No functional impairment after Robodoc total hip arthroplasty

Gait analysis in 25 patients

Christian M Bach[1], Peter Winter[1], Michael Nogler[1], Georg Göbel[2], Cornelius Wimmer[1], and Michael Ogon[1]

Departments of [1]Orthopaedic Surgery, [2]Biostatistics, University of Innsbruck, Anichstrasse 35, AT-6020 Innsbruck, Austria. E-mail: christian.bach@uibk.ac.at
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ABSTRACT – The Robodoc total hip replacement procedure requires a wider exposure of the proximal femur, especially of the greater trochanter, than the standard procedure. Moreover, the leg must be placed in a rigid leg-holder apparatus to obtain fixation in maximal hip adduction and external rotation. This may impair the hip abductors and reduce hip abduction in the mid- and terminal stance phase of the cycle. In this study we compared patients after Robodoc and conventional total hip arthroplasty with three-dimensional gait analysis (VICON System, Oxford Metrics, Oxford, U.K.) to assess the kinematics of the pelvis and hip. 25 patients underwent total hip replacement by means of the Robodoc total hip arthroplasty system, 25 patients were treated with conventional total hip replacement, and 40 healthy volunteers served as controls. None of the patients undergoing total hip replacement, robotic or conventional, obtained normal kinematic gait patterns 6 months after surgery. However, the reduction in hip abduction did not differ significantly in patients undergoing robotic or conventional total hip arthroplasty, which suggests that the robotic procedure did not impair hip abductor function more than the conventional method.

Robotic instrumentation systems have been introduced to increase the precision of total hip replacement. The Robodoc system (Integrated Surgical Systems, Davis, CA (ISS)) was thought to be safe and effective in producing radiographically better implant fit and positioning, while eliminating fractures (Bargar et al. 1998).

Nevertheless, drawbacks should also be considered. The Robodoc procedure requires an extended approach to the hip joint, a wider exposure of the proximal femur, especially of the greater trochanter, and leg-holder equipment to obtain rigid fixation of the leg and thus facilitate an accurate registration and cutting maneuver. The combination of wide exposure and prolonged fixation of the leg in a fixed adduction and external rotation position may damage the hip abductors as compared to the standard procedure.

The hip abductor muscles are considered important for gait and biomechanics of the hip joint. The gluteus minimus muscle, along with the gluteus medius, play an important role in hip abduction during gait, and stabilization of the pelvis (Kumagai et al. 1997). Impairment of the hip abductors may reduce hip abduction in the mid- and terminal stance phase of the cycle.

We assessed kinematic function after Robodoc total hip arthroplasty, using three-dimensional gait analysis to see whether patients undergoing Robodoc total hip replacement have reduced hip abduction in the mid- and terminal stance phase of the cycle compared to the conventional procedure.

Patients and methods

Starting in March 1999, a consecutive series of patients scheduled for total hip replacement was given the opportunity to be operated on by the Robodoc system or by the conventional method.

After 25 patients had joined the Robodoc group or the conventional group, recruitment was stopped. 25 patients (14 men) underwent total hip replacement using the Robodoc system (robotic group). Their mean age was 65 (45–78) years at the time of surgery. According to the Charnley classification, 12 patients were in class A, 9 in class B, and 4 in class C. Another 25 patients (12 men) were treated with conventional, cementless total hip replacement (conventional group). Their mean age was 68 (40–82) years at the time of surgery. In this group, 11 patients were in class A, 11 in class B, and 3 in class C. The preoperative diagnosis was osteoarthrosis in all patients.

Cementless total hip replacement was performed using the Duraloc cup (DePuy, Warsaw, IN, USA) and the Osteoloc stem (Howmedica, Rutherford, NJ, USA). We used a transgluteal approach (Bauer et al. 1979, Bauer and Russe 1984) with a skin incision ranging between 12 and 17 cm. However, the Robodoc procedure required a wider exposure of the proximal femur, especially of the greater trochanter, and partial detachment of the gluteal muscles. This was necessary because the Robodoc cutter proceeds straight into the intramedullary canal, which requires partial removal of the greater trochanter. Moreover, the leg must be placed in a rigid leg-holder apparatus to obtain fixation in a position of maximal hip adduction and external rotation to allow an accurate registration and cutting maneuver.

All patients had an uneventful postoperative course. They were discharged after a mean hospital stay of 11 (9–14) days. They were advised to maintain partial weight bearing with two crutches for 6 weeks and one crutch for 12 weeks from index surgery.

All patients underwent three-dimensional gait analysis (VICON System, Oxford Metrics, Oxford, U.K.) for dynamic assessment of pelvic and hip motion. Gait analysis was made 6 months after surgery because it has been shown that functional improvement is most evident in the first three to 6 months after surgery. Only small changes occurred during the following months (Mattsson et al. 1990, Skinner 1993).

The system consisted of five infrared light emission sources and a 5 camera data capture system, allowing a maximal frequency of 50 Hertz. This frequency was employed for all measurements. A body surface marker system was used to identify movements of the pelvis and hip. A total of five steps was recorded for each subject. After the measurements data were sent to a personal computer for further evaluation with a specific software program (VICON Clinical Manager, Oxford Metrics, Oxford, U.K.). The reproducibility of the gait analysis system has been assessed previously (Kadaba et al. 1989, Winter 1991, Eng and Winter 1995).

We recruited 40 healthy volunteers having no neuromuscular or skeletal disease, gait abnormality or previous on surgery a lower extremity for a control group. The volunteers consisted of two groups based on their age. The "normal elderly" consisted of 20 subjects with a mean age of 61 (41–70) years in whom gait data had been recorded previously. The "young controls" consisted of 20 volunteers with a mean age of 25 (20–32) years.

As the current analysis focused on movements of the pelvis and hip, the main gait parameters were: pelvic tilt (sagittal plane), pelvic obliquity (frontal plane), hip flexion/extension (sagittal plane), and hip abduction/adduction (frontal plane) (Tables 1 and 2). To permit proper group comparisons, the minima, maxima, and means were calculated individually for each gait parameter. The analysis was done for the whole cycle or for the stance, and swing phases separately. Analysis of variance was used to calculate the significance of the differences of the means. Post-hoc comparisons between groups were done by using pairwise t-tests with the Bonferroni correction. The SPSS software package was used for statistical analysis (SPSS for Windows, Version 9.0, SPSS, Chicago, Illinois, USA).

Results

Group comparisons

No differences were found between the robotic group, the conventional group, and the controls as regards age ($p = 0.09$) and gender ($p = 0.1$). Table 3 shows the clinical data that we assessed in the first groups. Likewise no significant differences were detected between the individual parameters ($p > 0.06$), or between the "young" and "elderly"

Table 1. Minima, maxima, and means calculated for pelvic and hip motions in the robotic, conventional, and control groups (all values in degrees)

Gait parameter	Statistic	Gait event	Control group	Robodoc group	Conventional group
Pelvic tilt	Mean	Stride	10.6	6.4	6.1
Pelvic obliquity	Minimum	Stride	–4.2	–2.2	–1.7
	Maximum	Stride	4.2	1.8	2.2
	Mean	Stride	0	0.1	0.3
Hip flexion	1st maximum	Stance	32.0	22.7	21.2
	2nd maximum	Swing	31.9	24.4	21.7
Hip extension	Minimum	Stance	–9.1	–13.2	–9.2
Hip adduction	Mean	Stance	1.9	3.3	3.1
Hip abduction	Minimum	Swing	–7.1	–1.4	–1.1
	Mean	Swing	–3.4	0.2	1.1

Table 2. Analysis of variance was used to calculate the significance of the differences in the means. Post-hoc comparisons between groups (robotic, conventional, and control) were done by using pairwise t-tests with the Bonferroni correction

Gait parameter	Statistic	P-value		
		Conventional versus controls	Robodoc versus controls	Robodoc versus conventional
Pelvic tilt	Mean	0.008	0.01	0.9
Pelvic obliquity	Minimum	< 0.001	0.005	0.9
	Maximum	0.004	< 0.001	0.9
	Mean	0.9	0.9	0.9
Hip flexion	1st maximum	< 0.001	< 0.001	0.9
	2nd maximum	< 0.001	0.002	0.6
Hip extension	Minimum	0.9	0.2	0.3
Hip adduction	Mean	0.6	0.4	0.9
Hip abduction	Minimum	< 0.001	< 0.001	0.9
	Mean	< 0.001	< 0.001	0.9

controls in the kinematic measurements of the pelvis, hip, knee, and ankle ($p > 0.08$).

Pelvic motion

Pelvic motions in the sagittal and frontal planes were similar in the robotic and conventional groups ($p = 0.9$). The results are summarized in Tables 1, 2 and Figure 1.

Hip motion

Hip flexion in stance and swing was significantly reduced in the robotic and conventional groups, as compared the control group. Maximal flexion of the hip in the early stance phase was reduced to 23° in the robotic group ($p < 0.001$) and to 21° in the conventional group ($p < 0.001$) (control group: 32°). In the late swing phase, maximal hip flexion was reduced to 24° in the robotic group ($p = 0.002$) and to 22° in the conventional group ($p < 0.001$) (control group: 32°).

Maximal hip abduction was significantly reduced in both arthroplasty groups. In the robotic group, maximal hip abduction was 1.4° ($p < 0.001$). In the conventional group, maximal abduction was 1.1° ($p < 0.001$) (controls: 7.1°).

No significant differences were found between the robotic and conventional groups ($p = 0.3$ to $p = 0.9$) in hip motion in the sagittal and frontal planes. The measurements of hip motion are summarized in Tables 1, 2 and Figure 2.

Discussion

The Robodoc system is thought to be safe and effective in producing radiographically better implant fit and positioning while eliminating fractures (Bargar et al. 1998). Since its introduction, the procedure has been performed in more than 5,000 patients (Taylor 1993, Borner et al. 1997a, b, Bargar et al. 1998, Jerosch et al. 1998).

It was our aim to exclude potentially adverse effects of the robotic procedure before routinely using it in the authors' institution. We hypothesized that the more extended exposure of the hip and the fixation of the leg in maximum adduction and external rotation in a rigid leg-holder apparatus may impair hip abductor function more than the conventional procedure. Impairment of the hip abductors may reduce hip abduction in the mid- and terminal stance phase of the cycle during gait.

This study was consecutive, but not randomized. A limitation of the test method is that patients were

Table 3. Comparison of various parameters of the patients in the robotic and conventional groups

Parameter	Robotic group	Conventional group
Number of patients	25	25
Mean age	65	68
Gender		
Female	11	13
Male	14	12
Charnley classes		
A	12	11
B	9	11
C	4	3
Preoperative diagnosis		
Osteoarthrosis	25	25
Rheumatoid arthritis	0	0
Other	0	0
Prosthesis		
Cementless	100%	100%
Leg length discrepancy		
Yes	40%	33%
No	60%	67%
Walking ability		
> 30 minutes	60%	71%
< 30 minutes	40%	29%
Mean passive hip flexion	101°	97°
Mean passive hip abduction	34°	37°
Hip abduction strength		
Mean duration of active hip abduction in the lateral position	39 s	42 s
Trendelenburg sign		
Positive	5	3
Negative	20	22

studied with gait analysis only after they underwent a hip arthroplasty. The measurements were compared with the data obtained from a control group. However, it may be more accurate to study the patients before surgery and then use them as their own controls.

In the present study, the authors used a control group to exclude age-related changes in gait. No statistically significant differences were found between the "young" and "elderly" controls and this accords with the findings in the literature (Murray et al. 1964, Finley et al. 1969).

The Trendelenburg test is a standard static test for gluteal insufficiency. At least four methods of performing the Trendelenburg test have been described but hardly anybody has explained how the test should be interpreted (Hardcastle and Nade 1985). Functional assessment is important and gait analysis is probably performed less often than it should be (Hardcastle and Nade 1985). Despite the controversial (Berman et al. 1987, Kelman et al. 1989) claim by Andersson et al. (1981) that "the information obtained in a sophisticated gait laboratory is of limited value to a surgeon in a clinical assessment", gait analysis is the only objective way to evaluate the clinical performance of a knee or hip prosthesis (Skinner 1993). Berman et al. (1987) stated that quantitative kinesiological measures are essential for objective evaluation of function.

Three-dimensional, dynamic movement of the pelvis and hip during level walking is complex. Normal hip motion in the sagittal plane includes hip flexion of about 35° on initial contact. The hip continues to extend until the end of terminal stance. After maximal extension at the end of terminal stance, the hip continues to flex until mid swing, at which time flexion remains constant until initial contact (Gage 1991). Hip flexion was significantly reduced in stance and swing in patients in both arthroplasty groups. Nevertheless, they were all able to flex the hip at least 85° on clinical examination, dynamic hip flexion was reduced to 24° (robotic group) and 22° (conventional group) in the swing phase of the cycle. No statistically significant differences were detected between the robotic and conventional groups. The authors cannot explain this loss of dynamic range of motion during gait. However, our findings show that dynamic assessment may add additional information which can not be obtained by standard methods of measurement.

In the frontal plane, at mid-stance during single support, the ground reaction forces act to drop the pelvis on the unsupported (swing) side. This must be resisted by the hip abductors. Eccentric action of these muscles produces a slight drop of about 5° of the pelvis on the swing side. This reverses at terminal stance as concentric action of the hip abductors levels the pelvis. The hip abductors remain active until preswing, and the onset of double support (Gage 1991). This pattern of dropping in swing and rising in stance was not found in patients with a total hip replacement. These patients had a "stiff" gait with little motion of the pelvis around the neutral level (Figure 1).

In the early stance phase, the hip normally is adducted. In mid- and terminal stance, the hip increases the abduction motion (Figure 2). Maxi-

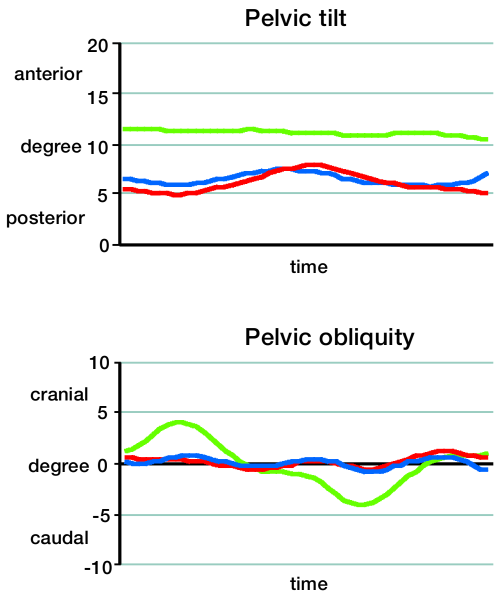

Figure 1. Pelvic motions (sagittal plane: pelvic tilt, frontal plane: pelvic obliquity) in the robotic group (red), conventional group (blue), and the control group (green), assessed by three-dimensional gait analysis.

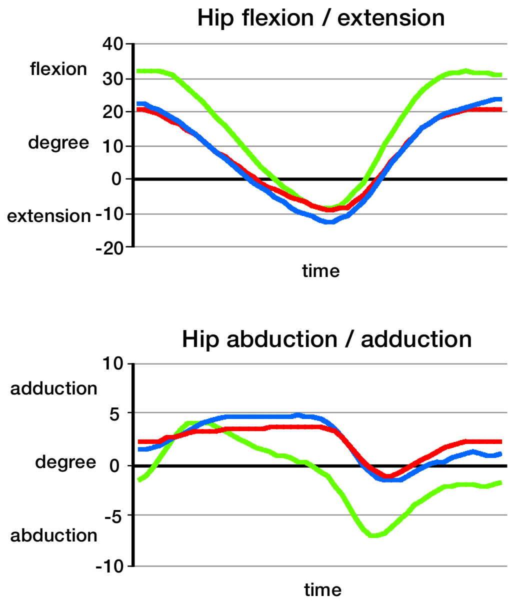

Figure 2. Hip motion (sagittal plane: hip flexion/extension, frontal plane: hip adduction/abduction) in the robotic group (red), conventional group (blue), and the control group (green), assessed by three-dimensional gait analysis.

mal hip abduction is achieved at terminal stance and early swing phase. In the control group, this maximal hip abduction was 7°. Patients in both the robotic and conventional groups, did not achieve this pattern of hip abduction in mid- and terminal stance. Their hips stayed adducted in mid-stance and reached a significantly diminished abduction in late stance and early swing (Figure 2). This gait pattern may indicate dysfunction of the gluteal muscles due to the surgical (transgluteal) approach.

None of the patients undergoing total hip replacement via a transgluteal approach, robotic or conventional instrumentation, achieved a normal gait pattern at six months after surgery. Both groups of patients showed less hip abduction in the mid- and terminal stance phase of the cycle. However, the reduction in of hip abduction did not differ significantly in patients undergoing robotic or conventional total hip arthroplasty, indicating that the robotic procedure had not impaired hip abductor function more than the conventional method.

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