Digital templating in hip replacement with and without radiological markers

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Digital templating in hip replacement is commonly performed with radiological markers to determine the magnification. The latter can also be determined by measuring the distance from the x-ray focal spot to the object and the distance from the x-ray focal spot to the radiological cassette or image receptor. We used post-operative radiographs of total hip replacements and hemiarthroplasties from 22 patients to calculate the magnification using both methods. The accuracy of each method was ascertained by measuring the size of the head of the implant projected on to the radiographs and comparing the result with the known size recorded in the medical records.

The accuracy was found to be similar with a mean absolute measurement error of 2.6% (SD 1.4; 0.0% to 5.2%) for the radiological marker and 2.8% (SD 2.2; 0.4% to 10.1%) for the distance method (p = 0.75). The mean radiation dose for templating radiographs (pelvis and lateral of the hip) was similar when taken using a radiological marker (328 mSv SD 142) (n = 51) or using the distance measurement method (324 mSv SD 39) (n = 39) (p = 0.90).

We conclude that the distance measuring method is as accurate as the radiological marker method, but may avoid some of the disadvantages such as misplacement of the marker or placement outside the radiological field. It may also be more acceptable to the patient and radiographer.

Pre-operative templating in total hip replacement (THR) may be considered to be part of the surgical procedure. Choosing the correct implant helps to restore the biomechanics of the hip, in particular the offset and leg length. In uncemented THR an undersized femoral component can result in poor fixation and early loosening1 and an oversized component can lead to intra-operative femoral fracture. The templating process provides the surgeon with the opportunity to anticipate specific problems and to ensure that the correct size of implant is available.

The key to successful templating is the determination of the magnification of the radiographs.2,3 The main problem with analogue templating is that the magnification of the image is often not measured and may vary.3 In addition, most implant manufacturers usually supply only one set of acetate templates with a single magnification factor. According to the guidelines of the National Programme for Information Technology4 all acute hospitals should now have either a computerised radiography system, a direct/digital radiography system or both coupled to a laser film imaging system or picture archiving and communications system (PACS). The introduction of these systems encourages orthopaedic surgeons to use digital templating and offers an opportunity to address shortfalls of analogue templating by determining and correcting for magnification. The usual method is the placement of a radiological marker of known size such as a ball or a coin in the radiation field at the level of the joint. Despite this, the superiority of digital templating has not been proven and some authors contend that old-fashioned analogue acetate templating is better.5,6 Others have suggested that taking digital radiographs with calibration from a disc placed directly on a cassette has a similar accuracy to that using radiological markers.7

When templating the hip, the marker is commonly taped to or held by the patient at the lateral aspect of the greater trochanter or between the legs. This marker may inadvertently slip thereby introducing an error in the determination of the magnification. In a recent study, misplacement of the radiological marker resulted in a magnification error of more than 10% in 7% of cases.5 The positioning of the marker between the legs is often uncomfortable for the patient and is unpopular with radiographers. The radiation field may
need to be enlarged to ensure that the marker is included and this results in a higher radiation exposure. Occasionally, the marker is missed or only partially seen and its margins can therefore only be determined with difficulty leading to errors, and repeated x-rays incur extra costs and exposure to radiation. In addition if the marker is placed between the legs of a male patient the testicles are exposed to radiation.

Because of these concerns, the Deputy Radiology Services Manager suggested an alternative method for the determination of the magnification factor, which we have evaluated. X-ray tube/collimator assemblies usually have a built-in tape measure which is calibrated specifically to measure distances from the focus spot within the x-ray tube (the source). This can be readily used to measure the distance from the focus of the x-ray to the object of interest (focus object distance, FOD) and from the focus of the x-ray to the cassette containing either film or a digital image receptor (historically known as the focus film distance, FFD). From these distances the magnification can easily be calculated by the equation (Fig. 1):

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\text{Magnification} = \frac{\tan(\alpha) \times \text{FFD} \times 2}{\text{FOD} \times 2} = \frac{\text{FFD}}{\text{FOD}}
\]

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\tan(\alpha) = \frac{L}{2} / \text{FOD} = \frac{L}{2} / \text{FFD}
\]

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L = \frac{\tan(\alpha) \times \text{FFD} \times 2}{\tan(\alpha) \times \text{FOD} \times 2} = \frac{\text{FFD}}{\text{FOD}}
\]

Diagram showing that the magnification factor can be determined by measuring the focus film distance (FFD) and the focus object distance (FOD) (L, length of object image on radiograph; l, length of object).

Patients and Methods
Our study was undertaken using the Impax PACS (Agfa HealthCare UK, Brentford, United Kingdom) with a computed radiography imaging system and MediCAD Orthopaedic Surgical Planning Software (Hectec GmbH, Niederviehbach, Germany), installed on an Impax OT3000 Orthopaedic Workstation (Agfa HealthCare UK). As computed radiography was used in this study the term cassette will be used in place of film in the description of the FFD.

The image receptor contained within the computed radiography cassette is tagged with a microchip, which has the dimension of the cassette stored in its memory. In this way the cassette reader stores the dimension of the plate with the image in a Digital Imaging and Communication in Medicine (DICOM) file. In the cassette reader set-up a zoom factor of 100% needs to be specified.

DICOM images were imported to the Orthopaedic Workstation, using the templating software. A line representing the FFD/FOD was electronically drawn and calibrated to 100 mm. Therefore with an FFD of 100 cm and an FOD of 82 cm, the magnification factor according to the equation would be 1.22 or 122%. An arbitrary line of 122 mm in length is drawn electronically and calibrated on the workstation (Fig. 2).

In order to examine the accuracy of the distance measurement method we obtained nine radiographs of a radiological ruler or a stainless-steel ball placed at various random distances from the radiological cassette. We then compared the measured dimensions using the FFD/FOD ratio and the true dimensions of the radiological ruler or the stainless-steel ball.

For the radiological marker method a 30 mm reference steel-ball was used. This was positioned by the radiographer either over the lateral aspect of the greater trochanter corresponding to the level of the hip or between the patient’s legs at the level of the hip. The DICOM images obtained were imported to the workstation and calibrated against the 30 mm ball.

In order to compare both methods we evaluated post-operative radiographs in 22 patients who had undergone either a THR or a hemiarthroplasty. The post-operative radiographs were taken with a radiological marker in place and at the same time the FFD and FOD were measured. The size of the head of the implanted femoral component was determined using both methods after importing it to the templating software. The determined size was then compared with the known size of the implant identified in the medical records (Fig. 2).

Additionally, we retrieved the radiation dose of a series of consecutive templating radiographs (pelvis and lateral of the hip) taken with a marker placed between the legs (n = 51) and templating radiographs taken using the distance measurement method (n = 39).
Statistical analysis. The results were expressed as the mean value with the SD and the range. Comparisons were made using the two-tailed Student t-test with a p-value < 0.05 considered to be statistically significant. A power calculation was performed after analysis of the first six radiographs. The aim was to detect a difference in accuracy of 2% with an alpha error of 0.05 and a power of 0.95. Using G*Power statistical software (Christian-Albrechts-Universität, Kiel, Germany) it was calculated that a minimum sample size of 12 was required. A post hoc power analysis (n = 22) gave a power of 0.94 to detect a difference in accuracy of 2%.

Results

Preliminary determination of the accuracy of the distance method. The mean magnification factor of the nine radiographs taken for this determination was 110% (SD 6; 102% to 123%). The mean error (averaging negative and positive errors) was -0.03% (SD 0.44; -0.67% to +0.8%). The mean absolute error obtained by disregarding the direction of the error was 0.32% (SD 0.27; 0.0% to 0.8%)

Results for comparison of methods in the post-operative radiographs. The mean magnification using the distance measurement method of the 22 post-operative radiographs was 120.0% (SD 5; 109.0% to 128.0%). The mean relative error (averaging negative and positive errors) for the radiological marker was 0.5 mm (SD 1.2; -2.1 to +2.8) (p = 0.41) for the distance method. The mean relative error for magnification (averaging negative and positive errors) for the radiological marker method was 1.2% (SD 2.8; -3.6% to +5.2%) and 1.0% (SD 3.4; -4.7% to +10.0%) for the distance measurement method (p = 0.84).

The mean absolute error (not averaging negative and positive errors) for the radiological marker was 0.9 mm (SD 0.7; 0.8 to 2.5) and 0.9 mm (SD 0.7; 0.1 to 2.8) (p = 0.93) for the distance method. In terms of magnification the mean absolute measurement error for the radiological marker method was 2.6% (SD 1.4; 0.0% to 5.2%) and 2.8% (SD 2.2; 0.4% to 10.0%) (p = 0.74) for the distance measurement method.

Radiation exposure. The mean radiation exposure for the templating radiographs (pelvis and hip lateral) taken with the radiological marker was 328 mSv (SD 142) (n = 51) and with the distance measurement method 324 mSv (SD 175) (n = 39). There was no statistically significant difference in these radiation exposures (p = 0.90). This included three patients in the marker group in whom the radiograph had to be repeated because the marker had been placed partially outside the radiation field.

Discussion

Previously-described alternatives for radiological markers in digital templating such as measuring the width between
the anterior superior iliac spines with a caliper were found to be inferior to radiological markers. Kulkarni et al showed that taking digital radiographs in a standardised way at a fixed FFD with a metal disc placed directly onto the cassette gave an accuracy similar to that with the use of a radiological marker. Since the disc was placed directly onto the cassette it was reproduced on the image without magnification, thus effectively calibrating only the cassette dimensions. The magnification was not determined directly and the method was only accurate if all patients had the same distance between their femoral head and the cassette. In their study the distance varied between 154 mm and 217 mm, which would have given a measurement error of approximately 4% between the patients with the smallest and those with the largest femoral head-to-cassette distance. The mean measurement error was 2%, which was slightly worse than we obtained using the distance measurement method with a mean relative error of 1%. Since the distance measurement method takes into account the distance between the hip and the cassette, and determines the magnification factor for every patient, it may be more accurate especially in obese or very small patients.

In our study the accuracy of the FFD and FOD measurement method appears to match that of the radiological marker method, which itself is comparable with the previously reported accuracy of using markers.

In our department the radiographers found the distance measurement method easier to use since no marker had to be taped to or be held in place by the patient. In addition, the tape measure is built into the x-ray tube assembly and, unlike the steel ball it cannot be misplaced.

Both techniques are dependent on choosing a reference location at the level of the hip, therefore both methods are similarly operator-dependent and radiographers need to be trained to identify the correct reference point. Recently, it has been suggested that placement of the radiological marker just lateral to the greater trochanter appears to give a more accurate measurement than placement of the marker at other sites. This is also our reference mark for measuring the focus-to-object distance.

Our study did not reveal a difference in the radiation-exposure for the two methods, possibly because the radiological marker was placed between the patient’s legs, which is usually part of the radiation field. If the field were to be enlarged to capture a marker placed at the trochanter this may not still hold true.

In summary the distance measurement method appears to be as accurate as using a radiological marker, but was found to be easier to use by our radiographers.

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References

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