Assessment of magnification of digital radiographs in total HIP arthroplasty

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ABSTRACT

Objective: Total hip arthroplasty (THA) preoperative planning requires the calibration of X-ray. We evaluate the magnification in standard pelvis hip X-ray and determine its relation with biometric factors.

Methods: The magnification of 140 THA X-ray were calculated with the known femoral head (MF_{FH}) and acetabular component (MF_{AC}). Gender, age, height, weight, and BMI were correlated to the magnification.

Results: The MF_{FH} and MF_{AC} were 113.2 ± 4.4 and 113.4 ± 3.6 respectively. No significant differences by gender and no correlation with height, weight or BMI.

Conclusion: The X-ray magnification should be calibrated in every institution to improve the accuracy of pre-operative planning.

1. Introduction

Total hip arthroplasty (THA) is a reliable procedure for relieving pain and restoring hip joint function. To achieve an optimal result, an important step is preoperative planning that has been classically performed by the use of analogic tools such templates of pelvic radiographs to assess the appropriate hip components size, to establish the level of neck osteotomy and the required femoral length and offset to restore the hip biomechanics and minimize the leg length discrepancy. Before the introduction of digital radiography, preoperative X-ray planning was performed over printed radiographs with fixed magnification templates (15% or 20%). There is a general agreement concerning that the bone image magnification was not well controlled. The introduction of digital methods for radiographic acquisition and, mainly, the introduction of Picture Archiving and Communication System (PACS), seemed to preclude a new era where accuracy could dominate based in the quantitative capabilities of the new image technologies associated to the digital computational developments. Digital templating applications have been developed to allow on-screen templating of PACS images. This software contains the digital prosthesis templates and requires the calibration of the image to match the templates to the bone.

Despite the technological advances inaccuracies still are present. Several error sources have been described. The focus-film distance (FFD) and the hip-film distance (HFD) can modify the image magnification (Fig. 1).¹ The HFD depends on the patient. In the literature, it can be checked the distinct FFD reported.^{2–4} There is no consensus regarding the use of a fix FFD to improve the magnification control. Many methods use an external marker to determine the magnification, including a coin, a caliper, a ball, ...but they are not error-free. The external calibration markers should be positioned at the height of hip center as near of the joint as possible. Identifying the correct position of the marker is frequently complicated by the difficulty of detecting the correct anatomic landmarks by palpation. Magnification errors will occur if the marker is significantly closer to or further away from the X-ray plate than the femoral head. By placing the marker on the side of the hip, either between the patient's leg or lateral to the thigh, an error is introduced.^{2,3} When located between legs, near the genitals, causes distress and is uncomfortable. Sometimes the external marker is not well projected on the film (cut or missing). It also consumes time and prolongs the process. Some papers have shown bigger errors with external markers and highlighted the need for better calibration methods.^{1–3}

Abbreviations: MF, Magnification Factor; FH, Femoral Head; AC, Acetabular Component; MF_{FH}, Magnification Factor from Femoral Head; MF_{AC}, Magnification Factor from Acetabular Component; FFD, Focus Film Distance; HFD, Hip Film Distance; PACS, Picture Archiving and Communication System; GE, General Electric; BMI, Body Mass Index; THA, Total hip arthroplasty

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Fig. 1. X-ray divergence since the focus to the film and the variation suffered increasing the focus-film distance (FFD), or the X-film distance, X symbolizes the hip (HFD). The greater FFD, the smaller magnification and, the greater HFD, the greater magnification.

The previous observations have driven into an apparent paradox: the introduction of advanced computerized technology has not carried on a clear improvement in preoperative planning that is frequently seen by surgeons with skepticism despite the promised advantages. The purpose of this paper is to provide further evidence on the physical and biometric variables that can affect preoperative planning. The gold standard used to test the right magnification of pelvis hip X-ray is to measure the head prosthesis in the postoperative X-ray. No other prosthesis components have been used to measure the right magnification. The acetabular component is hemispheric, bigger than the head, and then eases its accurate measurement. One of our aims was to evaluate the magnification of the prosthetic femoral head and also the acetabular component in the standard postoperative pelvis hip X-rays and to verify which of these components, if some, can be used as a

better reference. On the other hand, the male and female pelvis is different and could modify the magnification. Height, weight, and BMI could also affect the magnification because they modify the HFD.^{2–4} We also wanted, then, to evaluate whether the magnification factor is modified by gender, height, weight, and BMI.

2. Methods

Between January 2015 and January 2016, we operated 153 total hips prosthesis in 145 patients. We performed a retrospective study and reviewed the 153 post-operative digital radiographs with, at least, one total hip arthroplasty. All radiographs were acquired with a PACS service provided by General Electric (GE), Centricity. The FFD was 100 cm, patient located in supine position, and the beam was centered on the pubic symphysis. When it was possible, the patient stood with their feet internally rotated to neutralize the femur anteversion. When it was impossible, the same leg rotation was kept manually. The X-ray was considered to be of high quality with excellent visualization and symmetry of the pelvis, and the entirety of both hips and proximal femurs were obtained (Fig. 2). 6 patients were excluded because the X-ray did not show enough quality and 10 patients because data in clinical history (weight, height or prosthesis femoral head or acetabular component size) were missed.

We measured the implant size, the femoral head (FH) and the acetabular component (AC), with GE Centricity tools without knowing the actual diameter. Tagging the implant and adjusting the size of the circle to conform to the contour of every implant, FH or AC. The FH is a truncated sphere such that the portion of the head that fits onto the stem is flattened. The AC is a hemisphere. We placed a sphere tool on FH or AC to best fit the contour of the spherical portion of each one. Then the diameter was measured (Fig. 2). After this measurement, the known size of each prosthesis component was documented by the prior operative reports; it could be 28, 32 or 36 mm for the FH or 48, 50, 52, 54, 56, 58 or 60 for the AC. Then, we calculated the magnification factor (MF) for the FH (MF_{FH}) and the MF for the AC (MF_{AC}) of each radiograph (projected diameter/actual diameter $\times 100$) (Fig. 2). We also collected the demographic and anthropometric data of the patients including gender (male, female), age, height, weight, and BMI.

Statistics. Mean values, SD, and ranges of the measured variables are calculated. T-Student was used to compare the difference of MF by gender. Results with p values < 0.05 were considered statistically significant. Pearson correlation coefficients were used to assess the relationship between magnification of the femoral head prosthesis or that of the acetabular component with height, weight, and BMI or these parameters by gender. Pearson correlation coefficients close to 1 are required to accept the correlation between variables.

Fig. 2. Anteroposterior pelvis hip X-ray shows the pelvic symmetry, both hips, and proximal femurs. PACS circle tool over femoral head prosthesis (right hip) and acetabular component (left hip). The diameter circle was measured with the line tool. The zoom was used to improve the measurements accuracy. Later, it was collected the correct size of each prosthesis component from the clinical history, and it was calculated the magnification factor (MF) for the FH (MF_{FH}) and the MF for the AC (MF_{AC}) of each measure (projected diameter/actual diameter $\times 100$).

Table 1

Clinical characteristics and Magnification Factor (MF) calculated with the femoral head prosthesis (MF_{FH}) and with the acetabular component (MF_{AC}). Mean, SD and range of every date.

	THA (N = 137)	THA woman (n = 63)	THA men (n = 74)
Aged (years)	65,0 ± 12,4 (32–89)	67,5 ± 11,8 (32–89)	62,1 ± 12,5 (33–87)
Height (cm)	164,6 ± 9,3 (145–187)	157,6 ± 6,3 (145–178)	170,1 ± 7,1 (152–187)
Weight (kg)	78,7 ± 15,6 (51–128)	71,0 ± 13,22 (51–104)	85,4 ± 14,5 (61–128)
BMI (kg/m ²)	29,1 ± 5,0 (19,25–45)	28,8 ± 5,5 (19,83–45)	29,4 ± 4,5 (19,3–42,8)
MF _{FH} (%)	113,2 ± 4,4 (102,8–128,2)	114,0 ± 5,0 (102,8–128,2)	112,6 ± 3,7 (106,9–125,0)
MF _{AC} (%)	113,4 ± 3,6 (104,2–124)	113,8 ± 4,1 (104,2–124)	113,1 ± 3,1 (107,4–120,4)

3. Results

137 THA were reviewed in 129 patients, 71 male and 58 female, 8 cases were bilateral (3 men and five women). The mean age of the patients was 65,01 (range 32–89 years). The clinical characteristics, height, weight and BMI, and the MF of patients are shown in Table 1 in all patients and by gender.

The MF_{FH} mean was 113,2 ± 4,4 (range 102,8–128,2; n = 137) and that for the MF_{AC} was 113,4 ± 3,6 (range 104,2–124; n = 137) showing no significant differences between them while it was observed smaller variability (20%) in the acetabular than in the femoral component measurements. The fact of having pooled all data without discriminating gender can hidden details derived from biometric characteristics. To assess a potential influence for such factors we analyzed the data separately by gender obtaining a MF_{FH} mean of 114,0 ± 5,0 (range 102,8–128,2; n = 63) and that for MF_{AC} mean of 113,8 ± 4,1 (range 104,2–124,0; n = 63) in women. In men, the MF_{FH} was 112,6 ± 3,7 (range 106,9–125,0; n = 74) and the MF_{AC} was 113,1 ± 3,1 (range 107,4–120,4; n = 74). The magnification differences (MF_{FH} and MF_{AC}) between men and women were not found to be statistically significant ($P > 0,05$). No positive correlation between MF_{FH} or MF_{AC} with biometric factors (height, weight or BMI) were found using Pearson correlation coefficients (Table 2). Again, no positive correlation was found when the magnification pooled data were pulled apart by gender and analyzed looking for the correlation with biometric factors.

Altogether, these data indicate that in our radiographic conditions a magnification factor near to constant is obtained within a range that extends from 112,6 to 114. Such variability cannot be considered meaningful based on the lack of statistical significance of the comparisons, is negligible for practical purposes, and be attributed to inherent technical limitations. Then, we can discard the hypothesis of an interference of the analyzed parameters in the magnification factor values. Nevertheless, it is worth to remark the tendency to smaller variability in the acetabular component measurements that points to its potential usefulness in automatized planning.

4. Discussion

Preoperative planning for total hip arthroplasty provides guidelines during surgery. The preoperative X-rays magnification must be known to obtain reliable data. Some previous studies analyze the error of the external markers used to calibrate the magnification of digital X-rays. Archibeck et al. showed that the external marker underestimated around 6% the magnification of the radiograph when it was compared with the known diameter of the femoral head prosthesis. They assure

that the use of a magnification marker did not provide a more accurate measurement of hip magnification than the use of a standard 20% magnification.⁵ Sinclair et al. also compared the magnification of femoral head prosthesis with an external marker and they found a mean error between the two measurements of 7% (range, 0%–26%), concluding that such errors may result in incorrect component sizes, leg lengths, and offset.⁴ Boese et al. did not find a correlation between external and internal (femoral head prosthesis) calibration markers, indicating the need for a better calibration method.³ Our study calibrates the magnification not only with the prosthetic femoral head but also with the prosthetic acetabulum and, the latter shows less variability that highlights its potential usefulness in the more accurate calibration of the magnification.

According to the magnification theory of X-rays, the greater FFD, the smaller hip magnification and, the greater HFD, the greater magnification (Fig. 1). The different sizes of patient's buttocks, the legs rotation, and the pelvis-column position can influence the HFD and, obviously the magnification but these are characteristic of each patient and are not modifiable.¹ The FFD is the other of the major factor influencing magnification. This distance is determined by the radiological technique used, and it is the factor that we can modify and control. Surprisingly, the FFD is a non-standardized factor, and it undergoes great variations between different studies; most do it 100 cm away.^{4,6,7} White et al. reported a MF of 127,4% ± 1,89 (range 122–133%).⁶ Brew et al., with a 130 cm FFD get a MF of 119,8% ± 0,6 (range, 117,0%–123,4%).⁸ Boese et al. used 110 cm FFD,³ and they obtained a magnification of 122,5%. Stigler et al. used a FFD of 115 cm, but they do not refer the MF.⁹ Archibeck's method placed the x-ray tube 40 inches (101,6 cm) above the patient pubis,⁵ but the distance from pubis to the film was non-controlled. They get 21% ± 2% of MF. Heep et al. modified the distance between focus and patient (900–1200 mm) to include at least 8 inches of the proximal femur, and they get 117,95% for male and 111,71% for female.¹ Others do not specify the FFD and get different MF (126,1%² or 121,7%¹⁰).

In the present study, using a 100 cm FFD, the X-ray magnification for the femoral head was 113,2% ± 4,4 and, 113,4 ± 3,6 for the acetabular component. Both measurements, MF_{FH} and MF_{AC}, were very similar although the standard deviation when measuring the acetabular component was lower, indicating the measurement accuracy. It could be related to the larger size and better visibility of the acetabular component. The MF measured in our study was lower than most authors report and similar to that from Heep et al.¹ The FFD is one of the most influential factors to the radiographic magnification and it should be mandatory to establish a fix distance in all pelvis hip X-rays studies. The technique must be standardized for all preoperative pelvis hip X-rays provided to be used for preoperative hip prosthesis planning to

Table 2

R² Pearson correlation factor between MF_{FH} or MF_{AC} with height, weight, BMI and these parameters by gender.

	MF _{FH} total	MF _{FH} women	MF _{FH} men	MF _{AC} (total)	MF _{AC} women	MF _{AC} men
Height	−0,141	0,001	0,093	−0,062	−0,034	0,1
Weight	0,058	0,239	0,218	0,052	0,181	0,075
BMI	0,129	0,183	0,188	0,132	0,204	0,064

minimize the bias in implants sizes election and the measurements obtained, level of neck osteotomy and prosthesis neck length to restore leg length and offset. Because of the discrepancy in the FFD used and different magnification got in revised literature, our advice is to quantify the MF in standard pelvis hip X-ray to calibrate it in every institution. It can be done quickly; using the same standard technique in postoperative X-ray and measure the femoral head prosthesis or better the acetabular component with known size to get a magnification mean in some patients. The MF got can be used to perform the preoperative planning for hip arthroplasty with the specific software. This recommendation agrees partially with that from Archibeck et al.⁵ that criticizes the use of external markers and proposes the use of a fixed magnification of 20%. This view can be considered correct for a given institution where the X-ray procedure is highly protocolized allowing to establish a fixed magnification factor to be applied onwards. Nevertheless, such fixed magnification factor will vary between institutions, even inside institutions when the protocols could show changes. Then, it should be stressed the need for determining the magnification factor in every case and perform a follow up of the conditions that would require an update.

Individual's height, weight, BMI, and gender could influence over MF. Weight has been identified as a factor affecting magnification, while BMI has not.^{2–4} Boese et al. found weight only correlated weakly with internal or external markers magnification.³ In good agreement with Heep et al.¹ observations, we do not find correlations between MF_{FF} or MF_{AC} and height, weight or BMI, even when we compared it by gender. Heep et al. measured the distance from the hip rotation center to the CT table, and there was not much variation with different body shape (10.66 ± 1.04 cm for male and 11.23 ± 1.35 cm for female). Wimsey et al. found a narrow variant range between 6 and 12 cm from the greater trochanter to film.¹¹ The MF error obtained by the external markers^{2,3} and the small variation HFD^{1,11} could also advise to get the calibration in standard postoperative pelvis hip X-rays in every institution and using the mean MF obtained as a fixed value in all preoperative pelvis hip X-rays.

Our study has some limitations. First, the height, weight, and BMI were acquired retrospectively from the patients' records. Prospective data acquisition might be a more reliable means of recording biometric characteristics more accurately and precisely. The pelvis hip X-rays have been recovered from the PACS retrospectively as they were done in postoperative revision. On the other hand, the femoral head prosthesis is the most used, like a gold pattern, parameter to measure the

magnification of pelvis hip X-ray but the contour can be shaped/occluded by the acetabular component. Further studies should address these limitations.

Standardization of the pelvic hip radiological technique should be carried out in every institution to determine the local magnification factor, as well as a periodic, follow up should be established to avoid blind acceptance of a fixed magnification factor that can vary with the introduction of technical innovations. Such rather simple procedures in every institution can significantly improve the accuracy of preoperative planning.

Conflicts of interest

The authors declare that they have no conflict of interest.

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