A Report on Three Consecutive Cases using Computer Tomography 3D Preoperative Planning for Conversion of Arthrodesed Hips to Total Hip Replacements

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Received: 8 April 2014/Accepted: 6 November 2014/Published online: 13 January 2015
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Abstract *Background:* Conversion of an arthrodesed hip to a total hip arthroplasty (THA) is a technically demanding procedure with high complication rates. One important issue is that determining the amount of correction for a leg length discrepancy (LLD) can be difficult at the planning stage. *Questions/Purposes:* The aim of this study is to assess the reliable use of computer tomography (CT)-based three-dimensional (3D) preoperative planning for the conversion of arthrodesed hips to THAs. *Patients and Methods:* CT-based preoperative 3D planning was used to convert three arthrodesed hips to THAs. The efficacy of the planning was evaluated with postoperative radiographic measurements involving the amount of correction for LLD, position of components, difference

between targeted and actual values, and ratio of the moment arms. The clinical assessment was performed with the Japanese Orthopaedic Association (JOA) hip score before and after THA. *Results:* The mean amount of LLD correction and median LLD after THA were 16 mm (range, 15–17 mm) and 4 mm (range, 1–10 mm), respectively. The components were implanted close to the positions recommended by the preoperative simulation. The ratio of the moment arms indicated that the converted hips were reconstructed in a biomechanically correct manner. The implants for the conversion to THA were successfully positioned with respect to anatomy and functional outcome. The median JOA hip score improved from 50 points (range, 30–66 points) preoperatively to 79 points (range, 72–86 points) at the latest follow-up. *Conclusions:* CT-based preoperative 3D planning could be a powerful guidance tool for conversion of arthrodesed hips to THAs.

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Electronic supplementary material The online version of this article (doi:10.1007/s11420-014-9423-7) contains supplementary material, which is available to authorized users.

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Keywords arthrodesed hip · leg length discrepancy · preoperative planning · total hip arthroplasty

Introduction

Hip arthrodesis is traditionally performed in young and active patients with a unilateral, severely arthritic hip joint. Between 10 and 21% of patients with arthrodesed hips eventually request conversion to a total hip arthroplasty (THA) because of an unwillingness to accept the functional impairment in activities of daily living (ADL) [3, 4, 10, 12, 14]. The limitations in ADLs and degeneration of adjacent joints are primarily caused by the leg length discrepancies (LLDs) associated with long-term malposition of the affected limb [5, 10, 14]. Conversion of hip arthrodesis to THA can restore function in the arthrodesed hip joint and relieve pain in other joints. However, the operation is technically difficult with high complication rates (5–54%) because of

Fig. 1. Radiographs of case 3. **a** A preoperative radiograph of the 64-year-old woman who had a hip arthrodesis for dysplastic osteoarthritis at 48 years of age. Marked pelvic obliquity and an extreme malpositioned limb with flexion-adduction contracture were observed with the upright position. The sole of the affected limb could not be contact with the ground. The left femur was fused in the arthrodesis position at 5° of flexion, 15° of adduction, and 40° of internal rotation, with a 25-mm discrepancy in the leg length. **b** A preoperative radiograph. The X-ray of the pelvic ring showed an asymmetrical oval shape, which reflected pelvic rotation. **c** A postoperative radiograph. The acetabular cup was placed in the anatomical position with adequate leg lengthening. **d** A postoperative radiograph. The knee joint line of the affected limb was similar to the contralateral side due to recovery of the contracture.

the presence of anatomical abnormalities or poor hip abductor function [1, 2, 4, 7–9, 11, 14]. The correction of LLD, the restoration of the hip abductor mechanism with adequate leg lengthening, and the precise implantation of the acetabular component in the correct location are important goals for this operation. Several technical difficulties can arise in relation to these various steps. First, the determination of the osteotomy line of the femoral neck to expose the acetabulum and femur is difficult. This step is critical since the greatest possible preservation of the greater trochanter is important for restoring the abductor mechanism of an arthrodesed hip. Second, implanting the acetabular cup on the original hip center can be difficult because of the distorted anatomy of the fused hip joint. In particular, distinguishing the original acetabulum edge can be challenging given the presence of the fused femoral head within the native acetabulum after the femoral neck osteotomy. Third, LLD is often caused by subsequent malposition with flexion-adduction contracture and marked pelvic obliquity. At the stage of planning the THA, LLD resulting from a malpositioned limb complicates the precise leg lengthening and placement of the components. Using conventional X-ray templating or computer tomography (CT)-based two-dimensional (2D) preoperative planning, surgeons can experience difficulty or find it impossible to determine the femoral cut line, the exact location of the native acetabulum, or the amount of leg lengthening required for the patient. A previous study has reported that careful preoperative planning is essential for anticipating these problems [1]. As part of an effort to improve our preoperative planning stage, we used CT-based three-dimensional (3D) preoperative planning for the precise implantation of components in converting arthrodesed hips to THAs.

The study aimed to analyze the efficacy of CT-based 3D preoperative planning for the conversion of arthrodesed hips to THAs.

Surgical Technique

All procedures for the conversion of arthrodesed hips to THAs were performed through an anterolateral approach with the patient in the lateral decubitus position. Before osteotomy of the femoral neck, the anterior part of the articular capsule was completely removed to expose the site of fusion between the pelvis and femoral head. The femoral neck osteotomy was carefully performed with an oscillating

saw in accordance with the preoperative 3D image (Fig. 1d). We determined the osteotomy line of the femoral neck by referring to the landmarks measuring the distance from the lesser trochanter. Next, the remaining part of the articular capsule was removed to expose the entire margin of the original acetabular rim. After removal of the fused femoral head, a full view of the true acetabulum was obtained with a Charnley horizontal retractor and a cobra-type retractor under the inferior lip of the acetabulum. We determined the position of the acetabular cup by referring to the landmarks measuring the distance from the inferior lip of the acetabulum. The inferior lip of the acetabulum was confirmed through the pole vertically standing in the obturator foramen. The acetabular reaming was also carefully performed in accordance with the preoperative plan. The depth of the acetabular reaming was confirmed with a Kelly clamp during reaming in order to prevent perforation of the pelvic cavity. The measured data and the reference 2D- and 3D-visualized information of the preoperative cup positioning were compared. When broaching the femur, careful consideration was given to the malposition of the affected limb. It was important that the assistant maintained the neutral position of the femur.

Patients and Methods

We reviewed the medical records and radiographs of the subjects after approval of this study by the institutional review board committee. From March 2008 to June 2011, we converted three arthrodesed hips in three women to THAs using CT-based preoperative 3D planning (Fig. 1a–c). The operation was either performed or supervised by three members of the orthopedic staff at a single orthopedic institution. The diseases leading to arthrodesis were congenital dislocation (cases 1 and 3) (Figs. 1a, b and 3a–c) and tuberculosis (case 2) (Fig. 4a–c). Case 1 was reported in a previous study by different authors [11]. At the conversion, the patients' ages ranged from 59 to 64 years and had had an arthrodesed hip for a minimum of 20 years up to 48 years. The median duration of follow-up was 4.6 years (range, 3.0–6.3 years). The main indication for conversion was disabling low back pain (cases 1 and 3), ipsilateral knee pain (case 3), and restriction of gait and ADL because of immobility or malposition (all three cases) (Table 1).

Table 1 Preoperative results of the three study patients

Case	Age at arthrodesis	Indication of arthrodesis	Age at THA	Chief complaint	Other operations	Position of arthrodesed hip (deg)	LLD (mm)
1	21	CDH	59	Limit. of ADL, LBP	L4/5 PLIF	Flexion 20 Adduction 5 External rotation 10	17
2	20	Tuberculosis	64	Limit. of ADL, knee pain		Flexion 10 Adduction 10 External rotation 0	21
3	48	CDH	64	Hip pain, Limit. of ADL LBP	Right THA	Flexion 5 Adduction 15 Internal rotation 40	25

CDH congenital hip dislocation, *Limit* limitation, *ADL* activities of daily living, *LBP* low back pain, *PLIF* posterior lumbar interbody fusion, *LLD* leg length discrepancy, *THA* total hip arthroplasty

The affected limbs were fused at 5° to 20° of flexion, 0° to 15° of adduction, and −10° to 40° of internal rotation. The LLDs ranged from 17 to 25 mm (average, 21 mm). For case 1, the CT-based navigation software was also used (Vector Vision Hip ver 2.5.1, Brain Lab, Munich, Germany). Three screws were inserted from the proximal femur to achieve arthrodesis in this patient (Fig. 3a–c), and the screw heads provided good landmarks as based on the preoperative planning using the CT-based computer navigation system. In two patients, cemented THAs (K-MAX CLHO cup and PHS type 6 straight stem or HS-3 taper stem, Kyocera Medical

Ltd) were implanted (Figs. 2c, d and 3d–f). In the other patient (case 2), a hybrid THA (AHFIX Q3 cup and HS-3 taper stem, Kyocera Medical Ltd) was implanted because a large notch into the inferior site of the acetabulum was made when cutting the femoral neck using an oscillation saw. Following pin fixation of the acetabulum in this patient, a cementless cup was implanted to avoid a cement leak into the pelvis (Fig. 4d–f).

Radiographic and clinical evaluations were performed preoperatively and postoperatively. The positions of the components were measured by a single observer. The

Fig. 2. Representative preoperative planning (case 3) using the software “3D template” and intraoperative photographs after separation of a fused hip joint. **a** Simulation of the femoral neck osteotomy and positioning of the acetabular cup. **b** The three-dimensional (3D) image after virtual reduction in an upright position. **c** An enlarged 3D image of the femoral neck revealing the configuration of the cut line. **d** The intraoperative photograph after cutting of the arthrodesed hip joint. The femoral neck osteotomy was performed as planned using the 3D image. Behind the femoral neck, the original acetabular filled with a fused femoral head can be seen.

LLD, leg lengthening, inclination angle of the cup, and distance from the cup center were measured based on digital anteroposterior radiographs. Anteversion angle of the stem and cup was measured by CT images. The largest cup diameter on an axial plane was identified, and the anteversion was measured. Similar anteversion of the stem was measured. For determining the accuracy of the biomechanical restoration, the abductor moment arm (Ab) and the moment arm center of gravity (CG) were measured as described previously [8]. The ratios of the two measurements (Ab/CG) on the treated and contralateral sides were compared. The center of the cup was also compared with that of the contralateral side. Measurements for the biomechanical analysis were made on the anteroposterior radiograph of the pelvis that was considered the best quality (in terms of rotation projection) for that purpose.

Hip functional results were rated according to the Japanese Orthopaedic Association (JOA) hip score, which is based on pain (40 points), range of motion (20 points), walking ability (20 points), and ADL (20 points). Clinical results were grouped by JOA hip score with a maximum of 100 points [13]. The range-of-motion score was assessed by measuring the flexion and the abduction angle. The pain score was assessed as follows: no pain (40 points), slight pain just after a long walk (30 points), moderate pain while walking (20 points), infrequent resting pain (10 points), and continuous resting

pain (0 points). The ADL score was assessed using five modes, including sitting, standing, working, squatting, walking up stairs, and public transportation.

Results

We succeeded in performing the femoral neck osteotomy and preparation of the acetabulum. The median operative time was 140 min (range, 138–264 min), with a median blood loss of 498 mL (range, 298–717 mL).

On the postoperative radiographs and CT images (Figs. 2c, d, 3d–f, and 4d–f), the median inclination and anteversion of the acetabular cup were 42.1° (range, 42.0 – 47.0°) and 12.5° (range, 9.0 – 13.1°), respectively. The median anteversion of the femoral stem was 13.0° (range, 13.0 – 18.7°), and the median amount of correction for the LLDs ranged from 1 to 10 mm. The differences between the postoperatively determined median values and simulated values were -2.9° (range, -3.0 – -2.0°) in the inclination angle of the acetabular cup, $+2.5^\circ$ (range, -1.0 – 3.1°) in the anteversion angle of the acetabular cup, and -2.0° (range, -2.0 – 3.7°) in the anteversion of the femoral stem. The median arc of flexion after THA was 70° (range, 60 – 75°), while the median arc of abduction-adduction was 40° (range, 25 – 40°). The median JOA hip score improved from

Fig. 3. Radiographs and computed tomograms of case 1. **a** A preoperative radiograph of the 59-year-old-woman who had a hip arthrodesis for dysplastic osteoarthritis at 21 years of age. Preoperative computed tomograms (**b** coronal section and **c** axial section) are shown. Three screws were inserted from the proximal femur at the operation of arthrodesis. **d** A postoperative radiograph and computed tomograms (**e** coronal section and **f** axial section) are shown. The leg length discrepancy was improved.

Fig. 4. Radiographs and computed tomograms of case 2. **a** A preoperative radiograph of the 64-year-old-woman who had a hip arthrodesis for tuberculosis at 20 years of age. Preoperative computed tomograms (**b** coronal section and **c** axial section) are shown. **d** A postoperative radiograph and computed tomograms (**e** coronal section and **f** axial section) are shown.

50 points (range, 30–66 points) preoperatively to 79 points (range, 72–86 points) at the latest follow-up (Table 2). The median distance from the center of the socket to the vertical teardrop line was 30.8 mm (range, 29.0–33.6 mm), and the median distance from the center of the cup to the horizontal teardrop line was 25.9 mm (range, 20.4–26.8 mm). The vertical height of the reconstructed acetabulum was a median of 8.8 mm (range, –7.7–10.4 mm) more than that of the contralateral acetabulum. The horizontal width of the reconstructed acetabulum was a median of 2.7 mm (range, –2.4–5.2 mm) less than that of the contralateral acetabulum. The three acetabulum cups were implanted on the original hip center. The ratios of the two measurements (Ab/CG) on the treated and contralateral sides were similarly a median of 0.45 (range, 0.41–0.49) and 0.45 (range, 0.45–0.48) (Table 3).

One patient (case 2) started walking with partial weight bearing 5 weeks after THA, while the other patients (cases 1

and 3) started rehabilitation with full weight bearing 2 days after THA. At the final follow-up, one patient (case 2) required a cane full time, while the other two patients (cases 1 and 3) sometimes used a cane when going out of doors. For case 2, the Trendelenburg test score remained positive. All patients had functional improvement of walking ability and ADL. No postoperative complications were observed at the latest follow-up. Symptomatically, low back pain (cases 1 and 3) and knee pain (case 2) were relieved. No surgery was needed for the back or knee after conversion to THA.

Discussion

In the present cases, the correction of the LLDs and best possible restoration of the hip abductor mechanism were needed. Thus, careful preoperative planning for precise implantation was essential for overcoming these problems [1,

Table 2 Preoperative and postoperative results of the three study patients

Case	Cup: inclination/ anteversion (°)	Stem: anteversion (°)	Pre-THA JOA scores (points)	Post-THA JOA scores (points)	Leg lengthening (mm)	Post-THA LLD (mm)
1	47.0/12.5	13.0	50	72	16	1
2	42.0/9.0	13.0	66	79	17	4
3	42.1/13.1	18.7	30	86	15	10

LLD leg length discrepancy, JOA Japanese Orthopaedic Association, THA total hip arthroplasty

Table 3 Measurements of biomechanical restoration

Contralateral side						Conversion side				
Case	Ab (mm)	CG (mm)	Ab/CG ratio	H (mm)	W (mm)	Ab (mm)	CG (mm)	Ab/CG ratio	H (mm)	W (mm)
1	47.3	97.7	0.48	16.4	33.5	37.2	90.1	0.41	26.8	30.8
2	42.8	94.7	0.45	17.1	31.2	40.3	88.3	0.45	25.9	33.6
3	49.7	107.9	0.46	28.1	34.2	50.2	101.4	0.49	20.4	29.0

The contralateral side of case 3 received THA for osteoarthritis, and the data were obtained from X-ray before the osteoarthritic changes started. *Ab* abductor moment arm (measured from the tip of the greater trochanter to the center of the femoral head), *CG* moment arm of the center of gravity (measured from the center of the femoral head to the center of the pelvis [the pubic symphysis]), *H* vertical height of the acetabulum (measured from the center of the femoral head to a horizontal line drawn along the distal edges of the pelvic tear drops), *W* horizontal width of the acetabulum (measured from the center of the femoral head to a vertical line drawn along the distal edges of the pelvic tear drops)

8, 9]. During the planning of conventional primary THA, we typically used CT-based 2D preoperative planning as described previously [6]. However, in the present study, the affected hip joints were fused in extreme malposition in the adduction-flexion directions, which would have complicated the adjustment of leg length even using CT-based 2D preoperative planning. CT-based 3D preoperative planning possesses several advantages relative to CT-based 2D preoperative planning, as well as X-ray templating (Table 4). One important advantage of CT-based 3D preoperative planning is that the precise distance for lengthening the leg in an upright position can be calculated automatically. However, the most significant difference between 3D and 2D planning was that the input settings of the parameters for the 3D planning were coordinated between the parameters for axial rotation and the 2D plane view. The CT-based 3D preoperative planning released the surgeon from considering many complex parameters associated with severe malposition or LLD and provided an easily usable simulation of THA on visualized 3D images, which were also helpful in conducting the operation. In particular, the visualized 3D images provided powerful guidance for the greatest possible preservation of the greater trochanter during the cutting of the femoral neck.

Biomechanical restoration is considered difficult in the conversion of arthrodesed hips to THAs but can be obtained through the construction of a prosthetic offset to match the abductor moment arm with the moment arm at the pelvic center of gravity. Thus, the placement of the acetabular cup in its anatomical position is highly important, especially in the presence of abductor weakness [2, 7–9]. We determined the position of the prosthesis using intraoperative measuring techniques. The osteotomy line of the femoral neck, the vertical height of the acetabulum, and the medialization of

the cup were measured by various methods. The intraoperative measurements were compared with the reference 2D- and 3D-visualized information. In the present study, the ratios of two moment arms (*Ab/CG*) were restored to values equivalent to the contralateral ratio. Kilgus et al. reported that no patients in whom the ratio (*Ab/CG*) of the reconstructed hip was 10% less than that of the contralateral (normal) hip had a negative Trendelenburg test [8]. In our case, one patient using a cane had a positive Trendelenburg test. The alignments of the components were also close to the simulated values. The assessment of the radiographic measurements indicated that the acetabulum cups were implanted correctly with respect to both the anatomy and functional position. Although 5 mm of the LLDs remained, the patients had functional improvement and satisfaction. For the perfect correction of LLD, trochanteric advancement was required; however, the use of the trochanteric approach was declined. Moreover, all patients had effective pain relief in the neighboring joints. However, the range of motion was worse than that reported in other studies [4, 7, 8] and might be related to the routine adductors and iliopsoas tenotomies. Moreover, in one patient, intraoperative fracture of the acetabulum occurred when cutting the femoral neck.

Although few reports have been published on the use of highly accurate navigation systems for the conversion of an arthrodesed hip to a THA, a CT-based navigation system is a preferred solution for reducing the incidence of intraoperative complications [1]. In this study, the planning software programmed by the industrial maker of the THA components was free and easy to use. Because conversion arthroplasty is technically more demanding compared to routine THA, the preoperatively generated 3D-visualized information was useful during the cutting of the arthrodesed femoral neck and provided very reassuring assistance during

Table 4 Comparisons of various parameters between different visualization techniques during the preplanning stage for conversion to THA

Parameter	X-ray templating	CT-based 2D planning	CT-based 3D planning
Selection of suitable components: acetabular cup/femoral stem	×/○	○/○	○/○
Acetabular cup: anteversion angle/inclination angle	×/○	○/○	○/○
Pelvic rotation/pelvic tilt	×/○	△/○	○/○
Correction of femoral rotation	×	×	○
Simulating leg lengthening	×	×	○

× impossible, △ difficult, ○ possible

the operation. In particular, CT-based preoperative 3D planning was helpful for surgeons performing conversion arthroplasty for the first time. In the present study, one patient (case 3) was operated by a surgeon performing conversion arthroplasty for the first time. In conclusion, CT-based preoperative 3D planning is a powerful guidance tool for identifying the site for the femoral neck osteotomy, the anatomical placement of the acetabular cup, and correction of the LLD when converting arthrodesed hips to THAs.

Disclosures

Conflict of Interest: Yutaka Kuroda, MD, PhD, Haruhiko Akiyama, MD, PhD, Manabu Nankaku, BS, MS, Kazutaka So, MD, PhD, Koji Goto, MD, PhD and Shuichi Matsuda, MD, PhD have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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