent calibration but hampers the technique. The partial visualization of the coin when placed vertically at the greater trochanter or between the thighs, as depicted in ►**Figure 4D** (broken-line arrow), prevents measurement of the larger diameter, making calibration impossible.

reference, examiner 1 obtained accuracy of 90.9% (30 of the 33 radiographs) and examiner 2 achieved accuracy of 78.8% (27 of the 33 radiographs).

There was greater loss of images of both markers at the greater trochanter position, corresponding to 19 losses in 33 radiographs (57.6%). In that position, for the female sample, there were 11 losses in 18 radiographs (61.1%), while the figure for the males was 8 losses in 15 radiographs (53.3%). For the coin placed between the thighs, there were 13 losses in 33 radiographs (39.4%), with the breakdown by gender being 8 losses in 15 radiographs (53.3%) for men and 5 losses in 18 radiographs (27.8%) for women.

Discussion

This is a transversal study with the objective of assessing the accuracy, precision, and differences in the use of two metal markers (sphere and coin) to calibrate radiography of the pelvis. Considering accuracy, precision, coefficient of variation, visual inspection of the images, and ease of positioning, the coin placed between the thighs was the best marker, with a mean of 25 mm, but suffered from large loss of images (39.4%). The coin on the exam table presented a mean of 23 mm, smaller than the real size, but obtained a low coefficient of variation (1%) and appeared in all the images. Therefore, we suggest the use of coins in the two positions.

The best type of radiographic marker should be widely available, practical to position, reliably visible in the images, and easy to measure and precisely calibrate. The coin's dimensions are standardized, and it is available to any radiology service that does not have another type of marker. The identification of markers when positioned at the greater trochanter and pubic symphysis is susceptible to human error, unlike the exam table position, which is easy to achieve and free of this type of error.

In the pubic symphysis and exam table positions, all the images were easily visualized. Despite obese patients requiring special care when positioning the markers, which should be placed below the abdominal fold in the pubic symphysis position and below the thigh when on the exam table, no image losses occurred with these markers. The images of the coin between the thighs in 13 radiographs (39.4%) and of both markers at the greater trochanter in 19 radiographs (57.6%) were only partially visible or not visible, so no calculations were possible. There was a difference between

Table 1 Comparison of the position/marker with the real value (25 mm) by the examiners

Examiner 1		Mean (mm)	SD (mm)	CV	Min (mm)	Max (mm)	N	CI	*P*-value
Coin	Greater trochanter	24.71	0.61	2%	24	26	14	0.32	0.104
	Between the thighs	25	0.65	3%	24	26	20	0.28	1
	Pubic symphysis	27.7	0.47	2%	27	28	33	0.16	< 0.001
	Exam table	22.91	0.29	1%	22	23	33	0.1	< 0.001
Sphere	Greater trochanter	25.07	0.27	1%	25	26	14	0.14	0.336
	Between the thighs	25.58	0.5	2%	25	26	33	0.17	< 0.001
	Pubic symphysis	27.88	0.48	2%	27	29	33	0.17	< 0.001
	Exam table	23	0.25	1%	22	24	33	0.09	< 0.001
Examiner 2		**Mean (mm)**	**SD (mm)**	**CV**	**Min (mm)**	**Max (mm)**	**N**	**CI**	***P*-value**
Coin	Greater trochanter	24.79	0.58	2%	24	26	14	0.3	0.189
	Between the thighs	25	0.73	3%	24	26	20	0.32	1
	Pubic symphysis	27.7	0.59	2%	26	29	33	0.2	< 0.001
	Exam table	23.15	0.44	2%	22	24	33	0.15	< 0.001
Sphere	Greater trochanter	24.79	0.58	2%	24	26	14	0.3	0.189
	Between the thighs	25.27	0.57	2%	24	26	33	0.2	0.01
	Pubic symphysis	27.97	0.53	2%	27	29	33	0.18	< 0.001
	Exam table	22.97	0.3	1%	22	24	33	0.1	< 0.001

Abbreviations: CI, confidence interval; CV, coefficient of variation; Kg, kilogram; Max, maximum; Min, minimum; mm, millimeter; N, sample size; *P*-value, significance.

Table 2 Comparison between examiners in the same position of each marker

Coin		Mean (mm)	SD (mm)	CV (mm)	Min (mm)	Max (mm)	N	CI	*P*-value
Greater trochanter	Examiner 1	24.71	0.61	2%	24	26	14	0.32	0.336
	Examiner 2	24.79	0.58	2%	24	26	14	0.3	
Between the thighs	Examiner 1	25	0.65	3%	24	26	20	0.28	1
	Examiner 2	25	0.73	3%	24	26	20	0.32	
Pubic symphysis	Examiner 1	27.7	0.47	2%	27	28	33	0.16	1
	Examiner 2	27.7	0.59	2%	26	29	33	0.2	
Exam table	Examiner 1	22.91	0.29	1%	22	23	33	0.1	0.003
	Examiner 2	23.15	0.44	2%	22	24	33	0.15	
Sphere		**Mean (mm)**	**SD (mm)**	**CV (mm)**	**Min (mm)**	**Max (mm)**	**N**	**CI**	***P*-value**
Greater trochanter	Examiner 1	25.07	0.27	1%	25	26	14	0.14	0.04
	Examiner 2	24.79	0.58	2%	24	26	14	0.3	
Between the thighs	Examiner 1	25.58	0.5	2%	25	26	33	0.17	0.006
	Examiner 2	25.27	0.57	2%	24	26	33	0.2	
Pubic symphysis	Examiner 1	27.88	0.48	2%	27	29	33	0.17	0.263
	Examiner 2	27.97	0.53	2%	27	29	33	0.18	
Exam table	Examiner 1	23	0.25	1%	22	24	33	0.09	0.572
	Examiner 2	22.97	0.3	1%	22	24	33	0.1	

Abbreviations: CI, confidence interval; CV, coefficient of variation; mm, millimeter; Max, maximum; Min, minimum; N, sample size; *P*-value, significance.

the genders, with greater loss of images in female patients at the greater trochanter (61.1%), probably due to the pattern of posterolateral fat accumulation in the hips, while the loss was greater for male subjects when the marker was positioned between the thighs (53.3%), probably caused by the genital volume in this region. The circular images of the sphere and coin on the exam table and at the pubic symphysis were easier to measure. Considering the coefficient of variation lower than 3% for both markers at all positions, they can be considered stable in relation to the mean.

Table 3 Comparison of the markers for each position as evaluated by examiner 1

Examiner 1		Mean (mm)	SD (mm)	CV (mm)	Min (mm)	Max (mm)	N	CI	*P*-value
Greater trochanter	Coin	24.71	0.61	2%	24	26	14	0.32	0.019
	Sphere	25.07	0.27	1%	25	26	14	0.14	
Between the thighs	Coin	25	0.65	3%	24	26	20	0.28	0.002
	Sphere	25.55	0.51	2%	25	26	20	0.22	
Pubic symphysis	Coin	27.7	0.47	2%	27	28	33	0.16	0.032
	Sphere	27.88	0.48	2%	27	29	33	0.17	
Exam table	Coin	22.91	0.29	1%	22	23	33	0.1	0.083
	Sphere	23	0.25	1%	22	24	33	0.09	

Abbreviations: CI, confidence interval; CV, coefficient of variation; mm, millimeter; Min, minimum; Max, maximum; N, sample size; *P*-value, significance; SD, standard deviation.

Table 4 Percentage differences from the real values measured by examiner 1

Examiner 1		Mean	Median	SD	Min	Max	N	CI
Coin	Greater trochanter	1.14%	0.00%	2.44%	−4.00%	4.00%	14	1.28%
	Between the thighs	0.00%	0.00%	2.60%	−4.00%	4.00%	20	1.14%
	Pubic symphysis	−10.79%	−12.00%	1.87%	−12.00%	−8.00%	33	0.64%
	Exam table	8.36%	8.00%	1.17%	8.00%	12.00%	33	0.40%
Sphere	Greater trochanter	−0.29%	0.00%	1.07%	−4.00%	0.00%	14	0.56%
	Between the thighs	−2.30%	−4.00%	2.01%	−4.00%	0.00%	33	0.68%
	Pubic symphysis	−11.52%	−12.00%	1.94%	−16.00%	−8.00%	33	0.66%
	Exam table	8.00%	8.00%	1.00%	4.00%	12.00%	33	0.34%

Abbreviations: CI, confidence interval; Max, maximum; Min, minimum; N, sample size; SD, standard deviation.

Table 5 Accuracy with respect to 25 mm of the markers for each position and examiner

Accuracy (25 mm)		Examiner 1		Examiner 2		Total
		N	Accuracy	N	Accuracy	
Coin	Greater trochanter	8	57.10%	9	64.30%	14
	Between the thighs	12	60.00%	10	50.00%	20
	Pubic symphysis	0	0.00%	0	0.00%	33
	Exam table	0	0.00%	0	0.00%	33
Sphere	Greater trochanter	13	92.90%	9	64.30%	14
	Between the thighs	14	42.40%	20	60.60%	33
	Pubic symphysis	0	0.00%	0	0.00%	33
	Exam table	0	0.00%	0	0.00%	33

Abbreviation: N, sample size.

With respect to precision, the measures of coin between the thighs ($p = 1.000$), sphere at the greater trochanter ($p = 0.336$), and coin at the greater trochanter ($p = 0.189$) were the closest to the actual size of 25 mm. At the greater trochanter, the accuracies of the coin and sphere were, respectively, between 57.1 and 63.3% and between 64.3 and 92.9%. Between the thighs, the accuracy measures of the coin and sphere were between 50 and 60% and 42.4 and 60%, respectively. Even though not precise at 25 mm, the result for the coin and sphere on the exam table was reliable, with the best confidence interval (between 0.09 and 0.1), denoting low variation of the mean, and the accuracy for 23 mm was between 78.8% and 93.9%.

Markers, when located at the level of the pubic symphysis and on the exam table, have been found to be subject to variation due to the radiographic magnification of the emission cone of objects farther from the film in comparison to those that were closer.[12,23] For calibration with these markers, it is necessary to understand this influence so that errors do not occur outside the margin between +3% and -3%, which is acceptable for adequate preoperative planning.[23]

Wimsey et al.[8] used a caliper to compare the positioning of a coin between the thighs and the measurement of the anterior superior iliac spines in the patient. The results of the magnification calculation were favorable to the use of the coin, with accuracy of 98.9% and error < 0.5 mm in the digital measurements of the marker. When positioned between the thighs, the average coin size in our sample was 25 mm for both examiners, the coefficient of variation was at most 3%, and the accuracy was between 50 and 60%. The maximum error was 1 mm (4%), probably overestimated by the fact that the software used for measurement did not have millimetric precision.

In the present study, the markers were positioned by a physician with experience in identification of bony prominences, unlike in the great majority of previous studies.[8–17,23] The simplest position was on the exam table, since the identification of bony prominences can be difficult, especially in patients who are obese or have deformities. The et al.[23] reported the importance of correct positioning, demonstrating that the marker placed at the level of the trochanter at 1 cm anterior or posterior to the hip represents a 1% difference in magnification.

Some limitations of the present study should be mentioned. The sample loss at the greater trochanter probably occurred due to the difficulty of adapting this method in the fat pads lateral and posterior in relation to the hip, especially in female patients. Alterations in the surface anatomy of patients who have undergone multiple surgeries was another factor that might have influenced the precision of the positioning of the markers. Bias in the calibration precision and calculation of the diameter of the markers might also have occurred because the software used is not capable of measuring decimal values of millimeters.

Conclusion

We recommend using the coin placed between the thighs and suggest the concomitant use of another coin, or a sphere, on the exam table, considering the 8% reduction in relation to its real size, and to avoid failure to visualize the marker in the image.

The methods presented in the current study are useful for radiographic calibration in preoperative planning and can estimate the radiographic magnification with a safety margin between -3% and +3%.[23] We believe the coin can be used instead of a sphere without sacrificing precision when applied clinically for radiographic calibration in preoperative planning. It is necessary to understand the size variations of the markers around the hip before performing the radiographic calibration for accurate correction of the magnification and to achieve better precision in preoperative planning. In those patients who are morbidly obese, have an abdominal apron, hip deformity, or previous surgery, attention should be paid to the correct palpation of the bone structures to minimize marker positioning errors.

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Conflict of Interests
The authors have no conflict of interests to declare.

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