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Original Research

Comparative Analysis of Postoperative Outcomes in Robotic-Assisted Versus Conventional Total Knee Arthroplasty: A Multicenter Randomized Trial

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Abstract

Background: Total Knee Arthroplasty (TKA) has evolved with the advent of robotic assistance, promising enhanced alignment precision and potentially improved patient outcomes. However, comparative evidence from multicenter randomized trials remains limited. This study aims to evaluate postoperative outcomes between robotic-assisted and conventional TKA approaches in a diverse patient population.

Materials and Methods:A randomized, multicenter clinical trial was conducted across four tertiary care hospitals, enrolling 240 patients undergoing unilateral TKA. Participants were randomly allocated into two groups: Group A (Robotic-Assisted TKA, n=120) and Group B (Conventional TKA, n=120). Primary outcomes assessed included operative time, hospital stay duration, postoperative pain scores (VAS), range of motion (ROM), and functional outcomes (measured using the Knee Society Score - KSS) at 6 weeks and 6 months postoperatively. Complications were also recorded.

Results: The mean operative time was longer in Group A (112.4 ± 15.2 minutes) than Group B (96.7 ± 12.6 minutes). However, Group A demonstrated a significantly shorter hospital stay (3.1 ± 0.9 days vs. 4.3 ± 1.1 days, $p<0.01$). VAS scores at 48 hours post-surgery were lower in the robotic group (3.6 ± 1.2 vs. 5.1 ± 1.5, $p<0.001$). At 6 months, Group A had improved ROM (123.4° ± 7.8° vs. 117.1° ± 8.3°, $p=0.004$) and higher mean KSS (89.2 ± 6.5 vs. 82.6 ± 7.1, $p<0.001$). The incidence of complications was slightly lower in the robotic group (5% vs. 9%, $p=0.27$), though not statistically significant.

Conclusion: Robotic-assisted TKA offers improved short-term functional outcomes, reduced postoperative pain, and shorter hospitalization compared to conventional techniques, despite longer surgical times. These findings support the integration of robotic systems in orthopedic surgical practice, particularly in high-volume centers.

Keywords: Robotic knee arthroplasty, conventional total knee replacement, postoperative outcomes, Knee Society Score, randomized trial

Introduction

Total knee arthroplasty (TKA) is one of the most effective surgical interventions for end-stage knee osteoarthritis, providing substantial pain relief and improved function in affected individuals (1). With the global aging population and increasing prevalence of degenerative joint diseases, the demand for primary TKA continues to rise steadily (2). Although conventional TKA has demonstrated excellent long-term outcomes, limitations persist, particularly in achieving optimal component alignment and soft-tissue balancing, both of which are critical for postoperative function and implant longevity (3,4).

In recent years, technological advancements have led to the integration of robotic systems in orthopedic surgery, including TKA. Robotic-assisted TKA is designed to enhance surgical precision by providing real-time feedback, improved alignment accuracy, and reproducible bone preparation based on preoperative planning or intraoperative mapping (5,6). Several studies suggest that robotic systems may reduce the variability in component placement and improve the

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accuracy of mechanical axis restoration compared to manual techniques (7,8).

Despite these advantages, the clinical benefits of robotic-assisted TKA remain a subject of ongoing debate. Concerns have been raised regarding increased operative time, higher procedural costs, and the need for a learning curve among surgeons (9,10). Furthermore, the extent to which these technical improvements translate into superior functional outcomes, pain relief, and patient satisfaction compared to conventional methods is not yet fully established (11,12).

Given the increasing adoption of robotic systems in orthopedic practices worldwide, there is a need for robust evidence comparing clinical outcomes between robotic-assisted and traditional TKA. This multicenter randomized trial aims to address this gap by evaluating postoperative outcomes, functional scores, pain levels, and complication rates across both surgical modalities in a diverse patient population.

Materials and Methods

Participants: A total of 240 adult patients (aged 50–80 years) with a clinical and radiographic diagnosis of primary knee osteoarthritis indicated for unilateral total knee arthroplasty were included. Exclusion criteria comprised previous knee surgeries, inflammatory arthritis, severe deformities (>15° varus/valgus), neuromuscular disorders, or any contraindications for surgery or anesthesia.

Randomization and Allocation: Eligible patients were randomized using a computer-generated sequence into two equal groups:

- **Group A (n = 120):** Robotic-assisted TKA
- **Group B (n = 120):** Conventional manual TKA
- Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes opened immediately before surgery.

Surgical Technique: All surgeries were performed by experienced orthopedic surgeons with expertise in both techniques. For robotic-assisted TKA, a semi-active robotic system was used, guided by preoperative imaging and intraoperative feedback. In the conventional group, standard mechanical guides and intramedullary alignment were used. In both groups, the same implant design and postoperative protocols were followed.

Outcome Measures

Primary outcomes included:

- **Operative time** (measured from incision to closure)
- **Length of hospital stay** (in days)
- **Postoperative pain** (assessed using the Visual Analogue Scale [VAS] at 24 and 48 hours postoperatively)
- **Range of Motion (ROM)** at 6 weeks and 6 months
- **Functional outcomes** measured by the Knee Society Score (KSS) at 6 months
- **Complication rates** including infection, deep vein thrombosis, and need for revision

Follow-Up and Data Collection: Patients were followed at regular intervals postoperatively (2 weeks, 6 weeks, and 6 months). All data were collected by independent assessors blinded to the type of surgery. Standardized rehabilitation protocols were applied to both groups to minimize bias.

Statistical Analysis: Statistical analysis was performed using SPSS software version 26.0 (IBM Corp, Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation and compared using the independent t-test. Categorical variables were analyzed using the chi-square test. A p-value <0.05 was considered statistically significant.

Results

Out of the 240 enrolled patients, all completed the study protocol with no dropouts. The demographic characteristics such as age, gender distribution, and body mass index (BMI) were statistically comparable between the two groups (Table 1).

Operative and Post operative Outcomes: The mean operative duration was significantly higher in the robotic-assisted group (112.4 ± 15.2 minutes) compared to the conventional group (96.7 ± 12.6 minutes, $p< 0.001$). However, patients in Group A had a shorter average hospital stay (3.1 ± 0.9 days) than those in Group B (4.3 ± 1.1 days, $p< 0.01$).

Pain scores measured via the Visual Analogue Scale (VAS) at 24 and 48 hours postoperatively were lower in the robotic-assisted group, suggesting better early pain control ($p< 0.001$). Additionally, the robotic group exhibited improved knee range of motion (ROM) and higher mean Knee Society Scores (KSS) at 6 months postoperatively (Table 2).

Complications

The incidence of postoperative complications was lower in the robotic group (6/120, 5%) compared to the conventional group (11/120, 9.2%), although the difference was not statistically significant ($p = 0.27$). Most complications were minor, including superficial wound infections and transient stiffness; no revisions were reported during the follow-up period.

Table 1. Baseline Characteristics of the Study Population

Parameter	Robotic Group (n = 120)	Conventional Group (n = 120)	*p*-value
Mean Age (years)	66.4 ± 7.3	65.9 ± 6.9	0.56
Female (%)	68 (56.7%)	71 (59.2%)	0.71

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Mean BMI (kg/m²)	28.5 ± 3.4	28.7 ± 3.6	0.65
Affected Side (Right)	63 (52.5%)	66 (55%)	0.74

Table 2. Comparison of Operative and Functional Outcomes

Outcome Measure	Robotic Group (n = 120)	Conventional Group (n = 120)	*p*-value
Operative Time (min)	112.4 ± 15.2	96.7 ± 12.6	<0.001
Hospital Stay (days)	3.1 ± 0.9	4.3 ± 1.1	<0.01
VAS at 48 hrs	3.6 ± 1.2	5.1 ± 1.5	<0.001
ROM at 6 months (degrees)	123.4 ± 7.8	117.1 ± 8.3	0.004
KSS at 6 months	89.2 ± 6.5	82.6 ± 7.1	<0.001
Post-op Complications (n/%)	6 (5%)	11 (9.2%)	0.27

Discussion

This multicenter randomized trial demonstrated that robotic-assisted total knee arthroplasty (TKA) offers significant improvements in early postoperative outcomes compared to the conventional manual technique. Notably, patients who underwent robotic TKA experienced reduced pain scores, shorter hospital stays, improved range of motion (ROM), and higher functional scores at six months. These findings align with previous research highlighting the potential of robotic systems to enhance precision and optimize component positioning during arthroplasty (1,2).

One of the key advantages observed in the robotic group was superior early pain control. This may be attributed to improved soft tissue balancing and more accurate bony resections, which have been previously associated with reduced periarticular trauma and faster recovery (3,4). Reduced inflammation and improved early mobilization have also been cited in robotic TKA patients, contributing to quicker rehabilitation (5).

The improvement in range of motion and functional outcomes, as reflected by the Knee Society Score (KSS), corroborates earlier studies suggesting that improved alignment and ligament balancing achieved through robotic systems may lead to better joint kinematics (6,7). A randomized trial by Marchand et al. reported similar functional benefits with robotic-assisted procedures compared to conventional methods at one-year follow-up (8).

Although robotic TKA was associated with longer operative times in this study, such findings are consistent with early adoption of newer technologies, where increased surgical duration is often observed during the learning curve phase (9,10). However, evidence suggests that operative times typically decline with increased surgeon experience and procedural familiarity (11). Importantly, the longer surgical duration did not correlate with increased complications, supporting the overall safety of robotic procedures.

Our study also found a non-significant reduction in complication rates in the robotic group. While the difference was not statistically meaningful, previous meta-analyses have indicated that robotic systems may reduce the risk of outliers in alignment, potentially lowering the incidence of mechanical failures and the need for revisions in the long term (12,13).

Despite the improved clinical outcomes, the adoption of robotic-assisted TKA must be weighed against considerations such as increased cost, need for technical expertise, and institutional infrastructure. Economic evaluations are essential to assess long-term cost-effectiveness, particularly when balancing upfront technology investment against potential reductions in rehabilitation time and revision surgeries (14,15).

Limitations of this study include the relatively short follow-up period, which precludes assessment of long-term implant survival and revision rates. Furthermore, while efforts were made to standardize surgical protocols across centers, surgeon variability and institutional differences could have influenced certain outcomes.

In summary, the findings from this randomized multicenter trial add to the growing body of evidence suggesting that robotic-assisted TKA may offer measurable benefits in early recovery metrics and functional outcomes when compared to the conventional approach. Further long-term studies are required to determine whether these benefits translate into sustained implant survival and cost-efficiency over time.

Conclusion

Robotic-assisted total knee arthroplasty demonstrated superior early postoperative outcomes compared to the conventional approach, including reduced pain, improved functional scores, and shorter hospital stays. While surgical time was longer, the clinical benefits suggest that robotic TKA may offer a valuable advantage in patient recovery. Further long-term studies are needed to assess implant survival and cost-effectiveness.

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