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Primary and Revision Total Hip Replacement Using the Robodoc® System

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The ROBODOC® system was designed to address potential human errors in performing cementless total hip replacement. The system consists of a preoperative planning computer workstation (called ORTHODOC) and a five-axis robotic arm with a high speed milling device as an end effector. The combined experience of the United States Food and Drug Administration multicenter trial and the German postmarket use of the system are reported. The United States study is controlled and randomized with 136 hip replacements performed at three centers (65 ROBODOC® and 62 control). Followup was 1 year on 127 hip replacements and 2 years on 93 hip replacements. No differences were found in the Harris hip scores or the Short Form Health Survey outcomes questionnaire. Length of stay also was not different, but the surgical time and blood loss were greater in the ROBODOC® group. This was attributed to a learning curve at each center. Radiographs were evaluated by an independent bone radiologist and showed statistically better fit and positioning of the femoral component in the ROBODOC® group. Complications were not different, except for three cases of intraoperative femoral fracture in the control group and none in the ROBODOC® group. The German study reports on 858 patients, 42 with bilateral hip replacements and this includes 30 revision cases for a total of 900 hip replacements. The Harris hip score rose from 43.7 to 91.5. In these cases the surgical time declined quickly from 240 minutes for the first case to 90 minutes. No intraoperative femoral fractures occurred in 900 cases. Other complications were comparable with total hip replacements performed using conventional techniques. The ROBODOC® system is thought to be safe and effective in producing radiographically superior implant fit and positioning while eliminating femoral fractures.

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In the mid1980s when cementless femoral components first were introduced, there was a significant problem with postoperative thigh pain,[4] intraoperative fracture,[10] and failure of bony ingrowth.[5,7] Initially it was thought that this was because of inability to fit the femur optimally with the implant.[1] It then was realized that fit was a two-part problem: The implant should fit the femur well, but the bone also should be shaped accurately to fit the implant. The surgical instruments in use at that time were carryovers from the era when only cemented components were used. They created a rough irregular surface that is ideal for cement but grossly inaccurate for cementless application. These inaccuracies created gaps[11] at the

implant to bone interface that could lead to instability, decreased bony ingrowth, and possible debris pathways for osteolysis. In addition, the placement of the implant in the intended position was thought to be critical. Even the best designed implant placed in the wrong position will result in poor fit.

Based on these concerns, the authors set out to develop a system[12] that would improve implant selection and sizing, positioning of the implant within the bone, and improve the accuracy of preparation of the bone cavity to accept the implant. The result was a preoperative planning computer workstation based on computed tomography (CT) data input linked to a robotic arm with a high speed burr as an end effector that mills the femoral canal for the selected implant in the position chosen preoperatively on the computer workstation. The system was called ROBODOC® (Integrated Surgical Systems Inc, Sacramento, CA).

The ROBODOC® project has evolved in five phases during 11 years.

Phase I (1986–1987) was a laboratory feasibility study conducted at the International Business Machines, Inc (IBM) Thomas Watson Research Center in Yorktown Heights, NY to determine whether it was possible to program a robot to perform a complex milling task that was unique for each patient. A new computer language developed by IBM made it possible.

Phase II (1987–1989) was a 2-year study at University of California at Davis funded by a grant from IBM to develop the system in the laboratory. Major hurdles in image processing and registration were overcome and studies showed that the robotically machined femurs were prepared with improved accuracy of as much as 20 times.

Phase III (1989–1991) was another 2-year study at University of California at Davis and the Sacramento Animal Medical Group to bring the system into a surgical environment. Twenty-six canine total hip replacements were performed on dogs with hip dysplasia. The system was shown to be feasible, and all 26 dogs recovered well and seemed to have less pain and better function than dogs operated on without using the ROBODOC® system.

Phase IV (1992–1993) was performed at the request of the Food and Drug Administration. Initially, on the basis of the canine experience, the authors requested authorization to perform a large multicenter study on humans. The Food and Drug Administration thought that a human feasibility study should be done using only 10 patients. These operations were performed successfully and the results were reported at the 1994 meeting of the American Academy of Orthopaedic Surgeons. The conclusions were that the procedure seemed to be safe and feasible, but the number of patients was too small to determine efficacy.

Phase V (1994-present) consists of a Food and Drug Administration authorized multicenter study with concurrent controls using three sites in the United States and a prospective ongoing postmarket study at one site in Germany.

In August 1994, the first ROBODOC® system in Europe was installed at the Berufsgenossenschaftliche Unfallklinik Clinic in Frankfurt, Germany. Regular surgery started in November 1994. Because a controlled randomized trial evaluating robot assisted versus hand broached total hip replacement already was conducted in the United States, other aspects of computer assisted surgery became subject of the evaluation of the German series. These were as follows: integration of a robotic system into routine surgery and the operating room environment; operating room time in robot assisted surgery; safety of the robot regarding patients and personnel; and detection of specific, robot related complications.

Focusing on these aspects in a prospective study is well founded for various reasons:

The ROBODOC® system is the first active robot in any surgical field that performs a certain part of the procedure by itself.[2,3,12] The system is large, heavy, and not easy to handle. Aspects of sterility and harm for the patient

because of necessary position and fixation of the surgically treated leg are critical.

Operating room time in the controlled trial in the United States in the group of patients in which the ROBODOC® system was used averaged 240 minutes. This may be tolerable at the beginning of a learning curve, but certainly cannot be outweighed by any benefits in the long run.

Engineers trained in robotics are in part very critical of the use of modified industrial robots in a surgical environment. Rigidity, speed, and size of work space seem to pose a potential danger to patients and personnel.

The first three aspects of computer assisted surgery described above could add to robot specific complications that only may be identified in a larger series. Therefore, the fast and stringent conduction of a prospective series seemed to be advisable.

This paper reports the combined experience of the United States Food and Drug Administration trials and the German use of the device. The United States study will be presented first with the German study following. The use of this device for revisions of failed femoral components only recently has been developed and clinical use has been limited to selected cases in Germany.

UNITED STATES CLINICAL TRIALS

MATERIALS AND METHODS

Three centers contributed to this study: Sutter General Hospital (Sacramento, CA), New England Baptist Hospital (Boston, MA), and Shadyside Hospital (Pittsburgh, PA). Each center had two to four surgeons participating. Each prospective patient was screened with specific inclusion and exclusion criteria and then were randomized into either the ROBODOC® or control groups. Both groups followed the same preoperative and postoperative protocol which included 6 weeks of 10% weightbearing.

In the ROBODOC® group, the patients underwent a separate procedure to place locator pins in the affected femur: two in the epicondyles above the knee and one in the greater trochanter. This usually was performed with the patient under local anesthesia in an outpatient surgical setting within 24 hours of the total hip replacement. The patient then had a CT scan of the femur and the tape output was loaded into a computer workstation (IBM RS 6000, IBM, Armour, NY). Using special image analysis software, the three-dimensional image of the femur was viewed and manipulated by the surgeon using a mouse and icons similar to a Windows format.

Two brands of implants have been used: the AML (DePuy, Inc, Warsaw, IN) and the Hydroxylapatite-Osteoloc (Howmedica, Rutherford, NJ). The surgeon could choose from a menu which type implant he or she preferred and then manipulate a three-dimensional image of the implant within the three-dimensional image of the bone. The final position, type, and size of the implant was a judgment of each surgeon. Once this was determined, the computer recorded this information relative to the position of the three locator pins and a tape was produced to be loaded into the robot controller at the time of the total hip replacement.

The control group underwent standard preoperative radiographs with magnification markers and standardization of rotational position of the femur. The surgeon planned preoperatively the implant type (AML or Osteoloc), position, and size using acetate templates provided by the manufacturer.

All surgeries were performed using the posterior approach with the patient in the lateral decubitus position. The acetabulum was placed without cement using conventional techniques of 1 to 2 mm of press fit. Screws were used as needed.

In the ROBODOC® group, the femur was placed in a fixator that then was attached through a sterile interface to the robot (Fig 1). The locator pin sites were exposed and the robot was guided to each pin. The robot then probed the surface of the pin to determine the coordinates of the top center point. Interpin distances as found by the robot were compared with the interpin distances as found on the CT scan. These had to agree to an acceptable level of precision to continue. The robot's end effector then was changed to a specially designed bit for the MIDAS Rex (Dallas, TX) pneumatic high speed burr. The robot then milled the inside of the femur to the size and position of the implant selected preoperatively at the com-

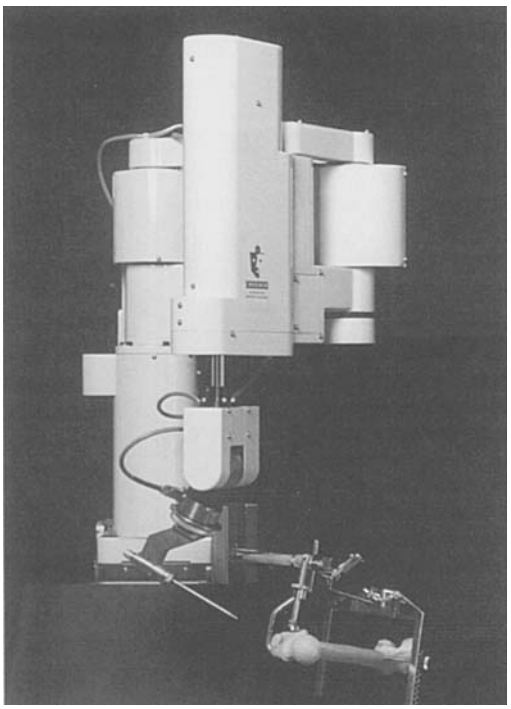

Fig 1. The ROBODOC® surgical assistant.

puter workstation. The robot was disconnected and the remainder of the surgery was completed in the standard fashion.

In the control group, the femur was prepared using a hand held reamer and broaches according to the manufacturer's recommended surgical technique. With the control group, the surgeon was free to choose whatever size and position seemed best during surgery regardless of the preoperative plan. In the ROBODOC® group, the implant used must be the implant selected preoperatively using the computer workstation.

The patients were evaluated using the modified Harris hip score, the Hip Society rating system, and the Short Form Health Survey. Surgical time, blood loss, length of stay, and complications were monitored.

Postoperative radiographs were reviewed independently by a bone radiologist in a blinded fashion. The 3-month postoperative radiographs were evaluated for fit (distance to cortical bone) and fill (percentage of canal occupied by prosthesis) at five levels. Also evaluated were axial seating (vertical distance from the prosthesis collar or medial edge to the osteotomy level) and alignment (angle between the stem axis and the proximal femoral canal axis) of the prosthesis and distal tip placement (distance of midpoint of stem tip to midpoint of canal). A composite score of proximal medial fit also was determined with scores ranging from one to five, where five denoted 50% or greater of prosthesis to cortex contact, four denoted 49% to 25% contact, three denoted less than 25% contact but greater than 2 point contact, two denoted parallel prosthesis and cortical edges with one or no point contact, and one denoted nonparallel edges with no point contact. Any prosthesis to cortex distance less than 1 mm defined contact. The 12- and 24-month radiographs were evaluated using the Engh and Bobyn classification[5] for ingrowth and stability, and for the presence of radiolucent zones with or without sclerotic lines (neocortex) according to Gruen zones.

RESULTS

There have been 120 patients with 136 hips enrolled in the study to date. Of these, 134 hips (69 ROBODOC® and 65 control) have completed a minimum 3-month followup and 127 hips (65 ROBODOC® and 62 control) have completed 1-year followup, and 93 hips (48 ROBODOC® and 45 control) have completed 24-month followup.

The modified Harris hip score at 3 months averaged 79.9 for the ROBODOC® group and 80.3 for the control. At 1-year followup the average score was 89.4 for the ROBODOC® group and 86.6 for the control group. At 2-year followup the average score was 88.5 for the ROBODOC® group and 91.1 for the control group. None of these differences are statistically significant. The breakdown of Harris total scores into groups are shown in Table 1. No statistically significant differences were seen.

Average length of stay was not significantly different (8.2 days for the ROBODOC® group versus 7.5 days for the control group. Surgical time was longer for the ROBODOC® group (258 minutes for the ROBODOC® group and 134 minutes for the control group, $p < .0001$). Average blood loss

TABLE 1. United States Food and Drug Administration Trial: Harris Hip Score (24 Months)

Harris Hip Score	Robot	Control
90–100	34	38
80–89	10	11
70–79	6	2
<70	4	1

also was greater for the ROBODOC® group (1189 cc for the ROBODOC® group versus 644 cc for the control group, $p < .0001$). Analysis of the parameter by center showed significant variation. Center 1 averaged 229 minutes surgical time for the ROBODOC® group and 122 minutes surgical time for the control group. Center 2 averaged 281 minutes surgical time for the ROBODOC® group and 147 minutes surgical time for the control group. Center 3 averaged 228 minutes surgical time for the ROBODOC® group and 107 minutes surgical time for the control group. Blood loss had similar center to center variations and seemed to correlate directly with surgical time.

Short Form-36 data were collected at 3-month, 6-month, 1-year, and 2-year followups. The results are seen in Table 2. No statistically significant differences were detected.

Postoperative complications are listed in Table 3. There were three intraoperative femoral fractures (cracks) in the control group and none in the ROBODOC® group ($p < .01$). There were no other significant differences between groups. One AML prosthesis in the ROBODOC® group had a loose porous coating that was observed to be detached partially on the immediate postoperative radiograph.

The results of the radiographic review are given in Tables 4 through 6. Significant differences were seen in fit and fill in favor of the ROBODOC® group (Table 4). Axial seating and alignment were statistically better for the ROBODOC® group, with no significant difference in distal tip placement (Table 5). The composite proximal medial fit score was also significantly better for the ROBODOC® group (Table 6) There were statistically less radiolucencies in Gruen Zones 3, 5, 6, 10, and 12 for the ROBODOC® group than in the control group (unpaired Student's t test). Also, there were more hips in the control group with radiolucencies in five or more zones than in the ROBODOC® group. For the AML prostheses at 12 months, there were two hips in the control group and one hip in the ROBODOC® group that were classified as Engh Class II[6] (stable fibrous ingrowth). The one hip classified as Engh II in the ROBODOC® group was the one with coating separation. The rest were all Engh Class I (bone ingrown). For the Osteoloc prostheses, all hips in both groups were classified as Engh Class I.

GERMAN EXPERIENCE

MATERIALS AND METHODS

Between November 1994 and November 1997, total hip replacement using the ROBODOC® system has been performed on 900 patients. This series included 30 revision cases, where either cement or fibrous tissue was removed by the robot. To all patients who were admitted for total

TABLE 2. United States Clinical Trial: Short Form 36 Overall Scaled Score

	Baseline		3 Months		6 Months		12 Months		24 Months	
Group	*Number*	*Score*	*Number*	*Score*	*Number*	*Score*	*Number*	*Score*	*Number*	*Score*
Control	50	51.1	50	68.3	41	76.1	44	76.3	41	76.7
ROBODOC	57	54.7	53	65.7	45	72.9	46	78.7	41	78.1

TABLE 3. United States Clinical Trial: Postoperative Complications

Complication	ROBODOC	Control
Intraoperative fractures	0	3
Loose porous coating	1	0
Dislocations	4	4
Deep vein thrombosis	1	1
Pulmonary embolism	0	1
Partial sciatic nerve palsy	2	0
Death	1*	0

*Cerebrovascular accident occurring 6 months postoperative.

hip replacement, the robot assisted surgery was proposed. Exclusion criteria were significant obesity (>20 kg over normal weight defined as height in centimeters minus 100 = kilograms) and age. The cutoff age was 70 years in the beginning of the series, but increasing demand of the patients led to a more flexible handling of age as exclusion criterion. Patients older than 70 years were excluded when the standard radiographs showed a significant osteoporosis and the bone seemed to be too weak to support a cementless implant. In addition to the standard informed consent, all patients were informed explicitly that the use of the robot on a patient still is considered as an experimental procedure, that uncertain risks may be associated with the procedure, and that long term results are not available. Five patients refused the robot assisted surgery and received hand broached cementless total hip replacement.

In the primary cases, all patients received a straight stem implant (Osteoloc™, Howmedica). The stem was supplied with a proximal hydroxyapatite coating. As an acetabular component, a Ti pressfit cup was used that received additional fixation with two to three screws. In revision cases where the new stem was a cementless component, the same stem was used as in primary total hip replacement. In cemented revision cases, the Lubinus™ stem (Link, Kiel, Germany) was implanted. The pin procedure was performed with the patient under spinal anesthesia, whereas the robot procedure was performed with the patient under general anesthesia.

RESULTS

Of 900 patients in this series, 529 were men and 371 were women. The mean age in males was 55.4 years, and in females it was 54.1 years, with an overall range from 18 to 76 years. Surgical indications were as follows: 71.2%, primary osteoarthritis; 12.7%, dysplasia; 13.9%, posttraumatic osteoarthritis; and 2.2%, revision situations.

TABLE 4. Fit and Fill by Level

All Implants	Control	ROBODOC	p Value
Number	65	64	
Anteroposterior radiograph lateral fit (mm)			
Level 1	16.79	13.75	0.002
Level 2	5.83	4.81	0.004
Level 3	3.09	2.28	0.006
Level 4	0.26	0.12	0.09
Anteroposterior radiograph medial fit (mm)			
Level 1	3.06	1.14	0.0001
Level 2	3.66	1.44	0.0001
Level 3	2.68	1.48	0.0006
Level 4	0.12	0.14	0.78
Anteroposterior radiograph fill (%)			
Level 1	66.3	73.8	0.0001
Level 2	73.1	82.9	0.0001
Level 3	80.0	86.9	0.0001
Level 4	97.9	98.5	0.84

TABLE 5. Implant Positioning

Osteoloc	Control	ROBODOC	p Value
Number	50	49	
Displacement (mm)	0.13	0.24	0.22
Anteroposterior radiograph axial seat	2.26	0.94	0.01
Anteroposterior radiograph alignment	0.72	0.43	0.02
Lateral radiograph axial seat	—	—	—
Lateral radiograph film alignment	1.06	0.69	0.02

In 19 (2.1%) cases with high subluxation of the joint, a two-step procedure was performed: pin placement, implantation of the acetabular component, and external fixator in the first surgery, then, after 3 weeks of extension with the adjustable external fixator, performance of the actual robot surgery with implantation of the cementless stem.

Preoperative CT scan had to be repeated in 64 (7.1%) of the patients, when relevant motion of the patient was detected in the Orthodoc™ group of patients in the routine designed to check for motion during the CT scan. These incidents became less frequent with more experience in placement of the patient during CT scanning and the introduction of spiral CT with significant enhancement of scan speed.

During surgery, a bone motion monitor is attached to the patient to detect relative motion between bone of the patient and the robot. In case of bone motion any action by the robot is stopped immediately and registration (pin finding) has to be repeated. This occurred in 99 (11%) cases, again less frequent recently because of better fixation and a scale on the monitor allowing the early detection of minor movements before an actual bone motion is registered.

Pin placement was performed in 932 cases. In 32 cases the robot procedure had to be aborted for various reasons and the cavity had to be prepared by hand. Reasons for abortions were as follows: CT errors (inaccuracy in table motion), user errors (false pin placement or loosening of pins), and system problems (mainly software problems). Again, the majority of these incidents occurred in the beginning of the series. In all of these cases the procedure could be completed by hand without any problems.

No awkward performances of the robot and no unpredicted or dangerous movements were detected in any of the 900 cases. In no case did the emergency stop button on the remote control have to be pressed by the surgeon.

In 42 (4.7%) patients the ROBODOC® procedure was performed on both hips with a mean interval of 312 days between surgeries. These bilateral cases gave the authors the chance to compare the original Orthodoc™ plan established for the first surgery with the image of this same implant on Orthodoc™ when the second side was planned. Position of the implant regarding proximal and distal fit and anteversion was measured. Deviations in height of the implant were between 0.4 and 1 mm, with a maximum deviation in angle of 1°.

TABLE 6. Proximal Medial Fit Score*

Composite Score	Control (n = 64)	ROBODOC (n = 63)
1	9	0
2	32	9
3	10	10
4	6	20
5	7	24

*Chi square (p = 0.001).

Neither during surgery nor on the postoperative radiographs were fissures or fractures detected. Infection occurred in one (0.1%) patient, embolism occurred in nine (1%) patients, deep vein thrombosis occurred in 25 (2.8%) patients, luxations occurred in 29 (3.2%) patients, and transient nerve palsies occurred in 36 (3.9%) patients. Operating room time declined steadily from 240 minutes in the beginning to a mean time of 90 minutes. In 61 patients receiving a primary total hip arthroplasty, the Harris hip score rose from a preoperative value of 43.7 points to value of 91.5 points at 24 months.

In 23 patients undergoing revision surgery the regular Orthodoc™ program was used to plan the procedure. Because of significant artifact reduction in the Orthodoc™ program, regular planning could be performed with the new implant overlaying the old implant. Thus, after manual removal of the old implant, the robot removed bone cement or, in cementless cases, fibrous tissue during the reaming and instantly created the cavity for a new cementless implant. In seven patients the new revision program as a prototype was used to remove extended cement mantles from the cavity. In this program the bone to cement interface was identified stepwise by the surgeon during the planning for the Orthodoc™ system. This created a new cutting file with the only purpose to remove all cement from the bone. After cement removal a new cemented stem was implanted. In these cases the robot removed the old cement without any problems, the complete removal was checked via an arthroscope introduced into the cavity. No fracture or fissure occurred, and no additional osteotomy was necessary to remove the cement.

DISCUSSION

The trends shown in the clinical data of the Harris hip scores and Short Form-36 data are encouraging, but statistically significant differences are not seen at 24 months. There were no differences in complication rates between the two groups, except that intraoperative fractures were eliminated in the ROBODOC® group.

The surgical time and blood loss were significantly greater for patients in the ROBODOC® group. Some of this represents a learning curve, with decreasing time at each center for patients in the ROBODOC® group as the number of cases increased. Analysis of the increased surgical time for patients in the ROBODOC® group shows that intrinsic delays such as application of the fixator, docking, pin finding, and milling account for approximately 1 hour of the difference. Other delays can be attributed to the computer safety system which halts the procedure if bone motion is detected or computer errors occur. Changes recently have been incorporated that will decrease the milling time. Efforts are underway to eliminate entirely the need for placement of pins. Pinless registration will avoid the need for a separate surgery for pin placement and the intrinsic delays associated with pin finding. A more robust computer safety system also is under development. It is hoped that these modifications will bring the surgical time and blood loss difference into parity.

To date, the most significant findings of this study are the radiographic differences. When ROBODOC® was conceived, its goal was to improve implant size selection, position, and accuracy of femoral preparation. The statistically significant differences found by the expert independent radiographic reviewer blinded to the study seem to prove that this goal has been met. The real question is, do these improvements in decision making and surgical technique make a difference in long term outcomes? Although most surgeons think that fit of the implant and accuracy of technique are important, the orthopaedic literature does not contain studies that prove a link with survivorship and long term outcome. The authors think that these improved radiographic results for patients in the ROBODOC® group represent surrogate variables that indicate

probable improvement in long term clinical performance.

This does not answer the question of cost effectiveness. Although no systems have been sold for non Food and Drug Administration use in the United States, the cost for a complete system is projected to be approximately $600,000. Placing a dollar figure on effectiveness is very difficult, if not impossible. The ROBODOC® system does eliminate the need for surgical instrumentation for femoral preparation. In many implant systems this represents several trays of instruments costing more than $50,000. In addition, because the surgeon can preplan the exact size and type of implant needed, large inventories of implants are not required. These implants could be ordered direct, thereby eliminating the costs of distributors and local company representatives (20%–30% off the cost of the implant). If the concept of the radiographic results serving as surrogate variables is accepted, then better long term performance of cementless hips performed with ROBODOC® can be anticipated. This should result in decreased societal costs associated with longer productive employment and less numbers of failures requiring costly revision surgery. The data from the current study at this time do not support the conclusion of cost effectiveness. Potential for this is seen, however, in this early report of the United States multicenter trial on ROBODOC®.

In contrast to the controlled United States trial on ROBODOC®, the study performed at the Berufsgenossenschaftliche Unfallklinik Clinic in Frankfurt focused more on the feasibility and safety of robot assisted surgery in daily routine. The results show that robot assisted surgery can be performed without exposing the patient to uncertain risks. The fear of engineers that a rather powerful robot with a large workspace can endanger patients or personnel seems to be unfounded. The numerous safety features installed in the systems' hardware and software seem to prevent any unpredicted action. Never in this series (and to the authors' knowledge also not in any of the other nine centers in Europe) has an emergency stop had to be performed. Instead, the robot aborted the surgeries by itself when certain safety or accuracy criteria were not met during surgery. This, for example, happened when the robot detected data errors because of false CT table motion. Aborted procedures, therefore, should not be regarded as failures but rather as proof of the system's reliability. In all aborted cases the procedure could be finalized by hand without any problems.

The revision cases showed the feasibility of this new application. The regular Orthodoc™ and the new revision program were used. Both programs were safe and practical. The regular program can be used in cementless cases or in cemented revisions where only a small cement mantle has to removed. In these cases cement or bone or both can be removed and the cavity simultaneously prepared for a new cementless implant. In cemented cases with a large cement mantle the revision software has to be applied, allowing very gentle removal of even large and deep cement mantles. Cement removal done with the robot can be safer and faster than done by hand.

One supposed benefit of robot assisted total hip replacement, the avoidance of intraoperative fractures, is seen in this series. Thus one factor that may contribute to long term failures in cementless total hip replacement can be excluded.[14] Also, no specific complications that may be connected to the use of the robot were detected. Although surgical times in the beginning of the learning curve were long, this caused no harm to the patients. No complications that may be attributed to long surgical times were found. The time of surgery declined steadily because the first 100 patients were operated on by the same surgeon. Since then four more surgeons joined the team, and surgical times have stayed in the range of 90 to 100 minutes. Thus, at the present time, a robot assisted total hip replacement takes an average

of 30 minutes longer than the hand broached procedure. The same difference in time was found in an animal experiment performed by one of the authors (AB) between robot assisted and hand broached hemiarthroplasty in greyhounds. These 30 minutes are consumed by the necessary fixation of the patient's femur, by pinfinding (registration), and the reaming itself. Even other forms of registration (pinless registration) presumably will not lead to a significant reduction in operating room time.

No detectable differences between the preoperatively established plan and the surgical outcome were seen. This was so especially in the series of patients who underwent bilateral procedure where a perfect matching of plan and execution was seen. Therefore, one of the great advantages of the system is the fact that preoperative planning is mandatory and that any established plan will be executed with the highest precision. Thus, well known mistakes in cementless total hip replacement that are acknowledged as factors contributing to failure (undersizing of implant, varus or valgus malposition, reaming defects, and fractures) consequently can be avoided.[8,9,13] Whether this will lead to a significant improvement of long term outcome will be subject of additional studies in this series.

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