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Failure to correct femoral anteversion on the AP Pelvis radiograph leads to errors in prosthesis selection in total hip arthroplasty

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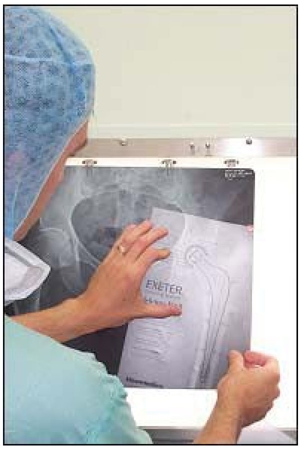
Abstract The antero-posterior pelvis radiograph is used in templating to calculate the size of components used in hip arthroplasty. This study investigates whether failure to account for femoral neck anteversion, when obtaining preoperative AP radiographs, may lead to the selection of an incorrectly sized femoral stem. Three anatomically correct sawbone models were labelled with radio-opaque markers. Serial radiographs were taken as each model was rotated though successive angles, as determined with a goniometer. The resultant offset was measured from each image. The length of offset is greatest at 15° degrees of internal rotation. The length of offset is altered by rotation (Friedman Xr^2 9.0, k 4, N 3, *P* <0.01, two-tailed test). The results indicate that, for the Exeter hip system, this could lead to the selection of a stem two sizes too small. Lesser degrees of rotation, not readily identified by looking at the image, could still lead to the selection of an incorrectly sized stem. This finding is applicable to other modular hip replacement systems in common use. To ensure that patients receive hip prostheses of correct size, preoperative radiographs should account properly for femoral anteversion. A foot box may help to standardise the amount of femoral anteversion when preoperative radiographs are taken.

Keywords: AP pelvis, arthroplasty, femoral anteversion, preoperative, radiograph, templating



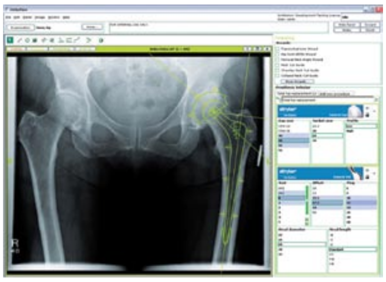


Figure 1a, **Figure 1b**: Manual and digital templating being performed.

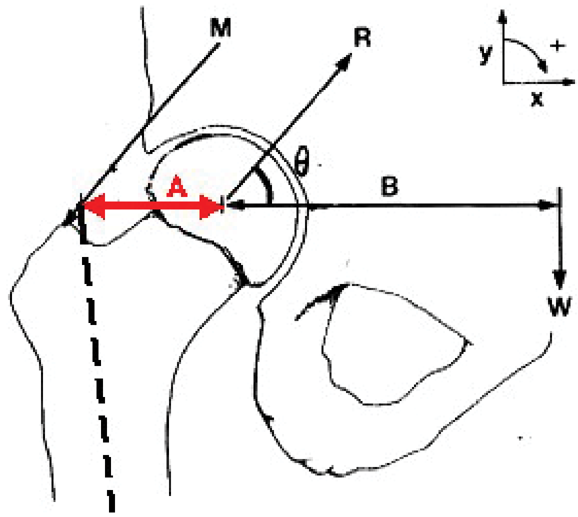


Figure 2: Measurement of femoral offset.
Key: A: Femoral offset, M: Insertion of abductors, R: Joint reaction forcem, B: Lever arm for action of body weight, W: body weight.

Introduction

Templating is the method by which a surgeon calculates the correct-sized prosthesis from a preoperative radiograph of the pelvis using a series of transparent templates. Recently, specialist software has allowed this process to be performed on digitally-stored systems such as a Picture Archiving and Communications System (PACS). Digital templating systems are highly accurate and have mechanisms for calibrating x-ray images to the correct magnification. However, they are unable to account for femoral anteversion.

Many studies have shown the importance of preoperative planning.[1,2,3] Today, surgeons seek to recreate the normal anatomical relationship of the pelvis to the femur and restore the normal biomechanics of the hip joint. The measurement of femoral offset is one of the variables measured during templating that determines the size of femoral component in hip replacement surgery.

Femoral offset is the perpendicular distance between the centre of the femoral head and a line drawn down the centre of the femoral shaft as determined from the AP pelvis x-ray. In clinical practice the centre of the head can be determined using an acetate template printed with concentric circles. A further template, printed with parallel lines, allows the centre of the shaft to be determined.[4] If digital templating software is used these points are calculated automatically. There are many clinical advantages associated with the reproduction of normal femoral offset. These include improved

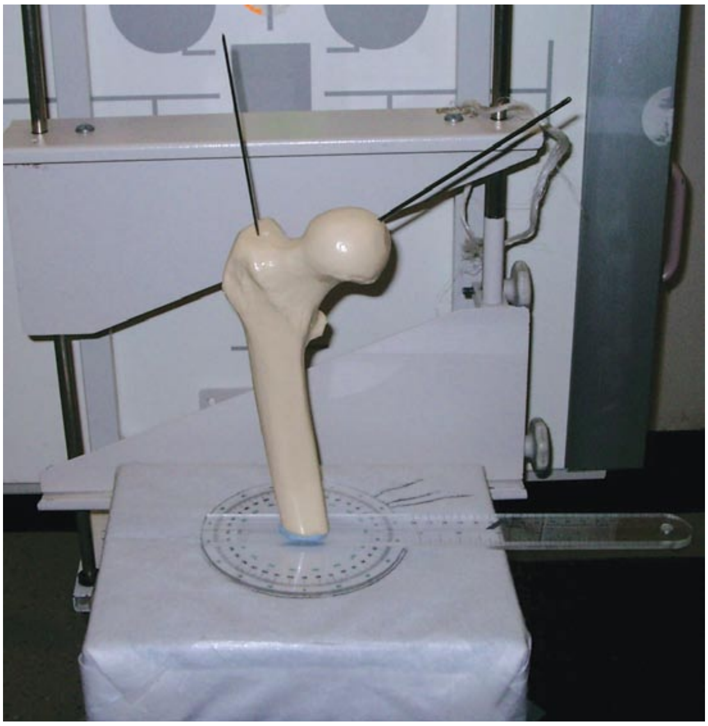


Figure 3: Saw bone model mounted on goniometer.

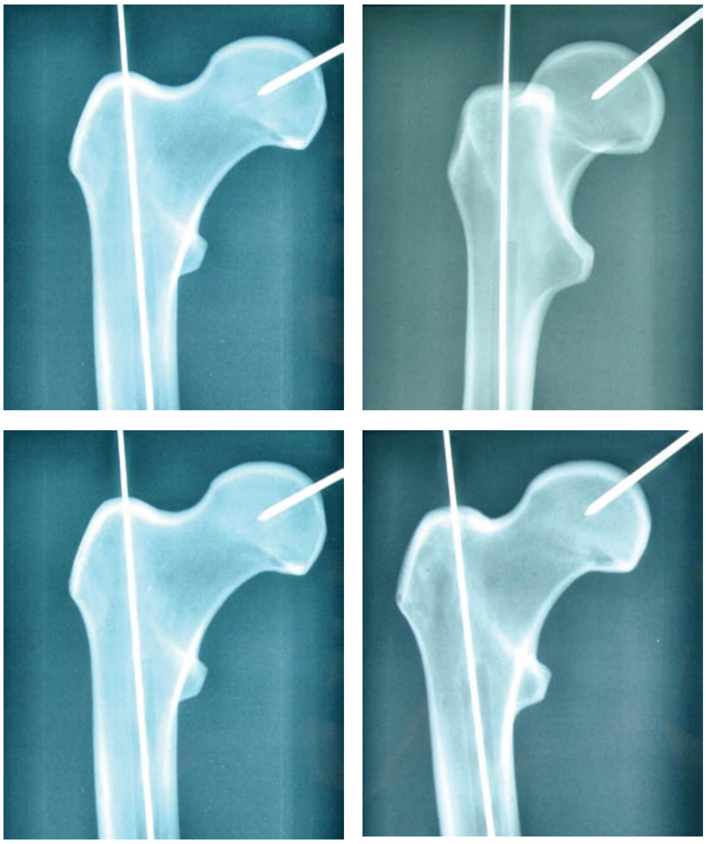


Figure 4a, **Figure 4b**, **Figure 4c**, **Figure 4d**: Example x-rays.

abductor strength,[5] enhanced stability,[6] greater range of motion[5], reduced rates of aseptic loosening[7] and polyethylene wear.[8]

The femoral neck is anteverted between 15° and 20°.[9] Therefore, a radiograph taken in the anatomical position provides a foreshortened view of the femoral neck. The correct length of femoral offset can only be measured if the femoral neck is perpendicular to the beam, parallel to the image receptor and when any magnification has been accounted for.

This study examines whether failure to correct for femoral anteversion on the AP pelvis radiograph can lead to errors in templating and hence prosthesis selection. This is investigated by examining how femoral offset varies with rotation at the hip.

Method

Three anatomically accurate saw bones of the femur were obtained from the orthopaedic manufacturer Stryker (Stryker UK Ltd, Newbury, UK). Each femur was cut 25 cm distal to the tip of the greater trochanter and in the same plane as the femoral condyles. Each femur was labelled with radiographic markers to readily allow the measurement of femoral offset from an x-ray. The radiographic markers were 2 mm k-wires obtained from the operating theatres. An electric drill was used to place a wire into the centre of each femoral head, at a distance of 27 mm from the surface. A second wire was placed down the middle of the shaft of the femur. Each shaft was hollow and wide enough to accept the casing of a biro that acted as a centralising device for inserting the second wire. The prepared femur was then mounted onto a goniometer with epoxy resin (Figure 1). The goniometer allowed the femur to be rotated through different angles. An AP radiograph was taken at each angle.

By mounting the model on a large Perspex goniometer allowed small angles of rotation to be accurately conveyed to the model. The x-ray plate was mounted immediately behind the model ensuring that magnification was negligible.

Three saw bone models (Model A, Model B, and Model C) were made in this way. The length of wire imbedded in the femoral head was 26 mm for Model A, 26 mm for Model B, and 29 mm for Model C (Figure 3).

Antero-posterior radiographs were taken of each saw bone model. For each model, x-rays were taken at +15° (i.e. 15° of internal rotation), 0° (when the model was in the anatomical position of the femur), -15° (i.e. 15° of external rotation), and -30° (i.e. 30° of external rotation). At zero degrees the model was in the anatomical position with the femoral neck anteverted 15°. A senior radiographer took all of the images.

Minus 15° ⟶ Plus 30°

It is immediately apparent that at the extremes of rotation (above) there is a difference in femoral offset. Between lesser degrees of rotation (below) any difference is much less noticeable.

Minus 15° ⟶ 0°

Seeking zero magnification of the femoral offset, the x-rays were taken with a focal film distance of 100 cm and with the x-ray cassette immediately behind the model. To see if there had been x-ray magnification of the model the length of wire, shown on the image, within the head of the femur was compared with the length of wire known to have been implanted in the femoral head when the model was made.

Femoral offset was taken as the perpendicular distance measured using a standard ruler and protractor from the wire running down the midline of the femoral shaft to the tip of the wire in the centre of the femoral head.

For each of Model A, Model B, and Model C, the femoral offset was measured on radiographs taken when the model was at each of +15°, 0°, -15° and -30° of femoral rotation. Independently of one another, three observers, all senior house officers in orthopaedics and trauma, made these measurements (as 'Initial Observations') and, one week later, performed the same measurements again (as 'Repeat Observations'), once more acting independently of one another.

Statistical methods

The length of femoral offset measured on radiographs relates to the rotation of the femur. Concerning the length of femoral offset on x-rays, the study made group comparisons, looking for differences among three observers, three models, and four angles of femoral rotation.

In the study, the samples, observers, models, or angles of rotation, were sufficiently small that it was decided, before data was collected, to use statistical methods which were non-parametric[10] (Siegel 1956). Thus, in the study, differences between or among sample groups were tested for statistical significance by the Wilcoxon Matched-pairs Signed-Ranks test or by the Friedman Two-Way Analysis of Variance.

For these tests the null hypothesis (H_o) was that there was no difference between or among the subjects concerned. The alternative hypothesis (H_1) was that a difference existed. It was decided to reject H_o in favour of H_1 if $P < 0.05$. In all cases H_1 did not predict the direction of difference so two-tailed tests were used.

Results

Zero magnification

When antero-posterior radiographs were taken when the femur was in 15° of internal rotation (i.e. when the femoral head and neck were at right angles to the x-ray beam and parallel to the image receptor), measurements from the images gave the length of wire embedded in the head of the femur as 26 mm for Model A, 26 mm for Model B, and 29 mm for Model C. These were identical to the known lengths of wire that had been embedded when the models were made. Thus it was reasonable to disregard possible magnification when assessing the measurements of femoral offset shown on the radiograph.

Raw data

For each of the three models, Table 1 gives the length in centimetres of femoral offset on the radiograph which was recorded, as Initial and Repeat Observations, for four angles (degrees) of femoral rotation by each of three observers.

Intra-observer consistency

Each observer made Initial and Repeat observations of femoral offset on x-ray for four separate angles of rotation for each of the three models, i.e. each observer made Original and Repeat observations for each of 12 radiographic positions.

For each observer there was no difference between Initial and Repeat observations for any of the 12 radiographic positions. Thus, for each observer, the group of Initial Observations did not differ from the group of Repeat Observations (Wilcoxon Matched-pairs Signed-Ranks test, T 0, N 12, $P > 0.10$, two-tailed test).

Inter-observer consistency

For all of the Initial and Repeat measurements made by the three observers, there was only one estimation (the Initial one concerning the length of femoral offset on the image when Model B was at -15° of femoral rotation) in which one observer differed slightly from the other two observers. For all the other estimations shown on Table 1, all three observers were in agreement.

For statistical study of inter-observer consistency, values of femoral offset on the radiograph were taken, with respect to measurement by an individual observer, as the average of his Initial and Repeat Observations for the relevant model and angle of femoral rotation.

For Model A, when Observer 1, Observer 2 and Observer 3 are ranked according to their scores (lengths of femoral offset on the

Table 1: For each of the three models, the length (cm) of femoral offset on x-ray which was recorded, as Initial and Repeat Observations, for four angles (degrees) of femoral rotation, by the three observers.

Model A

Model A Rotation (degrees)	Observer 1 Offset (cm) INITIAL	Observer 1 Offset (cm) REPEAT	Observer 2 Offset (cm) INITIAL	Observer 2 Offset (cm) REPEAT	Observer 3 Offset (cm) INITIAL	Observer 3 Offset (cm) REPEAT
+15	5.4	5.4	5.4	5.4	5.4	5.4
0	5.1	5.1	5.1	5.1	5.1	5.1
-15	4.4	4.4	4.4	4.4	4.4	4.4
-30	3.5	3.5	3.5	3.5	3.5	3.5

Model B

Model B Rotation (degrees)	Observer 1 Offset (cm) INITIAL	Observer 1 Offset (cm) REPEAT	Observer 2 Offset (cm) INITIAL	Observer 2 Offset (cm) REPEAT	Observer 3 Offset (cm) INITIAL	Observer 3 Offset (cm) REPEAT
+15	5.6	5.6	5.6	5.6	5.6	5.6
0	5.5	5.5	5.5	5.5	5.5	5.5
-15	5.0	5.0	5.1	5.1	5.1	5.1
-30	4.2	4.2	4.2	4.2	4.2	4.2

Model C

Model C Rotation (degrees)	Observer 1 Offset (cm) INITIAL	Observer 1 Offset (cm) REPEAT	Observer 2 Offset (cm) INITIAL	Observer 2 Offset (cm) REPEAT	Observer 3 Offset (cm) INITIAL	Observer 3 Offset (cm) REPEAT
+15	5.5	5.5	5.5	5.5	5.5	5.5
0	5.3	5.3	5.3	5.3	5.3	5.3
-15	4.6	4.6	4.6	4.6	4.6	4.6
-30	3.6	3.6	3.6	3.6	3.6	3.6

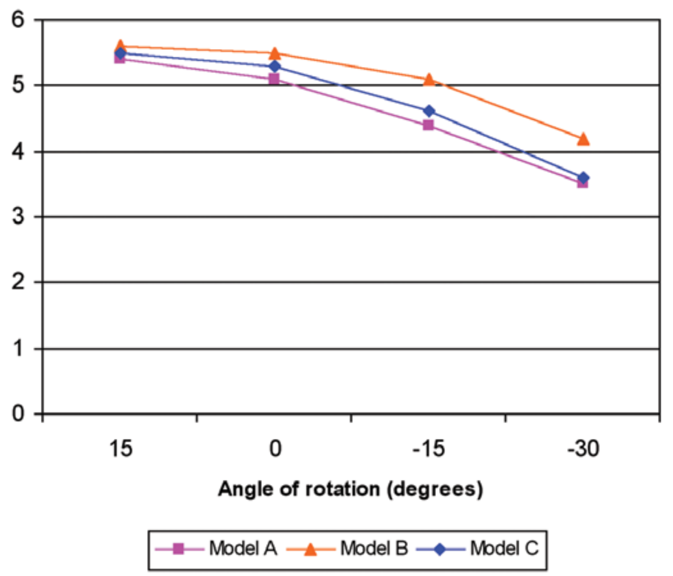


Figure 5: Graph showing the femoral offset for each of the three models. The length of femoral offset plotted against angles of femoral rotation for each of Models A, B and C.

radiograph) for each of the four angles (+15°, 0°, -15° and -30° respectively) of femoral rotation, there is no difference among the observers (Friedman Xr^2 0, k 3, N 4, *P* 1.00, two-tailed test).

This is so for Model B (Xr^2 0.38, k 3, N 4, 0.93 < *P* <1.00, two-tailed test), and also for Model C (Xr^2 0, k 3, N 4, *P* 1.00, two-tailed test).

Differences among models of femur

For each observer considered separately, if one ranks each of Model A, Model B and Model C for the measurement on the radiograph of femoral offset for each of +15°, 0°, -15° and -30° of femoral rotation, the models differ in the observed length of femoral offset (Friedman Xr^2 8.0, k 3, N 4, *P* 0.005, two-tailed test).

Concerning the average of observations made by the three observers for femoral offset on the radiograph at each of +15°, 0°, -15° and -30° of rotation, there was a difference (Xr^2 8.0, k 3, N 4, *P* 0.005, two-tailed test), among Model A (median 48 mm, range 35–54 mm), Model B (median 53, range 42–56 mm), and Model C (median 50, range 36–55 mm). This is shown graphically in Figure 5.

These findings are consistent with the view that the three saw bone models were not made exactly the same concerning the size of femoral offset.

Length of femoral offset according to angle of femoral rotation

For Model A, concerning the median (= mean) of measurements of femoral offset made from x-rays by the three observers, the femoral offset for +15° of femoral rotation is 54 mm, for 0° is 51 mm, for -15° is 44 mm, and for -30° is 35 mm.

For Model B, the median (= mean) femoral offset on x-rays for +15° of femoral rotation is 56 mm, for 0° is 55 mm, for -15° is 51 mm, and for -30° is 42 mm.

For Model C, the median (= mean) femoral offset on x-rays for +15° of femoral rotation is 55 mm, for 0° is 53 mm, for -15° is 46 mm, and for -30° is 36 mm.

For each of Models A, B and C, concerning the length of femoral offset on x-rays represented by the median (which is the mean) of measurements by the three observers, the difference among angles of femoral rotation is significant (Friedman Xr^2 9.0, k 4, N 3, *P* <0.01, two-tailed test).

For each model, the femoral offset was greatest on images taken when the femur was in 15° of internal rotation, i.e. when radiographs were taken with the femoral neck perpendicular to the x-ray beam and parallel to the image receptor. Measurements of femoral offset were less when x-rays were taken at 0° of rotation (the anatomical position of the femur) or at 15° or 30° of external rotation – i.e. when radiographs were not taken at right angles to the femoral neck.

Discussion

The results show that offset measured radiologically depends on the degree of hip rotation in relation to the x-ray beam. This may cause surgeons to misjudge the true length of offset needed for hip joint replacement. For the Exeter hip system that offers three common sizes of offset (3.75 cm, 4.4 cm and 5 cm) this could lead to the selection of a stem two sizes too small. Thus, a patient whose true anatomical femoral offset was 54 mm (Model A) might have a non-standardised radiograph indicate, incorrectly, that the femoral offset was 35 mm. Instead of being treated with an Exeter stem with femoral offset of 50 mm he might be treated inappropriately with an Exeter stem of 37.5 mm. Similar findings will be found with other modular hip replacements that provide a range of sizes, with regard to offset, to cover the variation in human hip anatomy.

Methods of accounting for femoral anteversion

There are many methods to attempt to account for femoral anteversion. The most common method is to position the patient supine with their feet apart and their big toes touching. This is a poor method for several reasons. It is left to the radiographer to decide how far the heels should be set apart. Failure to lock the ankle in a neutral position allows a significant degree of ankle movement before any hip movement takes place. Finally, within the population there is a wide range of foot size. Positioning patients with their heels a set distance apart and their toes touching inevitably rotates the hips of patients with smaller feet further than those with larger feet.

The most accurate way of measuring femoral offset is to perform a CT. This results in a much higher radiation dose to the patient. It is impractical as most hospitals only have one CT scanner. Using a footbox provides an acceptable compromise.

A foot box enables a standardised AP pelvis radiograph to be taken. The footbox internally rotates the legs 15° and keeps the ankles dorsiflexed to neutral. This ensures rotation of the foot is conferred to the hip. This provides an x-ray where the femoral neck is parallel to the image plane.

Assessing the adequacy of the x-ray

Images should be reviewed prior to templating. The ideal AP hip radiograph has the pelvis and femoral neck perpendicular to the x-ray beam and the femoral neck parallel to the image receptor. Rotation of the pelvis can be judged by checking that the symphysis pubis is aligned with the midline of the sacrum and that the obturator foramina are identical in outline.[11,12]

It is difficult to be sure that the femoral neck is perpendicular to the x-ray beam and parallel to the image receptor. This point can be assumed to have been reached when both medial cortices of the greater trochanter have been superimposed.[13]

Radiographs taken in marked external rotation (i.e. -30°) are normally identifiable since the lesser trochanter is totally visible and the femoral head is superimposed on the greater trochanter.

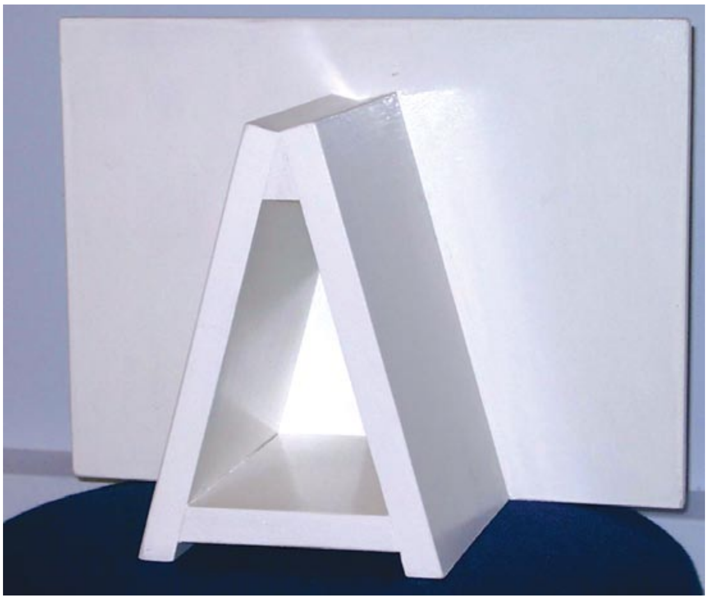


Figure 6a: Footbox device; **Figure 6b:** foot box in use.

These films may be discounted from use in templating. However for images taken with less rotation of the hip (+15°, 0° and -15°) it is much more difficult to identify, merely by inspection of radiographs, whether the radiograph gives a true representation of the femoral neck.

Surgeons do not solely rely on templating for choosing stem size. Experienced surgeons are able to make decisions regarding the choice of femoral stem from tactile feedback during the preparation of the proximal femur. A 'trial' stem can be inserted before committing to actual stem. With the trial stem in situ the surgeon can assess how well the soft tissues will repair and the tension in the soft tissues. If too great an offset has been selected it can be difficult to create an effective repair. Inexperienced surgeons are much less skilled at making decisions based on intraoperative feedback. Preoperative templating is important in providing accurate information that can reassure the surgeon he is making the correct choice of stem.

Conclusions

Failure to correct for femoral anteversion on the AP pelvis radiograph may lead to underestimation of femoral offset and the choice of an incorrectly sized femoral stem.

The benefits of highly accurate digital templating systems may not be fully realised. These systems have software for accounting for magnification but do not include a mechanism for correcting for femoral neck anteversion.

A standardised radiographic view of the pelvis should improve measurement of femoral offset and ensure the selection of the correct sized prosthesis. This can be readily achieved with the help of a foot box. By recreating a patient's anatomy more accurately, patients might receive a better-functioning, longer-lasting hip prosthesis with fewer post-operative complications.

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