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ORIGINAL STUDY

Measurement of radiographic magnification in the pelvis using archived CT scans

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Prosthesis or allograft selection usually relies on comparison of templates with radiographs of the patient. Radiographic magnification must be evaluated accurately to select the optimal implant. Radiographic magnification was retrospectively assessed in 40 patients by reference to the pelvic height measured on computed tomography scans. Intra-subject variation of the magnification was calculated in 14 patients for whom two different pelvic radiographs were available. A wide range of magnification was observed (112% to 129%) as well as a substantial intra-subject variation (8%). Paired samples t-test showed a systematic error (p < 0.001) in using 110% and 115% as magnification whereas a similar error was not found when using 120%. Mean value for magnification was 119%. Radiographic magnification measurement can be made using the pelvic height method in patients who have undergone thoraco-abdominal, abdominal or pelvic computed tomography.

Keywords : preoperative planning ; radiographic magnification ; total hip arthoplasty ; dimension.

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INTRODUCTION

Radiographic magnification is a well known problem in preoperative planning of orthopaedic operations. In prosthesis selection, templates with 115% or 120% magnification provided by the manufacturers are matched with patient's radiograph. Matching is performed either electronically by overlaying templates on digital radiographs (*13,14*) or manually using analogue radiographs (*4*). Similarly, in massive bone allograft selection, template comparison is the standard method used to select the optimal implant, assuming 110% magnification.

However, studies have shown that using a standardized value for magnification ratio may lead to an error in the selection of prosthesis size (*2,7,8*). Various methods have been suggested to evaluate magnification as accurately as possible. Radio-opaque markers (*1,5,6,11*), and even a simple calliper measurement of the pelvis (*15*) were tested, with varying success. Another approach was unsuccess-

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fully tested, to obtain radiographs with a requested magnification of 110%, 115% or 120% (9). A significant improvement in magnification estimation seems to be provided by the use of a radio-opaque coin of known dimensions (2,15). These methods require a trained and compliant radiologist to position the calibration object with the greatest care.

We assumed that considering a fixed magnification of 110%, 115% or 120% for pelvic anteroposterior radiographs would lead to a significant systematic error. We propose to calculate magnification using as a reference the pelvic height as measured on archived 3D Computed Tomography scans.

MATERIALS AND METHODS

CT scan was used in this study since it provides a good contrast for bony structures. Moreover, its wide use in distance measurement and volumetric estimation studies make this modality a "gold standard" with respect to accuracy in linear measurement (10).

Picture Archiving and Communication System (PACS, Kodak Carestream PACS, Eastman Kodak Company 2006, Rochester, NY, USA) was used to retrospectively select 40 consecutive patients who had a pelvic CT scan and one or two anteroposterior radiographs of the pelvis for various medical conditions. Radiographs should be acquired in the supine position to avoid any significant differences in patient orientation. However, the radiographic technique was deliberately not standardized, to replicate clinical conditions (no standard protocol was uniformly applied). Exclusion criteria were patients with pelvic distortion, previous hip arthroplasty, or osteolysis due to neoplastic process. CT scans and radiographs were retrieved on a powerful workstation in DICOM format.

Distances were measured between two points clearly identifiable both on radiograph and CT scan by the same blinded observer. The longest possible distance, i.e. pelvic height, was chosen in order to improve accuracy. This distance was measured on analogue radiographs (X-ray height, mm) printed to scale based on known pixel size. Distances on CT scan were measured with a 3D tool provided by Volview (Version 2.0.5, Kitware Inc., NY, USA). CT scan rendering was set to parallel projection of rays of light. This means that distances are maintained since no perspective is present in the 3D scene. Opacity values were set to make only bone tissues appear. Color mapping was chosen to obtain a radiograph-like image. Patient's volume was positioned to render an anteroposterior projection (fig 1). The values obtained (CT height, mm) were used to determine the magnification ratio as :

$$\textit{Magnification}\ (\%) = \frac{\text{X-Ray Height}}{\text{CT Height}} \times 100$$

CT scan measurements were made twice by the same observer at three weeks interval. Furthermore, a second anteroposterior radiograph of the pelvis was available in 14 patients. We measured the same distance on the second radiograph and calculated radiographic magnification from two different radiographs for the same patient (fig 1).

Radiographic measurements from all patients were then scaled from 110% to 100%, from 115% to 100% and from 120% to 100% to correct the radiographic magnification effects. First CT scan observation was considered as the reference value. Paired samples t-test was used to compare the mean differences between corrected radiographic measurements and CT height. Kolmogorov-Smirnov test was first used and found no evidence to reject the normality hypothesis of both sets of observations. Intra-observer error was estimated using intra-class correlation. Bland and Altman repeatability coefficient was calculated to estimate intra-observer agreement of the CT scan method.

RESULTS

Mean pelvic height on radiographs was 254 ± 19 mm while it was 213 ± 16 mm on CT scan. Mean radiographic magnification was 119.1 ± 4.1% with extreme values from 112.5% to 129.5% (fig 2). Mean variation in radiographic magnification for two consecutive radiographs in the same patient was 2.84 ± 2.91% with a range from 0% to 8%. This represents an intra-modality variation from 0 to 18 mm for pelvis height (fig 1).

Paired t-test showed a significant difference between CT height and 110% radiograph corrected observations and also between CT height and 115% corrected observations ($p < 0.001$ for both tests). However, no significant difference was found using our 120% estimation ($p = 0.11$).

Intra-observer error was low, with an intra-class correlation coefficient of 0.98. Repeatability coefficient of the CT scan method is 3.3 mm. This means that for 95% of observations, the measurement error will be less than 3.3 mm or 1.3% of the height.

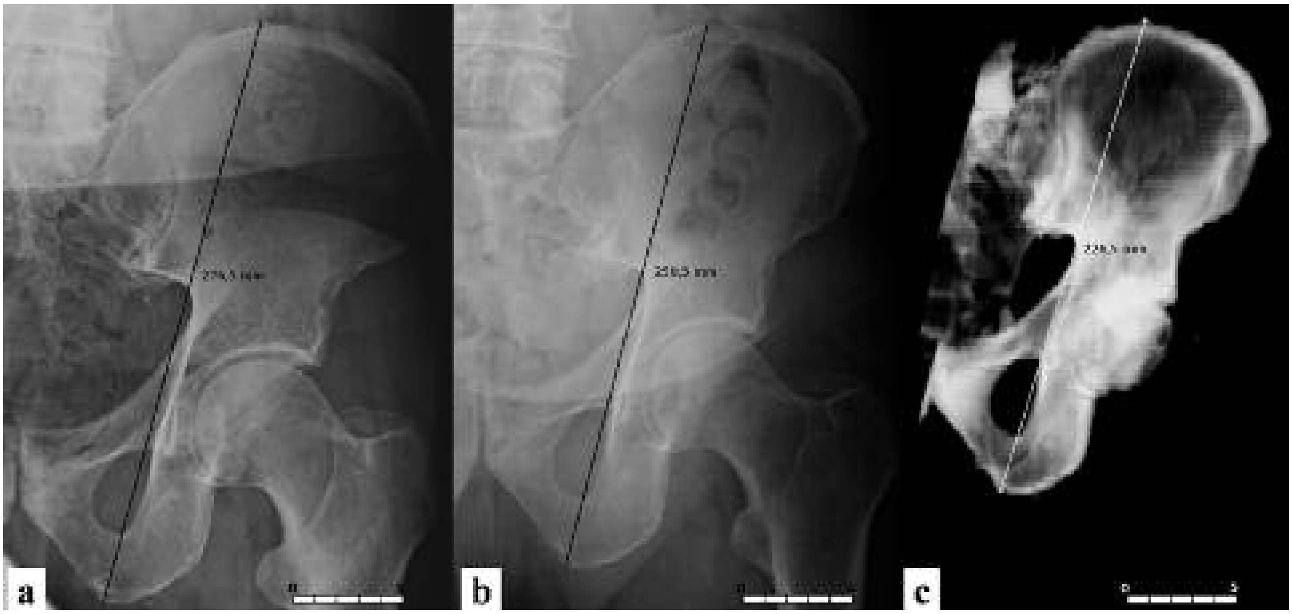

Fig. 1. — Three different views from the same patient. Note that the scale bar (5 cm) has the same size in the three documents. Using the CT scan as reference value (1c), magnification was calculated as being 122% for the first radiograph (1b), and 114% for the second radiograph (1b).

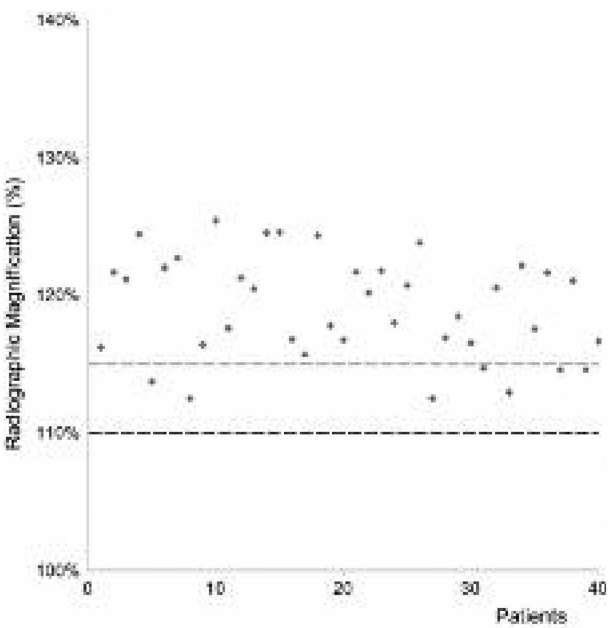

Fig. 2. — Radiographic magnification plot. Dashed lines represent magnification ratios usually used for prosthesis (115%) and allograft (110%) selection. Majority of points above the lines demonstrates an overall underestimation of radiographic magnification.

DISCUSSION

Radiographic magnification remains a major issue in preoperative planning. In this study, we paid attention to the variability of the radiographic magnification which may result in selecting a suboptimal implant. Magnifications of 110%, 115% and 120% are usually considered for implant selection. Our data showed that using 110% and 115% as a magnification ratio leads to a systematic error. The use of 120% as a magnification ratio for radiographs of the pelvis eliminates this error.

Using our CT scan method, we found a mean magnification value of 119% with a range from 112% to 129%. Similar findings were reported in the literature *(2,5,11)*. There is evidence that 120% should be considered as the adequate magnification value for preoperative planning on pelvic radiographs rather than 115%, which is still used in many institutions. However a standardised radiographic technique is usually not used for routine radiographs in clinical practice, so that variations in patient positioning and in the X-ray tube-to-patient distance result in variations in magnification.

Nonetheless, standard templates are supplied by prosthesis manufacturers with a fixed magnification value. Using 120% for X-Ray magnification involves a risk of up to 11% inaccuracy in prosthesis size selection (*11*). The magnification ratio should therefore be measured in each individual case to ensure better accuracy in preoperative planning.

Standardized source-to-object distance of 100 cm results in a radiographic magnification of 120% with an error of about 6% (*1,8*). The *et al* (*12*) reported an error of approximately 3% in magnification correction using the diameter of the prosthetic femoral head for calibration. The high repeatability of the method used in our study reduces to 1.3% the error in correction of the radiographic magnification in 95% of cases. The better repeatability coefficient is explained by two main reasons. First, in the method using a calibration object, magnification estimation relies on positioning the radio-opaque marker at the level of the centre of the joint. No standardized method has been described to correctly position the calibration object ; as a result, a slight misplacement is assumed (*5*). Second, pelvic height (213 mm) is much larger than the diameter of a prosthetic femoral head (22, 28 or 32 mm) or a coin (31 mm). Using the largest measured distance decreases the intrinsic error in its measurement. In conclusion, we propose to accurately measure magnification ratio using CT scans archived in the PACS system.

In hip reconstruction with a structural allograft, accuracy is also essential. Delloye *et al* have stressed that poor outcome may result from inadequate allograft matching (*3*). Achieving the smallest possible error in graft selection is essential. Our method can also be applied to selection of a structural allograft since most patients have a CT scan in their diagnostic workup. However, for patients undergoing total hip replacement, CT scan may not be available. The use of our method is restricted to patients who have had a thoraco-abdominal, abdominal or pelvic CT scan for any reason. PACS provides great advantages such as storing and retrieving images. The growing number of these digital systems should facilitate the use of this method.

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