A simple guide to determine the magnification of radiographs and to improve the accuracy of preoperative templating

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Templates are used in the preoperative planning of many orthopaedic procedures. The magnification of the bones on preoperative radiographs can vary despite using standardised radiological techniques. Templates will give misleading measurements unless this magnification is quantified.

A coin may be used to calculate the magnification, with significant improvement in the accuracy of templating (p = 0.05). A group of patients undergoing uncemented arthroplasty of the hip was at high risk for intraoperative fracture of the femur because the magnification of the radiograph was larger than that of the template.

The use of templates applied to radiographs before operation allows the surgeon to determine the most appropriate size of prosthesis to be used. A tight interference fit is desirable when introducing the femoral component of an uncemented hip replacement. A stem which is too small may not be stable and attempts to insert one which is too large increases the risk of intraoperative fracture. Such a complication has been reported in 3% to 24% of patients.1,2

The magnification of preoperative radiographs varies and templates which have a standardised magnification may therefore give unreliable information. An object of a known size or graduations projected on to the film is necessary to determine the magnification.

A marker of standard size laid on the skin of the patient at the time of taking the preoperative radiograph may be used as a guide to calculate the magnification. Ball-bearings set into perspex and rulers with clearly marked fine gradations can be employed. A graduated lead shield with pinholes 1 mm apart has been described.3 The ideal device should be readily available in the radiology department, easy to use, inexpensive, difficult to damage and manufactured to high specifications.

The specifications of the Royal Mint for ten pence coins are a diameter of 24.50 mm with a tolerance of ± 0.125 mm. The alloy is cast at more than 1000°C and it takes a pressure of 150 tonnes to imprint the design. The orientation of the coin does not affect the projected diameter and its measurement in the plane of the radiograph is not bound by a projection onto an x or y axis. It can be described as rotating around an axis in this plane (Fig. 1). The maximum diameter of the coin can be measured on the radiograph, whether it is a side-on bar or an ellipse. Even if a diagonal was measured across the thickness of 1.85 mm of a side-on coin, the maximum measurement would only increase by 0.01 mm.

X-ray beams diverge from the source with a maximum aperture of 12 mm. The distance from the source to the plate can be controlled. Paradoxically, the further the source is distant from the x-ray plate, the less is the magnification, but the magnification increases the further the distance of the bone from the plate (Fig. 2). Factors which affect this distance for a radiograph of the hip are the

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Fig. 1

Coin projection, irrespective of position, showing a constant diameter.
Plate distance from source = 1000 mm
Coin distance from x-ray plate = d
Coin distance from source = 1000 – d
Radius of coin (r) = 12.25 mm
\[ \tan \alpha = \frac{12.25}{(1000-d)} \]
Radius of magnified coin (r1) = \[ \frac{(12.25 \times 1000)}{(1000-d)} \]
Magnification = \[ \frac{(2 \times \text{radius of magnified coin})}{24.5} \]
Magnification = \[ \frac{1000}{(1000-d)} \]

Fig. 2
Calculation of magnification based on the distance of the coin from the x-ray plate.

size of the buttock and the rotation of the leg or pelvis. A schematic view illustrates the coin at the level of the bone from the side and in cross-section (Fig. 3). The magnification of the coin will match the magnification of the femur. The magnification will double from 10% to 20% if the distance from the femur to the x-ray plate is increased from 90 to 170 mm (Fig. 4). The distance from the source to the plate increases towards the periphery, but that from the source to the coin and from the coin to the plate increases proportionally giving the same magnification for a given vertical height above the plate.

Patients and Methods

We used a simple study to test the application of this technique, although manufacture of the prosthesis ceased for commercial reasons after this study was completed. The Bateman UPF II hip prosthesis (3M) has a straight 160 mm non-fenestrated Moore-type stem. Radiograph templates, assuming a magnification of 15%, were used to ensure a good anteroposterior (AP) fit within the proximal femur. Accurate preoperative templating allows the surgeon to have confidence in choosing which of the four sizes of the rasp and matching size of femoral stem to use. The manufacturer recommended placement of a metal ruler lateral to and level with the greater trochanter in order to determine the magnification of the radiograph. No ruler was supplied and no recommendations were made as to how to compensate for a change in magnification. At the time of taking the preoperative AP radiograph a ten pence coin (UK) was taped to the lateral skin of the patient’s thigh, at the level of the greater trochanter. The radiographs were taken at a distance of 1000 mm from the plate. The patient’s patella was in a neutral position of rotation with regard to the plate.

At the time of surgery the size of the femoral component was determined using the templates, ignoring the marker and thus not attempting to calculate the true magnification. At the completion of the series of operations the preoperative radiographs were presented in random order with the patients’ details masked. We applied the templates and the size was recorded. The exact magnification was then calculated by measuring the coin. The accuracy of surgeons measuring an x-ray projection of a metal femoral head has been reported as 0.5 mm.\(^4\) We can calculate the actual magnification between sizes of stem so that a smaller stem matches the template of a larger stem (Fig. 5) with a mean magnification of 25% (24% to 26%). We chose a cut-off of 22% which would result in a magnified stem being within 0.78 mm (0.63 to 0.94) of the larger template. A magnification of 6% or less would result in a smaller size being templated and a larger stem recommended.

The postoperative radiographs were reviewed. All interference fits were classified as ideal. An undersized prosthesis was used when the surgeon was either misled by the templating or decided when reaming that a press-fit had been achieved earlier than expected. Undersized stems were adjusted up by one size from that which was used to give a stem which would have been ideal. The accuracy of the templating after adjustment for magnification was com-

Fig. 3
Diagram of the coin and femoral projection.
pared with the ideal prosthesis in order to determine how many patients would have had a better fit had the more accurate templating been used.

We studied 32 patients after excluding ten with a very large canal in whom the template for the extra large prosthesis did not suggest an interference fit. The coins were measured to the nearest millimetre with a range of 26 to 32 mm giving seven calculated degrees of magnification. The mean magnification was 18% (Fig. 6).

The results were analysed using Fisher’s exact test.

### Results

When magnification was not taken into account, in 19 of the 32 hips (59.4%) preoperative templating corresponded to the implanted prosthesis, adjusted if necessary for a poor fit. When magnification was taken into account, in 22 of the 32 hips (68.8%) preoperative templating corresponded to the implanted prosthesis, adjusted if necessary for a poor fit. This increase in accuracy of 9% was not statistically significant (p = 0.3).

In 21 hips (65.6%) the magnification was considered to be close enough to that of the template setting of 15% and required no adjustment. The template prosthesis matched an ideal size in 15 hips. In five hips in which the template predicted a size larger than was used and accepted as ideal, the mean magnification was 15%. This would have made the template accurate and thus the larger prosthesis could have been inserted with a low risk of fracture and minimal extra reaming. In one hip the magnification was 10% and, although no adjustment would have been predicted after the use of a template, a larger prosthesis had been safely introduced.

Most at risk was the group of ten patients (31.3%) who had a magnification of at least 22% on the preoperative radiograph. The prostheses predicted by the templates would have been oversized with a potential for intraoperative fracture. In this group, when magnification was not taken into account, preoperative templating was over-
sized compared with the ideal prosthesis in seven of 32 hips (21.8%). When magnification was taken into account, however, in no case was the preoperative templating oversized compared with the ideal prosthesis. This difference was significant (p = 0.005).

One patient had a magnification of 6%, suggesting an undersized prosthesis. A smaller prosthesis, as indicated at templating, had been used and the postoperative radiograph was satisfactory.

**Discussion**

A perfect AP radiograph of the femur needs to account for anteversion of the femoral neck. Patients are required to rotate the leg internally by a mean of 15°. Restricted rotation of the hip in osteoarthritis sometimes makes it difficult to achieve this position. A study of the radiological dimensions of the femoral canal showed that the AP width of the medullary canal at the isthmus did not change significantly from 20° internal to 40° external rotation. At 20 mm below the lesser trochanter there was no significant change on internal rotation and an apparent increase of 1.1 mm with 20° external rotation. Thus the fit based on the templating of the diaphyseal region would be accurate even if there were small variations in femoral rotation. The difference in magnification caused by the change in distance from the femur to the x-ray plate with different rotation would be accounted for by the corresponding position of the coin. The mean distance from the femur to the plate, based on the mean magnification, was 153 mm (57 to 237) corresponding to a previously reported mean height of 165 mm.

Most radiographs were magnified to a greater extent than the 15% assumed by the template. The mean of 18% in our study corresponds to the 18% using a 28 mm femoral head and a 40 inch (1016 mm) distance from the x-ray source to the plate. In another study the desired magnification in 40% of hips was exceeded by an amount corresponding to one size of prosthesis. The accuracy of templating in predicting the size of the femoral component used has been reported as 50% with an incidence of 24% of fracture of the calcar. This was using templates with a magnification of 20% without assessing the true magnification. In a series of uncemented arthroplasties stems which were smaller by one or more size than templated were used in 50% of hips. Our overall accuracy in predicting the ideal size of prosthesis without considering the magnification was 59.4% (19 hips); and when this was considered, the accuracy was 68.8% (22 hips). The adjustment for magnification improved the accuracy of the choice of prosthesis in seven hips (21.8%). The accuracy was spuriously reduced when a larger prosthesis was safely used in three cases. In one case a smaller prosthesis than the one indicated had been inserted.

Experience with the design of a prosthesis helps when selecting an appropriate size. If templating is accurate a discrepancy between the preoperative planning and intraoperative experience should be considered as a warning that appropriate reaming has not been achieved. An experienced surgeon may be cautious and choose the correctly sized implant based on tight reaming, whereas a surgeon with less experience may persist when templating has overestimated the size of the femoral canal because of increased magnification, thus risking an intraoperative fracture. The adjustment for magnification, based on its accurate calculation, may prevent this complication.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

**References**