Arch Orthop Trauma Surg (2007) 127:381–385
DOI 10.1007/s00402-007-0349-0

ORTHOPAEDIC SURGERY

Preoperative templating of femoral components on plain X-rays

Rotational evaluation with synthetic X-rays on ORTHODOC

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Received: 1 May 2006 / Published online: 24 May 2007
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Abstract
Introduction Preoperative femoral templating for total hip arthroplasty (THA) has been performed by antero-posterior radiographs of both hips which should be taken with the femur rotated internally to reduce the effect of femoral anteversion. However, there is no criterion to evaluate the optimal rotated radiograph. Here, we quantitatively investigated 50 femora whether the thickness of the lesser trochanter (TLT) was useful when evaluating the femoral rotation, and assessed the effect of prosthetic templating on the inappropriate rotated radiographs.
Materials and methods We assessed 50 femora of 46 consecutive osteoarthritic patients using "synthetic X-ray" based on computer tomography (CT) images, which can be displayed as virtual plain radiographs with any magnification and any projected direction such as plain radiographs. We made four femoral radiograph groups of different rotation prepared (neutral, 15°, 30°, and 45° external rotation), and measured the TLT. We also templated femoral stem on the different rotated synthetic X-ray of each patient, and investigated the effect of inappropriate rotated radiograph by the measurement of the positon and the size of the stem.
Results Seventy-four percent of the neutral rotational group had less than 5 mm of the TLT. While 30° and 45° external rotation group had few cases with less than 5 mm of the TLT. Compared to the neutral group, smaller stem size was selected in more than 80% cases of 30° and 45° external rotational group, and the stem position in these two groups was more than 5 mm proximally.
Conclusion We suggest that when templating femoral stem, this criterion "the TLT is less than 5 mm" reduces some risks by inappropriate rotated radiograph.

Keywords Preoperative femoral templating · Femoral rotation · The thickness of the lesser trochanter · Synthetic X-ray · ORTHODOC

Abbreviations
THA Total hip arthroplasty
TLT The thickness of the lesser trochanter

Introduction

In the preoperative planning of cemented or cementless total hip arthroplasty (THA), templating, which involves a clear sheet of prosthesis that is fitted on antero-posterior (AP) X-rays of both hips, has been done [2–4, 7–10, 12]. This is an integral part of THA, and helps in deciding the appropriate size and position for acetabular and femoral components, equalizing leg length, and reducing intraoperative complications.

To select the appropriate femoral components, the preoperative AP X-rays of both hips should be taken with the femur rotated internally 15°–20° to reduce the effect of femoral anteversion [2, 4, 5, 21], otherwise, the optimal stem size and the best fit between bone and prosthesis may

Presented as a poster exhibit at the 5th Annual Meeting of the Computer Assisted Orthopaedic Surgery, 19–22 June 2005, Helsinki, Finland.

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not be obtained [14]. To determine if an appropriate preoperative X-ray has been done, Engh et al. reported that the extent of femoral rotation can be evaluated by the thickness of the lesser trochanter (TLT), which is between the contour of the proximo-medial femoral cortex and the end of the lesser trochanter [8]. However, there is no objective and quantitative criterion to evaluate whether the rotation of the femur is optimal on the preoperative AP hip X-rays.

The purpose of this study was to clarify whether quantitative measurements of TLT are useful when evaluating femoral rotation on AP X-rays, and to investigate the effect that femoral rotation plays in preoperative templating, with respect to the size and position of the femoral prosthesis.

Materials and methods

We assessed 50 femora of 46 consecutive osteoarthritic patients (2 men and 44 women), who had a cementless THA between 2003 and 2004. We made "synthetic X-ray" images based on the computer tomography (CT) images of these femora on the ORTHODOC. On the basis of the CT data, the synthetic X-rays can be displayed as virtual plain X-rays with any magnification and any projected direction, such as plain X-rays in an AP view or a lateral view. The synthetic X-rays have already been shown to be a useful image modality for evaluating the accuracy of THA implantation [16].

We first created a synthetic X-ray on AP view with 0° of femoral neck anteversion, and defined this as the neutral position (Fig. 1a). Next, based on the anatomical canal axis of the proximal femur at the neutral position we made three AP synthetic X-rays with the femur externally rotated 15°, 30°, and 45° (Fig. 1b–d). We converted the image data of the synthetic X-rays into TIFF format and measured the TLT using Scion Image (Scion Corporation, NIH image modified for use with Windows PC, version Beta 4.0.2) (Fig. 2). For each patient, we templated a virtual femoral prosthesis (VerSys Fiber Metal Taper, Zimmer) on the four femoral synthetic X-rays (neutral rotation, 15°, 30°, and 45° of external rotation) until good contact was achieved with endosteal cortical bone (Fig. 3). We also measured the positions of the femoral components. The position of the virtual femoral prosthesis was defined as the distance between the tip of the greater trochanter and the shoulder of the femoral stem in the proximo-distal direction (Fig. 3) [11]. We compared the size and the position of the three rotated synthetic X-rays to those of the neutral synthetic X-ray, which was defined as the standard for correct planning.

Statistical analysis of the measurements was performed with analysis of variance using the Kruskal–Wallis test. The threshold value for statistically significant differences was set at $P = 0.05$. Interobserver and intraobserver reliabilities of the size and the position were evaluated by having three different surgeons assess ten randomly selected

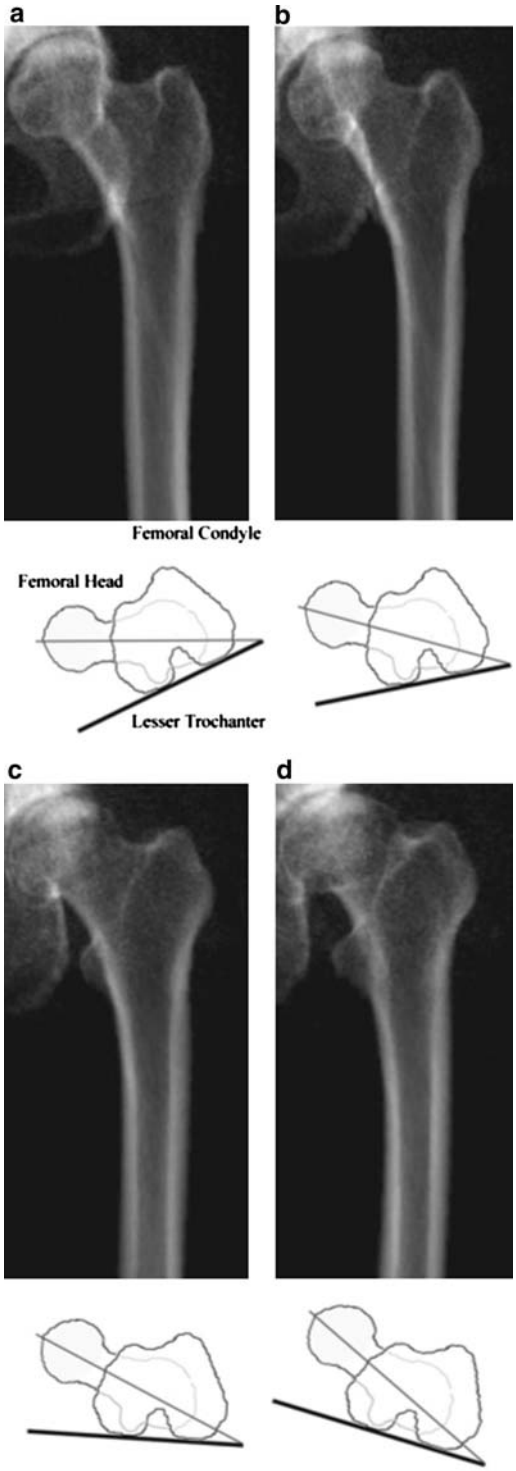

Fig. 1 *Above* Antero-posterior synthetic X-rays of the femur in the neutral position **a**, 15° **b**, 30° **c** and 45° **d** of external rotation relative to the proximal femoral axis. *Below* Projected figures of the axial direction for each rotated group are shown

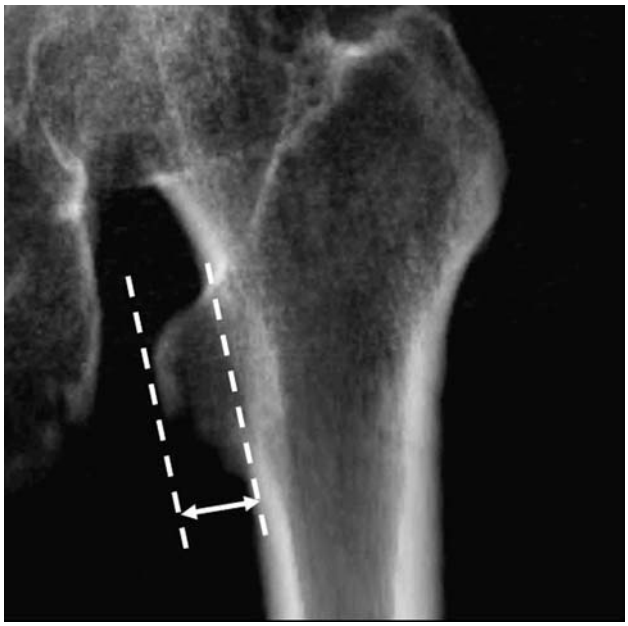

Fig. 2 The thickness of the lesser trochanter is represented by the perpendicular distance between the two *dotted lines*, from the external prominent contour of the lesser trochanter to the femoral cortex

Fig. 3 Virtual templating of the femur with the synthetic X-ray on ORTHODOC. The position of the femoral prosthesis was defined as the distance between the two *dotted lines*, from the tip of the greater trochanter to the shoulder of the femoral stem

patients three times. The reliability of the evaluation of position was calculated by subtracting each measurement [15]. The reliability of the evaluation of size was evaluated using correlation coefficients [18].

Results

The mean (±1 SD) TLT was 2.3 ± 3.1 mm in the neutral position, 6.2 ± 3.1 mm with 15° external rotation, 9.1 ± 2.4 mm with 30° external rotation, and 11.4 ± 2.2 mm with 45° external rotation (Table 1). There were significant differences in the TLT among all rotation groups ($P < 0.0001$). It should be noted that the TLT was less than 5 mm in 74% of the neutral rotation group (Table 1). Compared with the stem size selected based on the neutral rotation X-ray, it was smaller in 14 cases (28%) of the 15° external rotation group, in 42 cases (84%) of the 30° external rotation group, and in 47 cases (94%) of the 45° external rotation group ($P < 0.0001$). Compared to the position of the femoral stems in the neutral rotation group, the position of the femoral stems was shifted proximally 2.6 ± 1.8 mm in the 15° external rotation group, 5.8 ± 2.2 mm in the 30° external rotation group, and 10.4 ± 2.8 mm in the 45° external rotation group (Table 2). There were also significant differences in the position of the femoral stems among all rotational groups ($P < 0.0001$). The mean intraobserver error of the position was 0.31 ± 0.16 mm, and the mean interobserver error of the position was 0.63 ± 0.59 mm. The mean intraclass correlation coefficient of the size was 0.91 (0.89–1), and the mean interclass correlation coefficient of the size was 0.92 (0.86–1).

Discussion

Some reports have shown the usefulness and precision of using preoperative femoral templating on plain AP X-rays of both hips. The accuracy of preoperative templating in determining the size that is needed is 32–79% for cementless stems and 78–94% for cemented stems [2, 7, 9, 10, 12, 21]. The errors made in predicting the size are related to the magnification of plain X-rays and the rotation of the femur [17]. The effect of femoral rotation, however, has not been studied well. Although two X-ray studies have shown that there were changes in the width of the femoral medullary canal on the AP projection with femoral rotation [1, 6], these papers found no femoral morphologic feature that would be useful in acquiring accurate plain AP X-rays.

To find a criterion that would help evaluate femoral rotation on AP X-rays, we investigated the TLT using synthetic X-rays with four groups with different degrees of external femoral rotation. Our results showed that there were signifi-

Table 1 The thickness of the lesser trochanter for each femoral rotation group

Thickness of the lesser trochanter	Neutral position	The degree of external rotaion		
	0°	15°	30°	45°
Distribution (mm)				
0	30	3	–	–
0–5	7	12	2	–
5–10	13	29	29	13
10–15	–	6	19	34
>15	–	–	–	3
Average (mm)	2.3 ± 3.1	6.2 ± 3.1	9.1 ± 2.4	11.4 ± 2.2

Table 2 Amount of change due to femoral external rotation

Parameters	Change due to external rotaion		
	15°	30°	45°
The number of cases with smaller size (%)	14 (28)	42 (84)	47 (94)
The average (±SD) proximal displacement of the stem position (mm)	2.6 ± 1.8	5.8 ± 2.2	10.4 ± 2.8

cant differences in the TLT among the four rotational groups. Furthermore, we found that 74% of the neutral rotation group had TLT less than 5 mm, while only two cases in the 30° external rotation group and no cases in the 45° external rotation group had TLT less than 5 mm. Thus, a TLT less than 5 mm appears to be an acceptable criterion for evaluating femoral rotation on AP X-rays.

Our results also showed some adverse effects that can occur when templating using X-rays with inappropriately rotated femora, as with 30° and 45° external rotation. First, the greater the external rotation of the femur, the smaller the selected femoral prosthesis size, due to the narrow width of both the proximal and the distal femoral canal. Previous CT studies of the femur can help explain the reasons for the morphologic change of the femoral canal and the change of the stem size observed with rotation in this study. The femoral canal is elliptical in cross-section [13, 17, 19]. With external rotation, a line which has the longest transverse diameter of the canal was closer to the AP-projected line [13, 19], resulting in a smaller medio-lateral width of the femoral medullary cavity. Second, the more the femur is rotated externally, the more the position of the femoral prosthesis is templated proximally. The stem position was shifted proximally more than 5 mm in the 30° external rotation group and more than 10 mm in the 45° external rotation group. These proximal deviations that occur during templating of the femoral stem probably affect leg length equalization. To the best of our knowledge, the current study is the first report dealing with quantitative deviation of the femoral stem when templating is done using X-rays of externally rotated femora. Templating of the stem needs to be based on X-rays with the femora appropriately rotated, and the TLT is useful in determining if an appropriate X-ray was taken.Although our criterion that the TLT be less than 5 mm is valid to evaluate the femoral rotation of AP X-rays, some issues remain. First, the criterion did not apply in 13 (26%) cases of the neutral rotation group; the TLT was more than 5 mm in the AP radiographs of these 13 cases. Second, 24% of cases in the 15° external rotation group had a TLT of less than 5 mm. Thus, in the 15° external rotation group there was the possibility of a smaller size being selected than would be selected in the neutral rotation group, but the potential leg length discrepancy was only 2.6 mm. These situations of overlapping TLT values limit preoperative templating of femoral components based on plain AP X-rays. Thus, three-dimensional templating might be required to achieve more accurate preoperative templating [20, 22].

Conclusion

In conclusion, we found that when templating the femoral stem, using the criterion that the TLT be less than 5 mm would reduce some of the risks associated with using X-rays with inappropriately rotated femora. Nevertheless, surgeons need to understand that errors may still occur during femoral templating because the criterion did not apply in all cases.

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