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Clinical accuracy evaluation of femoral canal preparation using the ROBODOC system

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Abstract The purpose of this study was to evaluate the clinical accuracy of femoral canal preparation using postoperative reconstructed computed tomography (CT) images of 75 consecutive total hip arthroplasties performed with a two-pin-based ROBODOC system. Intraoperatively, the robot milled the femoral canal according to the preoperative planning performed with preoperative CT data and the ROBODOC workstation. Postoperative CT data was obtained 1 month postoperatively. Anteroposterior and lateral synthetic radiographs and axial images were reconstructed from CT data on the workstation. The mean difference between the preoperative planning and the postoperative CT images was less than 5% in canal fill, less than 1 mm in gap, and less than 1° in the mediolateral and anteroposterior alignment. Clinical femoral canal preparation using the ROBODOC system results in a high degree of accuracy.

Key words ROBODOC · ORTHODOC · Clinical accuracy evaluation · Femoral canal preparation

Introduction

Fit and fill of a cementless femoral component in the femoral canal are important factors for stable fixation and good clinical results.[3,7,10,13,15,25] The ROBODOC system provides three-dimensional preoperative planning of cementless femoral components on the preoperative planning workstation (ORTHODOC, Integrated Surgical Systems, Davis, CA, USA) and executes this plan using robotic machining to achieve good fit and fill.[1,26]

Patients with osteoarthritis of the hip secondary to developmental hip dysplasia have increased femoral anteversion.[6,11,23,28,29] Conventional radiographic two-dimensional evaluation of proximal femoral canal preparation has many potential sources of error, including rotation error,[12] because it is more difficult to obtain a true anteroposterior or lateral view of an anteverted dysplastic femur than of a normal femur. Reconstruction of computed tomography (CT) images using the ORTHODOC can reduce rotation error and aid in evaluating the clinical accuracy of proximal femoral canal preparation.

Accuracy evaluation of femoral canal preparation using the ROBODOC system has generally been limited to studies using cadaveric bones[14,26] or to clinical evaluation by radiographic two-dimensional analysis.[1] Lahmer et al.[17] reported clinical accuracy using CT images for 12 patients who underwent total hip arthroplasty using the ROBODOC system. However, there have been no reports of the use of reconstructed CT images to evaluate the clinical accuracy of consecutive total hip arthroplasties performed through a posterolateral approach.

The purpose of the present study was to evaluate the clinical accuracy of femoral canal preparation using postoperatively reconstructed CT images in consecutive total hip arthroplasties performed through a posterolateral approach with the ROBODOC system.

Materials and methods

The subjects were 69 patients (56 women and 13 men) who underwent 75 consecutive primary total hip arthroplasties performed using the pin-based ROBODOC system from September 2000 to October 2001. This study was approved by the Institutional Internal Clinical Research Committee. Informed consent was obtained from all patients after the nature of the procedure had been fully explained. VerSys fiber metal taper hydroxyapatite (HA)-coated femoral components (Zimmer, Warsaw, IN, USA) were used in all operations. The VerSys taper femoral component is a straight

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femoral component with a symmetry plane that contains the femoral component axis and the neck axis. The femoral component has two variations of the proximal metaphysis: standard (STD) and large metaphysis (LM). All patients were diagnosed with degenerative arthritis secondary to developmental hip dysplasia. Using the classification of Crowe et al.,[8] 49 hips were classified as Group I (0% to 50% subluxation), 18 as Group II (50% to 75% subluxation), and 8 as Group III (75% to 100% subluxation). The mean age of the patients at the time of total hip arthroplasty was 58 years (range, 27–76 years). After one locater pin was inserted into the greater trochanter of the affected femur and the other locater pin was inserted into the lateral condyle, CT images of the femur and the femoral condyles were taken, including of the two pins. The CT data were imported into the ORTHODOC, which was used for preoperative planning.

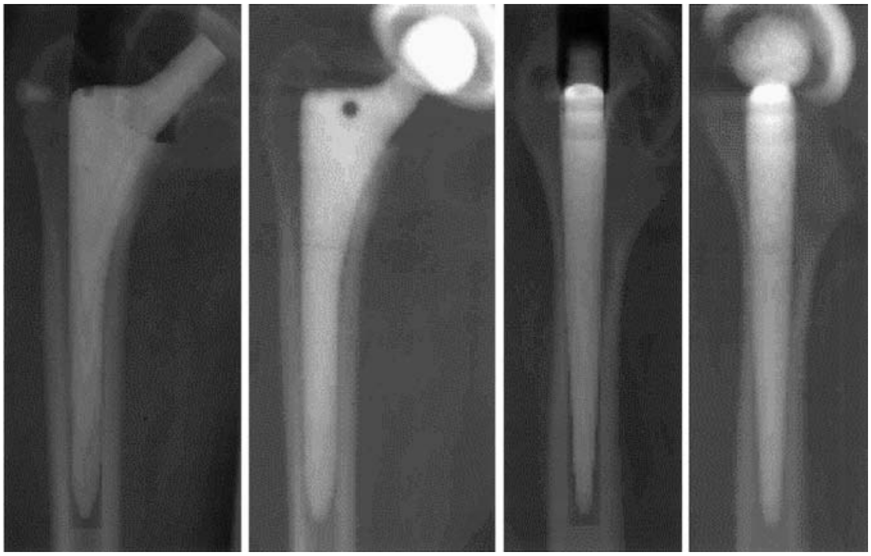
Preoperative planning of femoral components was performed as follows.[22] The ORTHODOC can show coronal, sagittal, and axial cross sections along an axis on the workstation display. The center of the femoral head was marked until a circle encompassed the femoral head contour on the coronal, sagittal, and axial views. The femur was reoriented on the workstation to obtain the coronal plane that passed through the head center and the proximal femoral medullary axis. Then, the sagittal plane through the medullary axis was obtained. Femoral components of the maximum size that would not overream the endosteal cortical bone were selected and virtually implanted into the femoral canal to achieve maximum proximal medial fit.[1,22] We then chose the type of proximal metaphysis (STD or LM) that would provide the best fit and fill in the proximal metaphysis for tight proximal fixation. Neck cut level and anteversion of the femoral component with respect to the femoral posterior condyles were not determined at first, but were later determined based on the position of the femoral component for the best fit and fill. Each preoperative plan was discussed by two of the senior authors until a consensus was obtained.

All total hip arthroplasties were performed using the ROBODOC system through the posterolateral approach, with the patient in the lateral decubitus position. After intraoperative registration using the two locater pins, the robot milled the inside of the femoral canal according to the preoperative plan. The step cut by the robotic milling coincided with the lower corner of the femoral neck cut, and was clearly visible. Surgeons inserted and impacted the femoral component manually until the junction of the HA coating and the neck was advanced to the level of the step cut. An anteroposterior conventional radiograph of the hip was taken immediately after the operation to evaluate migration between the day of the operation and 1 month after. CT images were obtained 1 month after the operation. Physical therapy with full weight bearing as tolerated was initiated on the third postoperative day.

The clinical results for each patient were assessed according to the Merle d'Aubigné hip score,[20] in which up to six points each are given for pain, motion, and gait. These scores were obtained preoperatively and 3 months postoperatively. The presence or absence of thigh or knee pain after pin implantation was recorded 3 months postoperatively. Patients were monitored for length of stay and complications, including intraoperative fracture.

Radiographic evaluation using reconstructed CT images was performed preoperatively and 1 month after total hip arthroplasty. Anteroposterior synthetic radiographs of the proximal femur parallel to the symmetry plane of the femoral component (Fig. 1), lateral synthetic radiographs of the proximal femur perpendicular to the symmetry plane of the femoral component (Fig. 1), and axial images of the femur perpendicular to the symmetry plane of the femoral component (Figs. 2 and 3) were reconstructed on the ORTHODOC from the CT data. These reconstructed CT images were created using both preoperative and postoperative CT data. The synthetic anteroposterior radiographs were used to evaluate mediolateral alignment of the femoral component (angle between the femoral component axis and the proximal femoral canal axis), medial gap between the Adams' arch,[2] the thick medial cortex of the femoral neck, and the femoral component (gap between the femoral component and the medial endocortical bone), lateral gap (gap between the femoral component and the lateral cortical bone), and mediolateral canal filling ratio of the femoral component (percentage of canal occupied by the femoral component) at the following five levels (Fig. 2): the lower corner of the femoral neck cut (level 1), the center of the lesser trochanter (level 2), 1.5 cm distal from the center of the lesser trochanter (level 3), 4.5 cm proximal from the femoral component tip (level 4), and 1.5 cm proximal from the femoral component tip (level 5). The synthetic lateral radiographs were used to evaluate anteroposterior alignment of the femoral component (angle between the femoral component axis and the proximal femoral canal axis). Axial images of the femur were used to evaluate vertical seating (vertical distance from the femoral component shoulder to the center of the lesser trochanter) and canal fill ratio of the femoral component (ratio of stem area to the total medullary cavity area) at all five levels (Fig. 3). The center of the lesser trochanter was determined as follows. The axial plane perpendicular to the femoral component axis was moved, and the coronal plane was rotated around the femoral component axis until both planes included the center of the lesser trochanter. The level of the axial

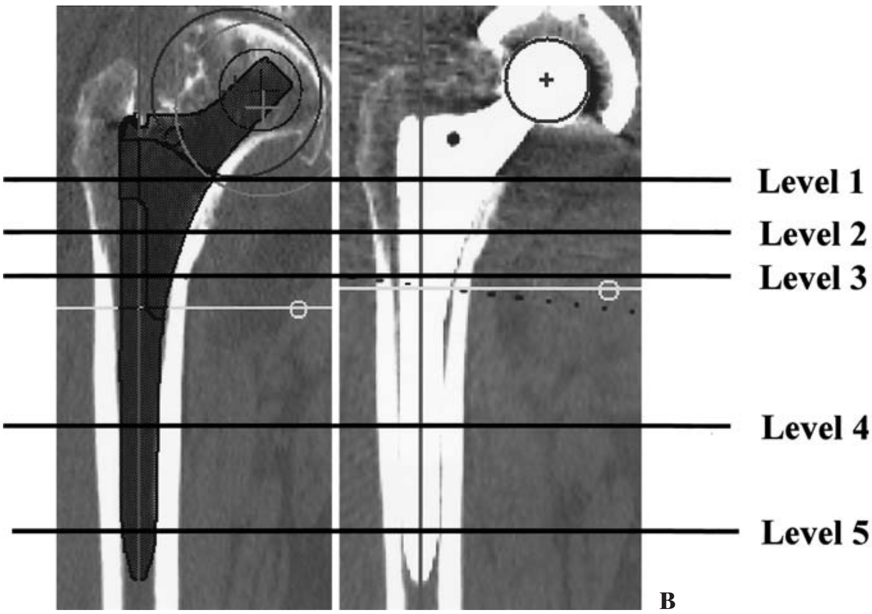
A,B



C,D

Fig. 1. A Anteroposterior synthetic radiograph from preoperative planning. **B** Anteroposterior synthetic radiograph reconstructed from postoperative computed tomography (CT) data. **C** Lateral synthetic radiograph from preoperative planning. **D** Lateral synthetic radiograph reconstructed from postoperative CT data

A



B

Fig. 2A,B. The five lines indicate levels *1* to *5*. **A** The symmetry plane of the femoral component from preoperative planning. **B** The symmetry plane of the femoral component reconstructed from postoperative CT data

plane was defined as the level of the center of the lesser trochanter, and was used for measurement of the canal fill ratio at level 2. The coronal plane was rotated around the femoral component axis to include the symmetry plane of the femoral component. The vertical distance between the lower corner of the femoral neck cut and the level of the center of the lesser trochanter was measured. The level of the center of the lesser trochanter in the synthetic anteroposterior radiograph can be defined as the lower level from the lower corner of the femoral neck cut by the vertical distance when the center of the lesser trochanter cannot be identified. Anteroposterior conventional radiographs taken immediately after the operation and 1 month postoperatively were used to calculate initial subsidence from the day of the operation to 1 month afterward. The initial subsidence was defined as the difference in vertical distance between the femoral component shoulder and the center of the lesser trochanter.

Differences between values from preoperative planning and measurements from postoperative CT images were calculated.

To analyze effects of fit, fill, and age on differences in vertical seating (planning versus actual), we compared

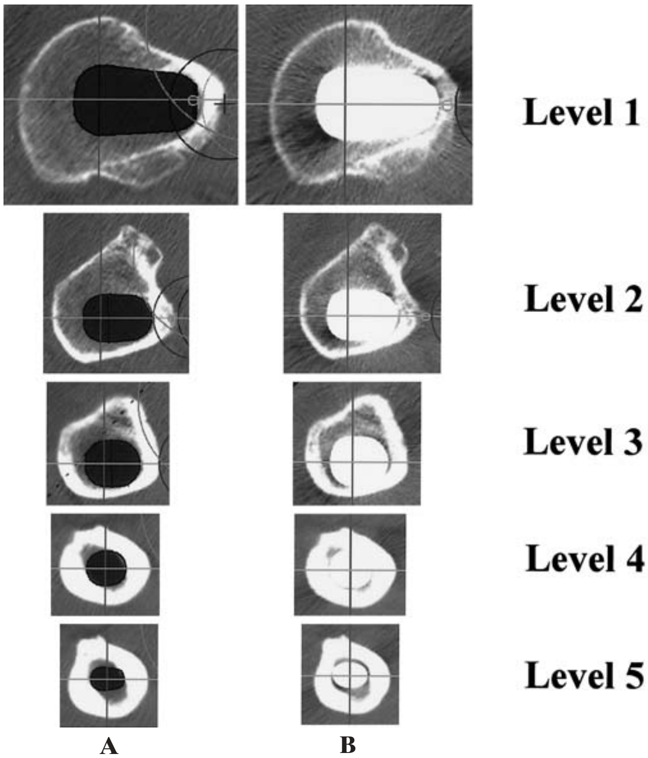


Fig. 3A,B. Axial cross-sectional images of the proximal femur perpendicular to the femoral component axis were reconstructed at levels *1* to *5*. **A** Axial images from preoperative planning. **B** Axial images reconstructed from postoperative CT data

the mediolateral canal filling ratio, canal fill ratio, and age between patients whose difference in vertical seating was 3mm or greater and patients whose difference in vertical seating was less than 3mm. Each cutoff level for discrimination between the two groups was defined as a value lower by one standard deviation than the mean of the mediolateral canal filling ratio and canal fill ratio at the respective five levels.

The Merle D'Aubigné hip score, the measurements from postoperative CT images, and the differences in measurements between preoperative planning and postoperative CT images were compared among Crowe groups I, II, and III, to analyze the effects of femur morphology on the results.

The type of the proximal metaphysis (STD or LM) and the size of each implanted femoral component were compared with those chosen in preoperative planning.

For the statistical analysis, the Fisher exact test was used to assess the significance of differences between the two groups in these categorical variables. Analysis of variance (ANOVA) followed by the Bonferroni/Dunn test was used to assess differences among Crowe groups I, II, and III. Differences were considered significant when the P value was less than 0.05.

Results

Clinical results

The mean preoperative Merle D'Aubigné hip scores were as follows: pain, 2.4 (range, 1–4); motion, 4.8 (3–6); walking, 2.8 (1–5). At 3 months postoperatively, the mean scores were 5.2 (4–6), 5.4 (4–6), and 3.7 (3–6), respectively. At 3 months, thigh pain was reported in 1 (1%) of the 75 hips. Knee pain after pin implantation was reported in 1 (1%) of the 75 hips. This knee pain had disappeared by 4 months postoperatively.

There were no significant differences in Merle D'Aubigné hip scores preoperatively or 3 months postoperatively among Crowe groups I, II, and III. Mean length of stay was 41 days (range, 22–118). There were no intraoperative femoral fractures.

Measurements from postoperative CT images

Measurements from postoperative CT images are shown in Table 1. The ROBODOC system achieved a 73.6% to 92.9% mediolateral canal filling ratio at the five levels and a 50.8% to 77.6% canal fill ratio at the five levels. There were no significant differences among Crowe groups I, II, and III in the measurements from postoperative CT images.

Differences in measurements between preoperative planning and postoperative CT images

Measurements for all hips are shown in Table 2. Mean differences in medial and lateral gaps at the five levels were less than 1mm. Mean differences in the mediolateral canal filling and canal fill ratios were less than 2%, except for the canal fill ratio at level 1. Mean differences in mediolateral and anteroposterior alignment of the femoral component were less than 1°. The mean difference in vertical seating was less than 1mm. The difference in vertical seating was greater than 3mm for two patients (patients X and Y), but was less than 3mm for all other patients (Fig. 4).

The measurements for the 73 patients whose difference in vertical seating was less than 3mm (group Z) are shown in Table 3. For these patients, the maximal differences in medial and lateral gap were less than 3mm at all five levels. Maximal differences in the mediolateral canal filling and canal fill ratios were less than 10% at all levels. Maximal differences in mediolateral and anteroposterior alignment of the femoral component were less than 3°. The mean difference in vertical seating between preoperative planning and 1 month after total hip arthroplasty was 1.1mm (95% confidence interval, 0.82–1.48). Mean initial subsidence from the day of the operation to 1 month

Table 1. Fit and fill by level and implant positioning on postoperative CT images

	Postoperative reconstructed CT images (n = 75)		
	Mean	95% CI	Range
Medial gap (mm)			
Level 1	0.44	0.40 to 0.48	0.31 to 1.15
Level 2	0.50	0.44 to 0.56	0.31 to 1.67
Level 3	0.60	0.55 to 0.66	0.31 to 1.67
Level 4	0.47	0.42 to 0.52	0.31 to 1.2
Level 5	0.75	0.68 to 0.82	0.32 to 2.0
Lateral gap (mm)			
Level 1	10.84	10.08 to 11.59	2.23 to 19.18
Level 2	4.84	4.27 to 5.42	0.78 to 14.47
Level 3	2.01	1.68 to 2.34	0.32 to 7.4
Level 4	0.46	0.41 to 0.51	0.31 to 1.20
Level 5	0.69	0.62 to 0.76	0.31 to 1.76
Mediolateral canal filling ratio (%)			
Level 1	73.6	72.2 to 75.1	58.5 to 91.5
Level 2	80.7	79.0 to 82.5	58.7 to 95.1
Level 3	86.4	84.9 to 87.9	67.6 to 94.7
Level 4	92.9	92.2 to 93.5	83.6 to 95.4
Level 5	88.3	87.7 to 89.0	81.5 to 94.7
Canal fill ratio (%)			
Level 1	50.8	49.2 to 52.4	36.4 to 70.9
Level 2	59.1	57.2 to 61.0	35.4 to 73.0
Level 3	69.1	67.1 to 71.1	46.6 to 87.5
Level 4	77.6	75.8 to 79.4	54.3 to 94.7
Level 5	61.6	59.8 to 63.4	44.3 to 78.9
Mediolateral alignment (degrees)	0.3	0 to 0.6	−1.7 to 4.3
Anteroposterior alignment (degrees)	0.5	0.2 to 0.8	−1.7 to 3.7
Vertical seating (mm)	40.3	38.7 to 41.9	20.2 to 54.0

CI, confidence interval; CT, computed tomography

Fig. 4. A Anteroposterior synthetic radiograph of the proximal femur of a 53-year-old woman from preoperative planning. **B** Anteroposterior synthetic radiograph reconstructed from CT data obtained 1 month postoperatively

postoperatively was 1.0mm (95% confidence interval, 0.61–1.38). Thus, there was no significant subsidence from the day of the operation to 1 month afterward in the 73 patients in group Z.

In Crowe groups I, II, and III, there were no significant differences in measurements between preoperative planning and postoperative CT images.

Comparison between patients X and Y and group Z

The ages of patients X and Y were 74 years and 76 years, respectively. Patients X and Y were classified as Crowe Group I. Patient X had 5.3mm initial subsidence from the day of the operation to 1 month postoperatively and 5.4mm difference in vertical seating between preoperative planning and 1 month postoperatively (Fig. 5). Patient Y had 1.5mm initial subsidence and 6.5mm difference in vertical seating between preoperative planning and postoperative CT evaluation.

Comparison of the mediolateral canal filling ratio, the canal fill ratio, and age between patients X and Y and group Z at the time of preoperative planning are shown

Table 2. Differences in measurements before elimination of patients X and Y

	Differences between pre- and postoperative CT images (n = 75)		
	Mean	95% CI	Range
Medial gap (mm)			
Level 1	0.04	0 to 0.08	−0.36 to 0.81
Level 2	0.03	−0.03 to 0.1	−0.93 to 1.03
Level 3	0	−0.08 to 0.06	−1.25 to 0.5
Level 4	−0.03	−0.07 to −0.02	−0.48 to 0.62
Level 5	0.08	0 to 0.16	−0.78 to 1.01
Lateral gap (mm)			
Level 1	−0.29	−0.61 to −0.03	−4.01 to 2.65
Level 2	−0.25	−0.55 to −0.05	−5.36 to 2.42
Level 3	−0.26	−0.45 to −0.06	−4.48 to 1.49
Level 4	−0.08	−0.12 to −0.03	−0.56 to 0.4
Level 5	0.01	−0.07 to 0.09	−1.11 to 1.03
Mediolateral canal filling ratio (%)			
Level 1	0.6	−0.04 to 1.3	−4.7 to 10.8
Level 2	1.3	0.4 to 2.3	−5.9 to 15.6
Level 3	1.8	1.0 to 2.6	−4.7 to 17.3
Level 4	1.4	1.0 to 1.8	−2.2 to 4.9
Level 5	0.1	−0.7 to 0.7	−8.3 to 5.2
Canal fill ratio (%)			
Level 1	4.4	3.6 to 5.2	−8.4 to 12.0
Level 2	0.7	−0.2 to 1.7	−8.9 to 13.7
Level 3	1.8	0.8 to 2.8	−7.6 to 12.1
Level 4	1.5	0.6 to 2.5	−5.8 to 8.6
Level 5	0.5	−0.5 to 1.6	−8.4 to 7.9
Mediolateral alignment (degrees)	0.2	0 to 0.5	−1.8 to 3.0
Anteroposterior alignment (degrees)	0.1	−0.3 to 0.4	−2.9 to 2.9
Vertical seating (mm)	0.9	0.5 to 1.3	−6.5 to 2.8

A,B

C,D

Fig. 5. A Anteroposterior synthetic radiograph of the proximal femur of a 76-year-old man from preoperative planning. **B** Radiograph taken immediately after total hip arthroplasty. **C** Radiograph taken 1 month postoperatively. **D** Anteroposterior synthetic radiograph reconstructed from CT data obtained 1 month postoperatively

in Table 4. A significantly small proportion of group Z patients had a mediolateral canal filling ratio at level 3 that coincided with that of patients X and Y (less than 80%) (Fisher exact test; $P < 0.05$). There was no such correlation between group Z patients and patients X and Y for the mediolateral canal filling ratio at any other level or for the canal fill ratio at any level. A significantly small proportion of group Z patients were of an age range that coincided with that of patients X and Y (70 years or greater) (Fisher exact test; $P < 0.05$).

Table 3. Differences in measurements after elimination of patients X and Y

	Differences between pre- and postoperative CT images (n = 73)		
	Mean	95% CI	Range
Medial gap (mm)			
Level 1	0.03	0 to 0.07	−0.36 to 0.81
Level 2	0.03	−0.03 to 0.1	−0.93 to 1.03
Level 3	0	−0.08 to 0.06	−1.25 to 0.5
Level 4	−0.03	−0.07 to −0.01	−0.48 to 0.62
Level 5	0.07	0 to 0.16	−0.78 to 1.01
Lateral gap (mm)			
Level 1	−0.20	−0.50 to 0.12	−2.85 to 2.65
Level 2	−0.15	−0.42 to 0.12	−2.62 to 2.42
Level 3	−0.18	−0.33 to −0.02	−2.13 to 1.49
Level 4	−0.07	−0.12 to −0.02	−0.56 to 0.4
Level 5	0.01	−0.07 to 0.08	−1.11 to 1.03
Mediolateral canal filling ratio (%)			
Level 1	0.4	−0.2 to 1.0	−4.7 to 5.9
Level 2	1.0	0.1 to 1.8	−5.8 to 7.9
Level 3	1.4	0.8 to 2.0	−4.7 to 6.1
Level 4	1.3	0.9 to 1.7	−2.2 to 4.9
Level 5	0.1	−0.5 to 0.8	−8.3 to 5.2
Canal fill ratio (%)			
Level 1	4.2	3.5 to 5.0	−8.4 to 9.2
Level 2	0.4	−0.5 to 1.3	−8.9 to 8.0
Level 3	1.5	0.6 to 2.5	−7.6 to 8.0
Level 4	1.4	0.5 to 2.4	−5.8 to 8.6
Level 5	0.5	−0.6 to 1.5	−8.4 to 7.9
Mediolateral alignment (degrees)	0.1	−0.1 to 0.4	−1.8 to 2.3
Anteroposterior alignment (degrees)	0.1	−0.2 to 0.4	−2.9 to 2.9
Vertical seating (mm)	1.0	0.8 to 1.4	−2.3 to 2.8

Comparison between type and size of the implanted femoral component and those chosen in preoperative planning

In all cases, we observed agreement in the type and size of the femoral component between that implanted and that chosen in preoperative planning.

Discussion

The advantages of CT images reconstructed by the ORTHODOC over conventional radiographs and nonreconstructed CT images include easy registration of the view planes between preoperative planning and postoperative results. The magnitude and direction of canal dimensions on conventional radiographs are highly variable.[12] In contrast, using CT data, ORTHODOC can reconstruct anteroposterior and lateral synthetic radiographs with constant magnitude and direction, and axial CT images with constant direction. Because the ORTHODOC program significantly reduces artifacts,[1] postoperative CT images can be used for accurate evaluation.

In the present study, we evaluated the clinical effectiveness of ROBODOC. The mean overall Merle D'Aubigné hip score improved from 10.0 (preoperative) to 14.3 (3 months postoperative). The incidence of thigh pain was 1% 3 months postoperatively. Huo et al.[16] reported a 9% incidence of thigh pain 6 weeks postoperatively in 46 hips implanted with the Zweymuller stem (Allopro, Berne, Switzerland). Burkart et al.[5] reported a 12% incidence of thigh pain 6 months postoperatively in 105 hips implanted with the Mallory-head stem (Biomet, Warsaw, IN, USA). D'Lima et al.[9] reported a 6% incidence of thigh pain 2 years postoperatively in 60 hips implanted with the Omnifit-HA stem (Stryker Howmedica Osteonics Corp, Allendale, NJ, USA). The lower incidence of thigh pain in the present study may be due to excellent initial mechanical stability with subsequent bone ingrowth. In the present study, knee pain after pin implantation was reported for 1 (1%) of the 75 hips 3 months postoperatively. Nogler et al.[24] reported that 12 (67%) of 18 patients suffered from knee pain for more than 1 month. The lower incidence of knee pain in the present study may be due to the different insertion point of the distal pin. Because the medial condyle has

Table 4. Comparison between group Z and patients X and Y

	Group Z	Patients X and Y	*P* value[a]
Preoperative planning			
Mediolateral canal filling ratio (%)			
Level 1			
≧67	59	2	
<67	14	0	NS
Level 2			
≧72	59	1	
<72	14	1	NS
Level 3			
≧80	58	0	
<80	15	2	<0.05
Level 4			
≧89	58	2	
<89	15	0	NS
Level 5			
≧85	63	2	
<85	10	0	NS
Canal fill ratio (%)			
Level 1			
≧40	62	1	
<40	11	1	NS
Level 2			
≧50	61	2	
<50	12	0	NS
Level 3			
≧58	65	1	
<58	8	1	NS
Level 4			
≧68	63	1	
<68	10	1	NS
Level 5			
≧52	60	1	
<52	13	1	NS
Age (years)			
≧70	10	2	
≦69	63	0	<0.05

NS, not significant
[a] Fisher exact test

more neural structures than the lateral condyle,[24] pin implantation in the lateral condyle (as in the present study) may result in lower incidence of nerve injury.

We evaluated measurements from postoperative CT images. The medial and lateral gaps, mediolateral canal filling ratio, and implant alignment in the present study were as good as those reported by Bargar et al.[1] In previous studies, standard cementless femoral components have achieved a canal fill ratio of only about 50%,[27] whereas the range of the canal fill ratio in the present study was 50.8% to 77.6%. The disadvantage of manual broaching (to improve canal fill) is that it may increase the risk of intraoperative femoral fracture.[27] However, milling by the ROBODOC system can achieve a high canal fill ratio using standard cementless femoral components without increased risk of intraoperative femoral fracture.

In the present study, two patients (patients X and Y) had a difference in vertical seating that was greater than 3 mm. These two patients were compared with the remaining 73 patients (group Z). A significantly small proportion of group Z patients had a mediolateral canal filling ratio at level 3 that coincided with that of patients X and Y (less than 80%) (Fisher exact test; $P < 0.05$). This suggests that the mediolateral canal filling ratio must be greater than 80% at level 3 to achieve initial fixation of the VerSys taper stem. Some authors have reported that a femoral component that achieves a high degree of canal fill is less likely to exhibit subsidence or loss,[10,27] a finding that is consistent with the present results. Eventual stability after limited subsidence may be the natural course of a tapered stem without a functional collar.[21] This early postoperative subsidence may achieve eventual mechanical stability, but can result in unexpected shorter limb length and muscle laxity on the operated side. A significantly small proportion of group Z patients were of an age range that coincided with that of patients X and Y (70 years or greater) (Fisher exact test; $P < 0.05$). Bone strength of the proximal femur decreases with advancing age.[4,18,19] Poorer bone quality due to old age may be a factor in the subsidence exhibited by patients X and Y.

The effects of femur morphology on the results were investigated. There were no significant differences among Crowe groups I, II, and III in the Merle D'Aubigné hip score, in measurements from postoperative CT images, or in differences of measurements between preoperative planning and postoperative CT images. The Crowe classification is a useful guide for the selection of femoral components. Previous findings suggest that conventional designs of femoral components are acceptable in cases classified as Crowe group I, II, or III,[28] which is consistent with the present results.

In summary, one of the advantages of robot-assisted total hip arthroplasty is lower risk of varus or valgus malposition of the femoral component, because ROBODOC can mill the medullary canal along the proximal axis of the femoral canal. Another advantage is avoidance of intraoperative femoral fracture, because the ROBODOC system can precisely mill the femoral canal according to three-dimensional preoperative planning. By contrast, one of the disadvantages is the need for a separate surgery for pin placement. In the present study, mean differences in distance and angle measurements between preoperative planning and postoperative CT images were less than 1 mm and 1°, respectively. We examined maximal differences in measurements for all patients other than patients X and Y. Maximal differences in distance and angle measurements were less than 3 mm and 3°, respectively. Maximal differences in the mediolateral canal filling and canal fill ratios at all five levels were less than 10%. Accuracy evaluation using postoperative reconstructed CT images showed that, with adequate preoperative planning, the ROBODOC system could prepare the femoral canal and implant the femoral component with a high degree of accuracy.

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