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Original Research Article

Robotic-Assisted versus Conventional Total Knee Arthroplasty: A Comparative Study of Functional and Radiological Outcomes

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Abstract

Background: Robotic-assisted total knee arthroplasty (TKA) has been introduced to improve surgical precision, component positioning, and limb alignment. This study compared the functional and radiological outcomes of robotic-assisted and conventional TKA.

Methods: This prospective comparative study included 140 patients undergoing primary TKA, with 70 patients each in the robotic-assisted and conventional groups. Functional outcomes were assessed using the Knee Society Score (KSS), WOMAC score, Visual Analogue Scale (VAS), and range of motion. Radiological assessment included hip–knee–ankle angle, mechanical-axis deviation, and component alignment. Patients were followed for 12 months.

Results: Both groups showed substantial postoperative improvement. Robotic-assisted TKA demonstrated significantly better KSS and WOMAC scores at 3 and 6 months; however, differences at 12 months were not statistically significant. Mechanical-axis alignment within ±3° of neutral was achieved in 94.3% of robotic-assisted and 81.4% of conventional TKAs ($p=0.020$). Mechanical-axis outliers occurred in 5.7% and 18.6%, respectively ($p=0.020$). Femoral and tibial component alignment deviations were significantly lower with robotic assistance ($p<0.001$). Operative time was longer in the robotic group (105.6 ± 15.8 vs 88.4 ± 14.2 minutes; $p<0.001$), while complication rates were comparable.

Conclusion: Robotic-assisted TKA provided superior radiological accuracy and fewer alignment outliers, with modest advantages in early functional recovery. However, both techniques produced comparable functional outcomes at 12 months. Longer-term studies are required to determine whether improved robotic precision translates into superior implant survival and sustained clinical benefit.

Keywords: Robotic-Assisted Total Knee Arthroplasty; Conventional Total Knee Arthroplasty; Mechanical Alignment; Knee Society Score; WOMAC; Component Positioning; Radiological Outcome.

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Introduction

Total knee arthroplasty (TKA) is an established surgical treatment for patients with advanced knee osteoarthritis who have persistent pain and functional disability despite adequate conservative management. Successful TKA aims to relieve pain, restore knee function, achieve appropriate limb alignment, and provide long-term implant stability. However, variations in component positioning and postoperative mechanical alignment may influence functional outcomes and implant performance.

Conventional TKA relies on intramedullary and extramedullary alignment guides, anatomical landmarks, and the surgeon's experience for bone preparation and component positioning. Although conventional techniques provide satisfactory outcomes in most patients, deviations from the planned component position and mechanical axis can occur. Robotic-assisted TKA has therefore been introduced to improve the precision and reproducibility of surgical planning, bone resection, component positioning, and limb alignment. [1,2]

Robotic systems incorporate preoperative or intraoperative anatomical information into patient-specific surgical planning and provide real-time guidance during bone preparation. This technology may allow more accurate restoration of the mechanical axis and reduce radiological alignment outliers compared with conventional

instrumentation. Prospective comparative studies have demonstrated improved accuracy of component placement and limb alignment with robotic-assisted TKA. [3,4] In addition to radiological accuracy, robotic assistance may facilitate more precise soft-tissue balancing and restoration of the joint line. Liow et al. [5] demonstrated improved accuracy in restoration of the mechanical axis and joint line with robotic-assisted TKA. Nevertheless, improved radiological accuracy does not necessarily translate directly into superior clinical outcomes.

Functional recovery, pain relief, patient satisfaction, and quality of life remain important measures of the success of TKA. Some studies have demonstrated potential improvements in patient-reported and quality-of-life outcomes following robotic-assisted procedures, whereas others have reported relatively small differences compared with conventional TKA. [6] Thus, further comparative evaluation of both functional and radiological parameters is required.

Therefore, the present study was undertaken to compare the functional and radiological outcomes of robotic-assisted and conventional total knee arthroplasty, with particular emphasis on postoperative functional scores, pain, and range of motion, limb alignment, and component positioning.

Materials and Methods

Study Design and Participants: This prospective comparative study included 140 patients with advanced knee osteoarthritis undergoing primary total knee arthroplasty. Patients were divided into two groups according to the surgical technique:

- **Group R:** 70 patients undergoing robotic-assisted total knee arthroplasty.
- **Group C:** 70 patients undergoing conventional total knee arthroplasty.

Patients fulfilling the eligibility criteria were enrolled consecutively during the study period.

Inclusion Criteria: Patients aged 50–80 years with primary knee osteoarthritis, persistent pain and functional limitation despite adequate conservative treatment, radiographic evidence of advanced osteoarthritis, and an indication for primary TKA were included.

Exclusion Criteria: Patients with inflammatory arthritis, active or previous knee infection, and previous major reconstructive surgery around the knee, severe extra-articular deformity, neuromuscular disorders affecting the lower limb, revision TKA, or medical contraindications to surgery were excluded.

Preoperative Assessment: All patients underwent detailed clinical and radiological evaluation. Demographic characteristics, body mass index, duration of symptoms, affected side, deformity, knee stability, and range of motion were recorded.

Functional assessment was performed using the Knee Society Score (KSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Pain severity was evaluated using the Visual Analogue Scale (VAS).

Preoperative radiological assessment included standing anteroposterior and lateral knee radiographs, skyline views where required, and full-length weight-bearing lower-limb radiographs. The hip–knee–ankle (HKA) angle and mechanical-axis deviation were recorded.

Robotic-Assisted TKA: Patients in Group R underwent TKA using a robotic-assisted system. Patient-specific anatomical data were obtained according to the requirements of the robotic platform. Intraoperative registration and surgical planning were performed to determine appropriate component size, position, alignment, and bone-resection levels.

Bone resections were subsequently performed with robotic assistance according to the planned parameters. Intraoperative assessment of ligament balance, alignment, and range of motion was performed before final implantation.

Conventional TKA: Patients in Group C underwent conventional TKA using standard intramedullary femoral and extramedullary tibial alignment guides. Bone resections and component positioning were performed using standard anatomical landmarks and conventional instrumentation. Soft-tissue balancing was performed as required to obtain satisfactory stability and alignment.

Postoperative Management: A standardized postoperative protocol was followed in both groups. Analgesia, thromboprophylaxis, early mobilization, quadriceps strengthening, and knee range-of-motion exercises were initiated according to institutional protocol. Patients were encouraged to progress to full weight-bearing as tolerated.

Outcome Assessment: Patients were evaluated preoperatively and at 6 weeks, 3 months, 6 months, and 12 months after surgery.

The primary functional outcomes included:

- Knee Society Score (KSS)
- WOMAC score
- VAS pain score
- Knee range of motion

Radiological outcomes included postoperative HKA angle, mechanical-axis alignment, femoral

component alignment, tibial component alignment, and proportion of alignment outliers, with an outlier defined according to the predetermined radiographic criteria.

Secondary outcomes included operative duration, length of hospital stay, postoperative complications, requirement for revision or reoperation, and patient satisfaction.

Statistical Analysis: Data were analyzed using SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The independent Student's t-test was used to compare continuous variables between the two groups, while paired t-test was used for within-group comparisons. The Chi-square test or Fisher's exact test was applied to categorical variables as appropriate. A p-value <0.05 was considered statistically significant.

Results

A total of 140 patients undergoing primary total knee arthroplasty were included in the study. Seventy patients underwent robotic-assisted total knee arthroplasty (Group R), while 70 underwent conventional total knee arthroplasty (Group C). Both groups showed significant improvement in pain and functional outcomes during the 12-month follow-up.

Table 1: Baseline Demographic and Clinical Characteristics

Variable	Robotic-Assisted TKA (n=70)	Conventional TKA (n=70)	p-value
Age (years), mean ± SD	65.2 ± 6.8	66.0 ± 7.1	0.497
Male, n (%)	29 (41.4%)	31 (44.3%)	0.734
Female, n (%)	41 (58.6%)	39 (55.7%)	
BMI (kg/m²), mean ± SD	28.1 ± 3.4	28.6 ± 3.7	0.406
Right knee, n (%)	38 (54.3%)	40 (57.1%)	0.733
Left knee, n (%)	32 (45.7%)	30 (42.9%)	
Duration of symptoms (years)	6.8 ± 2.5	7.1 ± 2.7	0.496
Preoperative VAS score	7.5 ± 1.0	7.4 ± 1.1	0.575
Preoperative KSS	48.7 ± 8.5	49.2 ± 8.3	0.725
Preoperative WOMAC score	64.3 ± 8.8	63.7 ± 9.1	0.692
Preoperative ROM (degrees)	103.6 ± 11.4	104.2 ± 10.9	0.751

There were no statistically significant differences between the groups with respect to age, sex, BMI, affected side, duration of symptoms, baseline pain, functional scores, or range of motion (p>0.05), indicating that the groups were comparable at baseline.

Table 2: Comparison of Functional Outcomes

Outcome	Robotic-Assisted TKA (n=70)	Conventional TKA (n=70)	p-value
Knee Society Score (KSS)			
Preoperative	48.7 ± 8.5	49.2 ± 8.3	0.725
3 months	76.8 ± 7.5	73.9 ± 7.8	0.027
6 months	84.5 ± 6.7	82.1 ± 7.0	0.040
12 months	89.6 ± 6.2	87.8 ± 6.5	0.096
WOMAC score			
Preoperative	64.3 ± 8.8	63.7 ± 9.1	0.692
3 months	28.5 ± 7.4	31.7 ± 7.8	0.014
6 months	19.3 ± 6.2	21.8 ± 6.5	0.022
12 months	14.2 ± 5.4	15.6 ± 5.7	0.138
VAS at 12 months	1.5 ± 0.7	1.7 ± 0.8	0.118
ROM at 12 months (degrees)	122.8 ± 8.6	120.7 ± 9.1	0.163

Both groups demonstrated marked improvement in functional scores after surgery. Robotic-assisted TKA showed significantly better KSS and WOMAC scores at 3 and 6 months, suggesting slightly faster early functional recovery. However, by 12 months, differences in KSS, WOMAC, VAS pain, and range of motion were not statistically significant.

Table 3: Comparison of Postoperative Radiological Outcomes

Radiological Parameter	Robotic-Assisted TKA (n=70)	Conventional TKA (n=70)	p-value
Postoperative HKA angle (degrees)	179.4 ± 1.2	178.3 ± 2.4	0.001
Absolute deviation from neutral mechanical axis (degrees)	1.1 ± 0.8	2.3 ± 1.5	<0.001
HKA within ±3° of neutral	66 (94.3%)	57 (81.4%)	0.020
Mechanical-axis outlier (>3°)	4 (5.7%)	13 (18.6%)	0.020
Femoral component alignment deviation (degrees)	1.0 ± 0.7	1.8 ± 1.2	<0.001
Tibial component alignment deviation (degrees)	0.9 ± 0.6	1.7 ± 1.1	<0.001
Femoral component outlier (>3°)	2 (2.9%)	8 (11.4%)	0.049
Tibial component outlier (>3°)	2 (2.9%)	9 (12.9%)	0.028

Robotic-assisted TKA demonstrated significantly greater radiological accuracy. The mean deviation from the neutral mechanical axis was significantly lower in the robotic group (1.1° vs 2.3°, p<0.001). Alignment within ±3° of neutral was achieved in 94.3% of robotic-assisted procedures compared with 81.4% of conventional procedures. Component-positioning outliers were also significantly less frequent following robotic-assisted TKA.

Table 4:Perioperative Parameters and Complications

Parameter	Robotic-Assisted TKA (n=70)	Conventional TKA (n=70)	p-value
Operative time (minutes)	105.6 ± 15.8	88.4 ± 14.2	<0.001
Hospital stay (days)	4.1 ± 1.2	4.4 ± 1.3	0.158
Superficial infection	1 (1.4%)	2 (2.9%)	1.000
Deep infection	0	1 (1.4%)	1.000
Knee stiffness	2 (2.9%)	3 (4.3%)	1.000
Thromboembolic complication	1 (1.4%)	1 (1.4%)	1.000
Reoperation/revision	1 (1.4%)	2 (2.9%)	1.000
Any complication*	4 (5.7%)	7 (10.0%)	0.346
Satisfied/very satisfied	64 (91.4%)	61 (87.1%)	0.411

***Patients with more than one complication were counted once in the overall complication rate.**

The mean operative duration was significantly longer in the robotic-assisted group (105.6 vs 88.4 minutes, p<0.001). There was no statistically significant difference in hospital stay or overall postoperative complication rates. Patient satisfaction was high in both groups.

Discussion

The present study compared functional and radiological outcomes of robotic-assisted and conventional total knee arthroplasty in 140 patients. Both techniques resulted in substantial improvement in pain, knee function, and range of motion. Robotic-assisted TKA demonstrated superior radiological accuracy and modestly better early functional recovery, although functional differences between the groups were no longer statistically significant at 12 months.

The robotic-assisted group showed significantly better KSS and WOMAC scores at 3 and 6 months, suggesting faster early functional recovery. However, at 12 months, the differences in KSS, WOMAC, VAS, and range of motion were not statistically significant. Liow et al. [6] similarly reported that robotic-assisted TKA may provide improvements in certain quality-of-life measures, suggesting a potential early clinical advantage associated with more accurate surgical execution. Robotic systems may facilitate precise bone preparation and individualized soft-tissue balancing, potentially contributing to early postoperative recovery. [7] The principal advantage of robotic-assisted TKA in the present study was improved radiological accuracy. Mechanical-axis alignment within ±3° of neutral was achieved in 94.3% of robotic-assisted procedures compared with 81.4% of conventional procedures. Mechanical-axis outliers were consequently less frequent in the robotic group (5.7% vs 18.6%). These findings support the proposed role of robotic technology in improving the precision and reproducibility of implant positioning.

Despite this improved radiological accuracy, its influence on longer-term clinical outcomes remains uncertain. Kim et al. [8] found no significant advantage in long-term clinical outcome scores or survivorship with robotic-assisted TKA compared with conventional TKA. Similarly, Jeon et al. [9] reported that improved surgical precision did not necessarily translate into superior long-term clinical or radiological outcomes. These observations are consistent with our finding that functional differences between the groups diminished by 12 months. Early comparative evidence has nevertheless demonstrated improved accuracy with robotic techniques. Xu et al. [10] reported favorable early radiographic outcomes following robot-assisted TKA. Park and Lee [11]

also demonstrated differences in implantation accuracy between robotic-assisted and conventional techniques. Collectively, these findings indicate that improved component positioning and mechanical alignment remain among the most consistent benefits of robotic-assisted TKA.

The mean operative time in our study was significantly longer with robotic-assisted TKA (105.6 versus 88.4 minutes). Additional time for registration, robotic planning, and execution may account for this difference. Despite longer operative duration, overall complication rates were comparable between the groups. Recent systematic reviews have similarly suggested that robotic-assisted TKA provides greater alignment precision without a consistent major advantage in clinical outcomes. [12,13] The clinical importance of achieving a neutral mechanical axis also continues to evolve as contemporary TKA increasingly considers individualized alignment strategies.

Aflatooni et al. [14] emphasized the expanding role of robotic technology in accurately executing different alignment philosophies. Thus, the value of robotics may extend beyond simply achieving neutral alignment toward reproducibly achieving a patient-specific surgical plan.

Overall, robotic-assisted TKA provided greater precision in mechanical-axis restoration and component positioning, while conventional TKA achieved comparable functional outcomes by 12 months.

Therefore, robotic assistance appears particularly advantageous for surgical accuracy, although longer follow-up is required to determine whether this translates into improved implant survivorship and clinically meaningful long-term benefits.

Conclusion:

Both robotic-assisted and conventional total knee arthroplasty provided significant improvement in pain and functional outcomes. Robotic-assisted TKA demonstrated superior mechanical-axis restoration, more accurate component positioning, and fewer radiological outliers, along with modestly better early functional recovery. However, functional outcomes at 12 months and complication rates were comparable between the groups. Robotic-assisted TKA therefore offers greater surgical precision, but its long-term clinical superiority over conventional TKA remains to be established.

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