Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-011-1400-9

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Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study

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Received: 21 February 2010 / Accepted: 13 January 2011

Abstract
Purpose The authors performed this study to compare the outcomes of robotic-assisted and conventional TKA in same patient simultaneously. It was hypothesized that the robotic-assisted procedure would produce better leg alignment and component orientation, and thus, improve patient satisfaction and clinical and radiological outcomes.
Methods Thirty patients underwent bilateral sequential total knee replacement. One knee was replaced by robotic-assisted implantation and the other by conventional implantation.
Results Radiographic results showed significantly more postoperative leg alignment outliers of conventional sides than robotic-assisted sides (mechanical axis, coronal inclination of the femoral prosthesis, and sagittal inclination of the tibial prosthesis). Robotic-assisted sides had non-significantly better postoperative knee scores and ROMs. Robotic-assisted sides needed longer operation times (25 min, SD ± 18) and longer skin incisions. Nevertheless, postoperative bleeding was significantly less for robotic-assisted sides.
Conclusion The better alignment accuracy of robotic TKA and the good clinical results achieved may favorably influence clinical and radiological outcomes.
Level of evidence I.

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Keywords Total knee arthroplasty · Surgical robot · Mechanical axis · Inclination of component · Clinical outcome

Introduction

Total knee arthroplasty (TKA) is a reliable treatment for pain relief and the restoration of joint function in arthritic knees and achieves satisfactory outcomes in more than 90% of patients [9, 24, 26]. Several factors influence outcome after TKA such as patient, and implant characteristics, surgical technique, and the restoration of limb alignment. Mechanical alignment and soft tissue balance play pivotal roles in treatment success and implant longevity [6, 11, 23, 29]. In particular, a mechanical limb axis varus or valgus alignment range of 3° has been reported to be associated with superior long-term results [7, 21, 23]. However, Jenny et al. reported, after conventional TKA only 72% of 235 cases showed a mechanical leg alignment deviation of less than 3° varus/valgus, whereas after computer-assisted TKA, 92% of patients showed mechanical leg alignment of less than 3° varus/valgus [8].

To further improve the accuracy of implant selection and position, alignment and bone resection robotic systems have been developed for TKA [3, 5, 27, 30]. Robotic systems are referred to as active systems. They serve as a delivery tool for a surgical procedure planned offline on a computer prior to surgery [15]. The surgeon positions the robot using the planned procedure as a reference and then supervises the reaming process without modifying the procedure. Robot-assisted TKA is known to have the merits of more accurate alignment, a lower number of outliers, and to allow preoperative accurate surgical planning when compared with conventional TKA. Several studies have evaluated the outcomes of robotic-assisted TKA [2, 3, 5, 18, 30], but no study conducted to date has compared the outcomes of simultaneous bilateral TKA using a robot-assisted and a conventional procedure in same patients. Accordingly, we undertook this prospective study to address this issue. We hypothesized that robot-assisted TKA would lead to a better leg alignment and component orientation, and thus, improve clinical and radiological outcomes.

Materials and methods

Thirty patients scheduled for bilateral TKA were enrolled in this prospective study, after obtaining approval from our institutional review board and written informed consent from all participating patients (Table 1). The study inclusion criteria were as follows: primary osteoarthritis of the knee, no previous hemiarthroplasty or total knee arthroplasty, a mechanical axis between 20° varus and 5° valgus, and no severe instability that could not be treated by cruciate-retaining TKA. The exclusion criteria were previous open knee surgery, revision TKA, a body mass index of >40 kg/m^2, or a neurological problem. Initially, we recruited 50 patients (100 knees) with bilateral osteoarthritis requiring simultaneous total knee arthroplasty. However, 10 patients were excluded after applying the exclusion criteria, and 10 patients refused to participate. The remaining 30 patients constituted the study cohort. A randomized protocol was used to decide which method to use on which side. In all patients, one knee was assigned to robot-assisted TKA using the ROBODOC® system (Integrated Surgical Systems, Sacramento, CA), and the other knee was assigned to conventional manual implantation. Surgeries were conducted from August 2004 to March 2006. Bilateral robot-assisted and conventional TKA were performed under general anesthesia at a single institute by a single surgeon who had experience of more than 150 cases of robot-assisted TKA. Intraoperatively, operative time, skin incision length, and flexion and extension gap were checked just prior to prosthesis implantation. Postoperative Hemovac® drainage amounts were measured for both sides.

The study group consisted of 30 female patients of mean age 67 years (SD ± 6.3) with a mean BMI of 27 kg/m^2 (SD ± 6.5). All patients underwent follow-up for at least 12 months (average 16 months, SD ± 3.2). The posterior cruciate ligament was retained, and a NexGen prosthesis (Zimmer, Warsaw, Indiana) was implanted with cement for arthroplasty. Follow-up evaluations were performed by independent blinded evaluators with no direct involvement in the surgical procedures. In addition, evaluators were unaware of knee identities (conventional versus robot-assisted).

Clinical assessment

Clinical assessments were performed preoperatively, at 3, 6, and 12 months postoperatively, and last follow-up visits. The clinical results analyzed included ranges of motion, Hospital for Special Surgery (HSS) scores, Western Ontario and McMaster University (WOMAC) scores (for pain and function), and complications. In addition, the subjective preferences of patients were evaluated preoperatively, at 3 and 12 months postoperatively, and at last follow-up visits.

Radiographic assessment

All radiographic measurements with regard to changes in mechanical axes and the inclinations of femoral and tibial components were checked with consistent distance according to the Knee Society Roentgenographic Evaluation System. In addition, radiographic measurements were accurately measured using PACS (Picture Archiving and Communication Systems). Two independent investigators performed all radiological measurements to reduce observation bias. The interobserver and intraobserver reliability (intraclass correlation coefficient) was calculated for the coronal inclination of the femoral (θ, optimum, 90) and tibial prostheses (β, optimum, 90) on standing anteroposterior radiographs and sagittal inclinations of femoral

Table 1 Demographic data on all patients

	Robotic-assisted TKA	Conventional TKA	P value
Preoperative range of motion	120° (SD ± 16.0°)	123° (SD ± 14.3°)	n.s
HSS score	65 (SD ± 7.0)	66 (SD ± 7.4)	n.s
WOMAC score	80 (SD ± 16.0)	75 (SD ± 15.0)	n.s
Preference	8 patients	16 patients	
Mechanical axis	9.1° (SD ± 5.9°)	10.9° (SD ± 8.6°)	n.s
Mean length of incision (cm)	15.2 (SD ± 1.2)	13 (SD ± 1.5)	n.s
Drainage (ml)	568.6 (SD ± 385)	816 (SD ± 425)	0.005*
Operative time (min)	95 (SD ± 18)	70 (SD ± 15)	n.s

* Statistically significant differences between two groups ($p < 0.05$)

(γ, optimum, 0) and tibial prostheses (δ, optimum, 83) on lateral tibial radiographs at last follow-up visits. The two individuals who performed the interobserver and intraobserver reliability test were the same individuals who developed and agreed on the measurement technique together. A time period of 4 weeks elapsed between test and retest measurements. For intraobserver and interobserver reliability, the intraclass correlation coefficient, 95% confidence interval for the intraclass correlation coefficient, and standard error of measurement were reported. Outcome was defined as "excellent" when values were within 2°, "acceptable" when within 3°, and as "outliers" when more than 3° from optimum.

Surgical techniques

Robotic TKA was carried out in two steps, i.e., CT-based preoperative planning using ORTHODOC and robot-assisted surgery using the ROBODOC® Surgical Assistant (Fig. 1). A helical CT scan was obtained preoperatively and transferred to the ORTHODOC presurgical planning workstation. ORTHODOC combines CT data and displays three-dimensional cross-sections of bone on a high-resolution screen. After creating a surface model of the tibia and femur, the first planning step involves establishing femoral and tibial mechanical axes according to the anatomical centers of the hip, knee, and ankle, and aligning the bone along these axes. The second step involves femoral and tibial component planning. Component size, position, alignment, and rotation are set individually. We set the position of the femoral component to allow a relatively lax flexion gap (2 mm larger than the extension gap) for good postoperative flexion. After verifying the correct position using virtual surgery, information data for the robot control unit was created and uploaded to the control unit of the surgical robot.

After flexing the knee to 70–80 degrees using a special leg holder, a conventional medial parapatellar arthrotomy with patellar eversion was used to expose the knee joint. The leg was then fixed to the robot using two Steinmann and Hoffman fixation systems, and 4 recovery markers and 2 bone motion monitors were installed. After the surface registration and verification processes had been completed using the robot's DIGIMATCH™ ball probe, milling of the femur and tibia was started. Having completed the cutting, the robot was removed from the operative field. Soft tissue release was then performed using a tensor device (Stryker Howmedica Osteonics, Allendale, NJ). After completing soft tissue release, medial and lateral gaps were recorded in millimeters at full extension and 90° of flexion. Knee flexion–extension gaps were considered "balanced" when the flexion gap was 0–3 mm larger than the extension gap, and the medial to lateral gap difference was less than 3 mm in flexion and extension. After obtaining soft tissue balance, implants were inserted manually with cement.

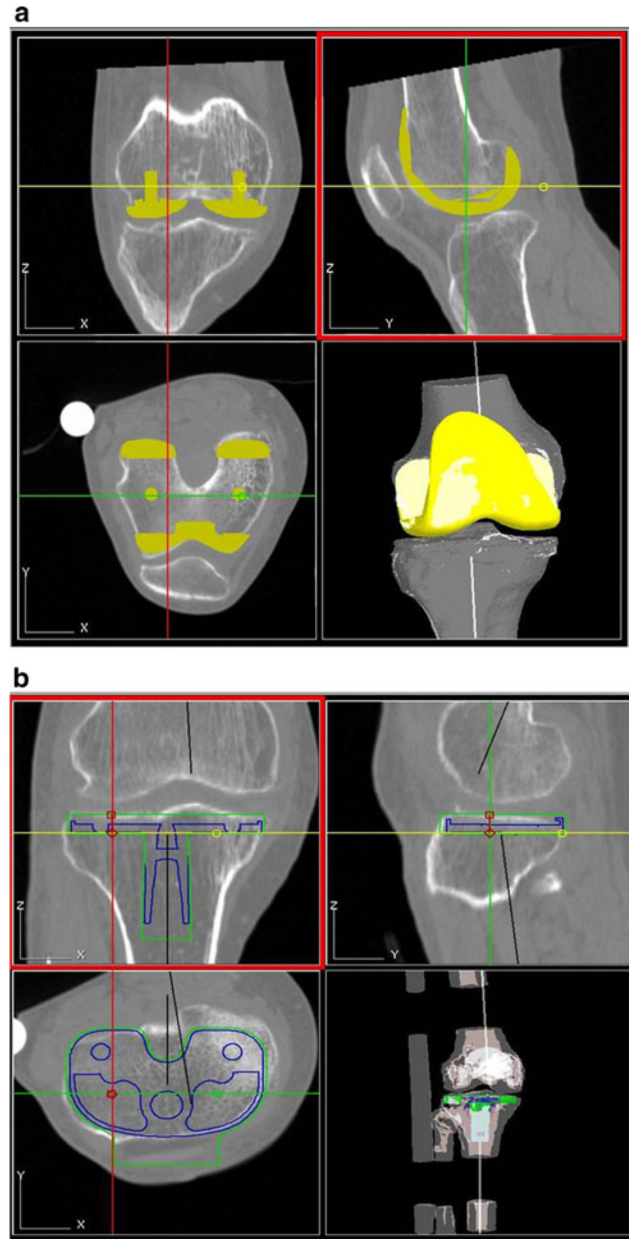

Fig. 1 Virtual surgery conducting to verify femoral (**a**) and tibial (**b**) alignment and size with respect to the established femoral and tibial mechanical axes

On the contralateral side, conventional TKA was performed using medial parapatellar arthrotomy (extending approximately 3–4 cm into the quadriceps tendon) with patella eversion. Intramedullary instrumentation was used for femoral alignment (3° of external rotation with respect to the posterior condylar axis), and a 6° valgus cut was selected for all knees. The tibial cut was performed using extramedullary instrumentation with the goal of making the cut perpendicular to the tibial shaft in the coronal plane with a 7° posterior slope in the sagittal plane. Alignment was checked with extramedullary rods referenced versus the anterior superior iliac spine (ASIS) and placed 5–10 mm medially from the midpoint of both malleoli. After completing soft tissue release and checking that flexion and extension gaps matched those on robotic-assisted sides using a tension device, implants (Zimmer, Warsaw, Indiana) were inserted manually with cement.

Statistical analysis

A priori power analysis was performed with percentage of outlier cases less than 2° varus in lower extremity alignment as the primary outcome variables. The sample size was calculated based on the data from first 10 cases of this study, which revealed 50% of conventional and 92% of robotic group less than 2° varus in lower extremity alignment. Based on these results, 28 patients for incidence of less than 2° varus in lower extremity alignment per group were found to be required (power = 0.8 (1-β); confidence level 0.05).

Descriptive statistics (arithmetic means, SDs, and ranges) were calculated using standard formulas. The independent *t*-test was used to determine the significances of intergroup differences, and the paired *t*-test was to determine the significances of intragroup differences in WOMAC and HSS scores and ROMs before and after surgery. The chi-square test was used to determine associations between outliers and radiographic outcomes and odds ratios and 95% confidence intervals were calculated. The analysis was performed using SPSS software (SPSS for Windows Release 17.0, Chicago, Ill), and significance was accepted for P values of <0.05.

Results

Robot-assisted implantation took about 25 min longer (mean 95 versus 70) than manual implantation (P = n.s). Mean incision length was 15.2 cm (SD ± 1.2) on robotic-assisted sides and 13 cm (SD ± 1.5) on conventional sides (P = n.s), and mean blood loss was 568.6 ml (SD ± 385) in robotic-assisted sides and 816 ml (SD ± 425) on conventional sides ($P = 0.005$).

In the knees operated with robotic technique, the mean intraoperative extension gap was 21.5 mm (SD ± 2.2) and the mean flexion gap was 23.2 mm (SD ± 2.9), and flexion–extension gap balance was achieved in 27 knees (92%). In the remaining three knees, flexion was loose in one (2%) and tight in two (6%). Mean medial and lateral gap asymmetry in extension and flexion gap was 0.6 mm, and no cases had an imbalance of >3 mm. On the other hand, on conventional sides, the mean intraoperative extension gap was 21.8 mm and the mean flexion gap was 22.9 mm, and flexion–extension gap balance was achieved in 23 knees (77%). In the remaining 7 knees, flexion was loose in two (5%) and tight in five (18%). Mean medial and lateral gap asymmetry in extension and flexion gap was 1 mm, and no cases had an imbalance of >3 mm.

Clinical results

As shown in Table 2, preoperative ROM averaged 120° in the robot-assisted group and 123° in the conventional group, and these values improved to 129° and 129°, respectively (SD ± 13.8° and SD ± 12.8°, $P = 0.006$ and $P = 0.042$) at last follow-up visits.

Mean preoperative HSS scores were 62.2 in the robot-assisted groups and 63.8 in the conventional group, and these improved to 91.1 and 90.5 at 3 months, 93.4 and 93.5 at 6 months, 95.9 and 94.7 at 1 year, and 95.2 and 94.7 at last follow-up, respectively ($P = 0.000$ for preoperative versus last follow-up in both groups).

In terms of WOMAC scores, mean preoperative scores of 77.8 in the robot-assisted and 75.2 in the conventional group improved to 36.8 and 36.4 at 3 months, 28.1 and 27.9 at 6 months, 18.5 and 20.1 at 1 year, and 11 and 13 at last follow-up ($P = 0.000$ for preoperative versus last follow-up WOMAC scores in both groups).

Regarding patient preferences, preoperatively 11 preferred robotic-assisted sides and 13 the conventional side, at 3 months postoperative 10 preferred robotic-assisted sides and 10 the conventional side, at 1 year postoperative 10 preferred robotic-assisted sides and 8 the conventional side, and at last follow-up 12 preferred the robotic-assisted sides and 6 the conventional sides. The other patients found both sides the same (6 preoperative, 10 at 3 months postoperative, 12 at 1 year postoperative, and 12 at last follow-up).

Radiographic results

As shown in Table 3, mean mechanical axis improved from 9.1° varus and 10.9° varus (SD ± 5.9 and SD ± 8.6°) to 0.2° varus and 1.2° varus (SD ± 1.6° and SD ± 2.1) in the robot-assisted and conventional groups ($P = 0.000$), for mean preoperative versus mean postoperative in the robot-assisted and conventional groups, 28 (93.3%) and 15 patients (50%) were classified as having achieved an excellent outcome with mechanical axis restoration within 2°. However, in the conventional group, 7 patients (23.3%) were classified as outliers (Fig. 2). Mean coronal inclinations of the femoral and tibial component were 89.2° and 90.1° in robot-assisted group and 88° and 90.7° in the conventional group. Mean sagittal inclinations were 0.9°

Table 2 Comparison of clinical results between robotic-assisted and conventional TKA

		Robotic-assisted	Conventional	*P* value
ROM	Preoperative	120° (SD ± 16.0°)	123° (SD ± 14.3°)	n.s
	Postoperative	129° (SD ± 13.8°)	129° (SD ± 12.8°)	n.s
HSS	Preoperative	65 (SD ± 7.0)	66 (SD ± 7.4)	n.s
	3 month	91.1 (SD ± 6.7)	90.5 (SD ± 6.6)	n.s
	6 month	93.4 (SD ± 6.5)	93.5 (SD ± 5.9)	n.s
	1 year	95.9 (SD ± 5.2)	94.7 (SD ± 5.5)	n.s
	Last follow-up	95.2 (SD ± 4.0)	94.7 (SD ± 5.0)	n.s
WOMAC	Preoperative	80 (SD ± 16.0)	75 (SD ± 15.0)	n.s
	3 month	36.8 (SD ± 12.0)	36.4 (SD ± 12.4)	n.s
	6 month	28.1 (SD ± 11.0)	27.9 (SD ± 10.1)	n.s
	1 year	18.5 (SD ± 4.0)	20.1 (SD ± 8.5)	n.s
	Last follow-up	11 (SD ± 4.5)	13 (SD ± 6.6)	n.s
Preference	Preoperative[a]	8 patients	16 patients	
	3 month[b]	10 patient	10 patients	
	1 year[c]	10 patients	8 patients	
	Last follow-up[d]	12 patients	6 patients	

[a] The other 6 patients answered that both sides were even

[b] The other 10 patients answered that both sides were even

[c] The other 12 patients answered that both sides were even

[d] The other 12 patients answered that both sides were even

and 85.4° in the robot-assisted group and 1.1° and 86.1° in the conventional group. In terms of outliers, there was only 2 (6.7%) sagittal inclination outliers for the tibial side in the robot-assisted group, but 8 (26.7%) outliers for femoral side coronal inclination, 3 (10%) for femoral side sagittal inclination, and 15(50%) for tibial side sagittal inclination in the conventional group.

No major adverse events related to the use of the robotic system, such as deep infection or loosening requiring revision, were observed during follow-up.

Discussion

The most important finding of the present study was the robot-assisted TKA resulted in better lower extremity alignment with statistically significant difference and non-significantly better clinical & radiographic outcomes.

Jeffery et al. [7] analyzed outcomes after TKA in 115 patients and reported a 24% rate of prosthetic loosening when the mechanical axis exceeded ±3° varus/valgus deviation, but a rate of only 3% for knees with an axis within 3° of neutral, clearly showing that limb malalignment influences long-term survival. Mahaluxmivala et al. [13] found a varus/valgus deviation of the mechanical axis of more than 3° in 25% of 673 TKAs, and Ritter et al. [23] analyzed femorotibial angles in 421 TKAs and concluded that the highest rate of aseptic loosening occurred in patients with varus malalignment. Using conventional techniques, Petersen et al. [19] reported a postoperative deviation of the mechanical axis of the limb by >3° in 26% of patients. Likewise, in the present study, mean mechanical axis improved from 10.9° varus to 1.2° varus when the conventional method was used. Although, we used intramedullary instrumentation to obtain femoral alignment, the tibial cut was performed using extramedullary instrumentation, with the goal of making the cut perpendicular to the tibial shaft in the coronal with a 7° posterior slope in the sagittal plane. However, considerable numbers of patients (mechanical axis in 7 patients, coronal and sagittal inclination in the femoral side in 8 and 3, respectively, sagittal inclination in the tibial side in 15) were outliers postoperatively.

During the conventional technique, extramedullary alignment guides or intramedullary rods were used to achieve component orientation. However, this technique is prone to errors of component malalignment [4, 10, 17, 22], and therefore, navigation systems were developed to help surgeons improve alignment accuracies, and since, these systems have been shown to reduce some types of limb and component alignment errors. Furthermore, encouraging results have been reported. Furthermore, encouraging results have been reported for navigated TKA by several groups [9, 12, 14, 16, 25, 28]. However, even when performing the computer-assisted technique, a deviation of the saw blade, particularly in dense bone stock, might cause a

Table 3 Comparison of radiological results between robotic-assisted and conventional TKA

		Robotic-assisted	Conventional	*P* value
Mechanical axis	Preoperative	9.1° (SD ± 5.9°)	10.9° (SD ± 8.6°)	n.s
	Postoperative	0.2° (SD ± 1.6°)	1.2° (SD ± 2.1°)	0.035*
	P value	<0.001§	<0.001§	
Coronal inclination	Femoral prostheses	89.2° (SD ± 1.3°)	90.1° (SD ± 1.7°)	n.s
	Tibial prostheses	90.0° (SD ± 1.3°)	90.7° (SD ± 1.1°)	n.s
Sagittal inclination	Femoral prostheses	0.8° (SD ± 0.8°)	1.0° (SD ± 0.6°)	0.004*
	Tibial prostheses	85.2° (SD ± 1.4°)	85.7° (SD ± 2.7°)	n.s
Outcomes	Excellent	28 (93.3%)	15 (50%)	
Mechanical axis	Acceptable	2 (6.7%)	8 (26.7%)	0.001*
	Outliers		7 (23.3%)	
Femoral side	Excellent	23 (76.7%)	15 (50%)	
Coronal inclination	Acceptable	7 (23.3%)	7 (23.3%)	0.008*
	Outliers		8 (26.7%)	
Sagittal inclination	Excellent	27 (90%)	21 (70%)	
	Acceptable	3 (10%)	6 (20%)	n.s
	Outliers		3 (10%)	
Tibial side	Excellent	27 (90%)	24 (80%)	
Coronal inclination	Acceptable	3 (10%)	6 (20%)	n.s
	Outliers			
Sagittal inclination	Excellent	20 (66.7%)	10 (33.3%)	
	Acceptable	8 (26.6%)	5 (16.7%)	0.001*
	Outliers	2 (6.7%)	15 (50%)	

Excellent outcome (mechanical axis) was defined as "excellent" when values were within 2°

Acceptable outcome was defined when values were within 3°

Outliers outcome was defined when values were within when >3° of optimum

§ Statistically significant differences between preoperative and postoperative values ($p < 0.05$)

* Statistically significant differences between two groups ($p < 0.05$)

deviation of mechanical leg axis [1, 20]. Bathis et al. [1] reported cutting errors of up to 2° and 4° in the frontal and sagittal planes, respectively.

Current navigation systems, like the conventional system, rely on guides, cutting blocks, and oscillating saws. Plaskos et al. [20] concluded that the inaccuracy of bone sawing contributes to overall implant alignment variability by 0.6°–1.1°(SD) of varus/valgus and 1.8° of flexion–extension under experimental conditions. Thus, optimum alignment would be difficult to achieve even if navigated or mechanical alignment guides could place cutting blocks in a perfect position. For these reasons, robotic systems were developed for TKA to improve the accuracy of implant alignment and bone resection [3, 5, 27, 30]. Robotic systems allow the surgeon to choose freely among different strategies for placing the component, but only according to bony landmarks. In addition, these systems execute preoperative plans without any possibility of intraoperative changes. Preoperative CT scans allow more accurate preoperative planning than navigation systems in terms of individual patient bone geometry, and thus, further intraoperative registration by robotic systems could provide more accurate cutting. In our study, the mechanical axis improved from 9.1° varus to 0.2° varus in robot-assisted sides. Furthermore, when compared with conventional sides, all knees were restored to the ideal mechanical axis with no outliers in coronal and sagittal inclination for femoral side and only 2 outliers in sagittal inclination for tibia side in robotic group. We believe that, in general, CT-based preoperative planning allows better implant position and intraoperative simulation of implant overlap during complete knee movements. Consequently, this type of planning enables surgeons to alter plans and includes more patient-specific data intraoperatively. The joint line and the orientation of the implant can be planned and executed more accurately than with conventional techniques.

In this study, well-balanced flexion and extension gaps and routine medial soft tissue release were achieved in more than 90% of knees after the milling process. These results are superior to those reported by Griffin et al., [6], 3 mm of flexion–extension mismatch was noted in 13.5% of TKAs laterally and 10.6% medially. Our relatively good

Fig. 2 A 67-year-old woman with bilateral TKA. An outlier result on the *right side* (conventional) and an excellent femorotibial angle on the *left side* (robotic)

balance results are attributable to precise femoral component rotation and the restoration of a normal tibial slope based on preoperative CT data. On the other hand, only 77% of flexion and extension gaps were balanced in conventional sides due to 3° of external rotation relative to posterior condylar axis. During surgery, applying the transepicondylar axis was somewhat difficult, but preoperative CT planning of femoral rotation according to the transepicondylar axis enabled a balanced rectangular flexion and extension gap to be performed. These better results suggest that the transepicondylar axis is better than posterior condylar axis for balanced gap techniques.

Siebert et al. [27] recommended that the robotic technique might allow accurate planning of the milling track and the type of cutting used, which should reduce the risk of injury to ligaments, vessels, and nerves, which are undoubtedly endangered by manually directed oscillating saws. In addition, the osseous insertion of the posterior cruciate ligament, for example, can always be preserved. Implants fit better in robotic group because the milled surfaces are always precisely flat; a matter of particular importance when cementless systems are used. Finally, the amount of removed bone can be minimized, which could simplify later revision surgery. In the present study, although mean incision length was greater in robotic-assisted sides, robotic surgery resulted in significantly less blood loss (568.6 ml for robotic-assisted sides versus 816 ml for conventional sides). In addition, although the mean operative time was 25 min longer for robot-assisted sides, there was no increase in short-term complication rates. In addition, robotic TKA may be cost-effective by improving radiographic prosthetic alignment, and thus, implant longevity, patient satisfaction, and clinical outcomes.

In the present study, the average operative time was 95 min (SD ± 18 min) from skin incision to dressing application (excluding tourniquet time) after the initial learning curve. In terms of complications, Park et al. [18] reported a high complication rate (6 cases among 32 patients), such as superficial infection, patellar tendon rupture, patellar dislocation, supracondylar fracture, patellar fracture, and peroneal nerve injury, during the learning stage. However, no major adverse results have been observed after completion of the learning process.

This study has some limitations that require consideration. Although this study was performed in a randomized, prospective manner, patients were able to deduce from skin incisions which procedure had been used on which knee, and this could have significantly impacted our results. Furthermore, the relatively small number of patients recruited could have weakened the power or our analysis. In addition, though we found that blood loss for robot-assisted knees was significantly less than for conventional knees, we only measured the amount of postoperative drainage, which only provides a crude measure of actual blood loss. Finally, we performed a 6° conventional TKA correction in every case without considering the preoperative femoral anatomy.

Conclusion

Despite the disadvantages of cost and time required for preoperative planning, surgery, and tourniquet time, robot-assisted TKA resulted in significantly better leg alignment (no outliers) than conventional TKA, which showed 8 (26.7%) outliers for femoral side coronal inclination, 3 (10%) for femoral side sagittal inclination, and 15(50%) for tibial side sagittal inclination, and showed non-significantly better clinical and radiographic results. However, blood loss was significantly less in robotic group. Overall, we conclude that the better results of robot-assisted TKA could influence patient satisfaction levels or preferences.

Conflict of interest None of the authors received financial support for this study.

References

1. Bathis H, Perlick L, Tingart M, Perlick C, Luring C, Grifka J (2005) Intraoperative cutting errors in total knee arthroplasty. Arch Orthop Trauma Surg 125:16–20
2. Bellemans J, Vandenneucker H, Vanlauwe J (2007) Robot-assisted total knee arthroplasty. Clin Orthop Relat Res 464:111–116
3. Decking J, Theis C, Achenbach T, Roth E, Nafe B, Eckardt A (2004) Robotic total knee arthroplasty: the accuracy of CT-based component placement. Acta Orthop Scand 75:573–579
4. Delp SL, Stulberg SD, Davies B, Picard F, Leitner F (1998) Computer assisted knee replacement. Clin Orthop Relat Res 354:49–56
5. Fadda M, Marcacci M, Toksvig-Larsen S, Wang T, Meneghello R (1998) Improving accuracy of bone resections using robotics tool holder and a high speed milling cutting tool. J Med Eng Technol 22:280–284
6. Griffin FM, Insall JN, Scuderi GR (2000) Accuracy of soft tissue balancing in total knee arthroplasty. J Arthroplasty 15:970–973
7. Jeffery RS, Morris RW, Denham RA (1991) Coronal alignment after total knee replacement. J Bone Joint Surg Br 73:709–714
8. Jenny JY, Clemens U, Kohler S, Kiefer H, Konermann W, Miehlke RK (2005) Consistency of implantation of a total knee arthroplasty with a non-image-based navigation system: a case-control study of 235 cases compared with 235 conventionally implanted prostheses. J Arthroplasty 20:832–839
9. Laskin RS (2001) The Genesis total knee prosthesis: a 10-year followup study. Clin Orthop Relat Res 388:95–102
10. Laskin RS (2003) New techniques and concepts in total knee replacement. Clin Orthop Relat Res 416:151–153
11. Laskin RS, Rieger MA (1989) The surgical technique for performing a total knee replacement arthroplasty. Orthop Clin North Am 20:31–48
12. Lutzner J, Krummenauer F, Wolf C, Gunther KP, Kirschner S (2008) Computer-assisted and conventional total knee replacement: a comparative, prospective, randomised study with radiological and CT evaluation. J Bone Joint Surg Br 90:1039–1044
13. Mahaluxmivala J, Bankes MJ, Nicolai P, Aldam CH, Allen PW (2001) The effect of surgeon experience on component positioning in 673 press fit condylar posterior cruciate-sacrificing total knee arthroplasties. J Arthroplasty 16:635–640
14. Maniar RN, Johorey AC, Pujary CT, Yadava AN (2011) Margin of error in alignment: a study undertaken when converting from conventional to computer-assisted total knee arthroplasty. J Arthroplasty 26:82–87
15. Matsen FA 3rd, Garbini JL, Sidles JA, Pratt B, Baumgarten D, Kaiura R (1993) Robotic assistance in orthopaedic surgery. A proof of principle using distal femoral arthroplasty. Clin Orthop Relat Res 296:178–186
16. Mielke RK, Clemens U, Jens JH, Kershally S (2001) Navigation in knee endoprosthesis implantation–preliminary experiences and prospective comparative study with conventional implantation technique. Z Orthop Ihre Grenzgeb 139:109–116
17. Novotny J, Gonzalez MH, Amirouche FML, Li YC (2001) Geometric analysis of potential error in using femoral intramedullary guides in total knee arthroplasty. J Arthroplasty 16:641–647
18. Park SE, Lee CT (2007) Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. J Arthroplasty 22:1054–1059
19. Petersen TL, Engh GA (1988) Radiographic assessment of knee alignment after total knee arthroplasty. J Arthroplasty 3:67–72
20. Plaskos C, Hodgson AJ, Inkpen K, McGraw RW (2002) Bone cutting errors in total knee arthroplasty. J Arthroplasty 17:698–705
21. Rand JA, Coventry MB (1988) Ten-year evaluation of geometric total knee arthroplasty. Clin Orthop Relat Res 232:168–173
22. Reed SC, Gollish J (1997) The accuracy of femoral intramedullary guides in total knee arthroplasty. J Arthroplasty 12:677–682
23. Ritter MA, Faris PM, Keating EM, Meding JB (1994) Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res 299:153–156
24. Rodriguez JA, Bhende H, Ranawat CS (2001) Total condylar knee replacement: a 20-year followup study. Clin Orthop Relat Res 388:10–17
25. Saragaglia D, Picard F, Chaussard C, Montbarbon E, Leitner F, Cinquin P (2001) Computer-assisted knee arthroplasty: comparison with a conventional procedure. Results of 50 cases in a prospective randomized study. Rev Chir Orthop Reparatrice Appar Mot 87:18–28
26. Scott WN, Rubinstein M, Scuderi G (1988) Results after knee replacement with a posterior cruciate-substituting prosthesis. J Bone Joint Surg Am 70:1163–1173
27. Siebert W, Mai S, Kober R, Heeckt PF (2002) Technique and first clinical results of robot-assisted total knee replacement. Knee 9:173–180
28. Sparmann M, Wolke B, Czupalla H, Banzer D, Zink A (2003) Positioning of total knee arthroplasty with and without navigation support—A prospective, randomised study. J Bone Joint Surg Br 85B:830–835
29. Takahashi T, Wada Y, Yamamoto H (1997) Soft-tissue balancing with pressure distribution during total knee arthroplasty. J Bone Joint Surg Br 79B:235–239
30. Van Ham G, Denis K, Vander Sloten J, Van Audekercke R, Van der Perre G, De Schutter J, Aertbelien E, Demey S, Bellemans J (1998) Machining and accuracy studies for a tibial knee implant using a force-controlled robot. Comput Aided Surg 3:123–133