

Original Research Article

Conventional versus robotic total knee arthroplasty – a comparative study of accuracy, alignment and early functional results

Sathi Venu G. K. Reddy, Nageswara R. Vutharkar, Satya S. T. Rongala,
Praveen T. Kunapareddy*, Pedapati S. Chandra

Department of Orthopaedics, G. S. L. Medical College and General Hospital, Rajahmundry, Andhra Pradesh, India

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*Correspondence:

Dr. Praveen T. Kunapareddy,

E-mail: kpoteja1999@gmail.com

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ABSTRACT

Background: Restoration of mechanical alignment and optimization of functional outcomes are critical for total knee arthroplasty (TKA). Robotic systems aim to improve the accuracy of bone cuts and reduce malalignment. Evidence from Indian populations remains limited.

Methods: The present study was a prospective, non-randomized control study. The sample size was 43 knees in each group (robotic and traditional), for a total of 86 knees, using a two-sided $\alpha=0.05$ and power of 80%. Functional outcomes were evaluated with oxford knee score (OKS) and knee society score (KSS) at 0 weeks, 6 weeks, 3 months and 6 months. Perioperative variables, including operative time, blood loss, length of stay, pain score and complications, were recorded.

Results: Baseline demographic and clinical characteristics were comparable between groups. Robotic TKA demonstrated fewer alignment outliers (11.6% versus 25.6%, $p=0.166$) and significantly lower mean absolute HKA error ($1.4^\circ \pm 1.1$ versus $2.4^\circ \pm 1.7$, $p=0.002$). Functional outcomes improved in both groups over time. Robotic TKA showed higher OKS at 6 weeks (32.2 ± 3.5 versus 29.9 ± 4.3 , $p=0.009$) and higher KSS at 6 weeks (75.6 ± 9.7 versus 69.6 ± 7.9 , $p=0.003$) and 6 months (90.3 ± 4.9 versus 85.0 ± 5.6 , $p<0.001$). Robotic TKA required longer operative time (94.2 ± 9.4 versus 81.9 ± 9.7 min, $p<0.001$) but resulted in lower blood loss (293.9 ± 52.2 versus 350.5 ± 46.3 ml, $p<0.001$). Length of stay and complication rates were similar between groups.

Conclusions: Robotic TKA improves alignment accuracy and enhances early functional outcomes compared to conventional techniques, with acceptable perioperative safety in Indian settings.

Keywords: Conventional total knee arthroplasty, Robotic total knee arthroplasty, TKA, Oxford knee score, Knee society score

INTRODUCTION

Millions of people worldwide receive substantial relief from pain and functional restoration from total knee arthroplasty (TKA), which continues to be the gold standard for resolving end-stage osteoarthritis of the knee. In India, where osteoarthritis affects over 15% of the adult population-predominantly in rural and urban elderly cohorts-the demand for TKA has surged, with projections estimating over 200,000 procedures by 2025 due to rising

longevity and lifestyle factors.¹ Despite its efficacy, conventional jig-based TKA faces challenges, including implant malalignment in up to 20-30% of cases, which correlates with accelerated polyethylene wear, instability, and suboptimal long-term survivorship.² Such outliers often stem from human variability in bone cuts, soft-tissue tensioning, and intraoperative decision-making, potentially contributing to the 15-20% dissatisfaction rates reported globally, including in diverse Indian populations.³

The advent of robotic-assisted TKA (RATKA) addresses these limitations by leveraging semi-autonomous systems for precise preoperative planning, real-time quick feedback, and millimetre-level bone resection accuracy. Introduced in the early 2000s, RATKA integrates computed tomography-based or imageless navigation to optimize component positioning, ligament balancing, and constitutional alignment-mimicking native knee kinematics rather than rigid mechanical axes.⁴ Meta-analyses of randomized controlled trials (RCTs) demonstrate that RATKA reduces alignment outliers by 50-70%, particularly in coronal and sagittal planes, enhancing joint line preservation and reducing soft-tissue releases by up to 40% compared to conventional techniques.^{5,6} Early functional outcomes, assessed via knee society scores (KSS) and western ontario and mcmaster universities osteoarthritis index (WadOMAC), show modest improvements in pain scores and range of motion at 3-6 months post-RATKA, attributed to balanced gap techniques and minimized iatrogenic instability.⁷ However, long-term data (>10 years) remain sparse, with conflicting evidence on revision rates and cost-effectiveness, especially in resource-constrained settings like India, where RATKA adoption is nascent yet accelerating.

In the Indian context, where varus deformities predominate (up to 80% of cases) and patients often present with advanced disease, RATKA's potential to tailor alignments-such as functional or kinematic variants-could mitigate ethnic-specific risks like higher implant loosening.⁹ Yet, comparative studies are limited, with few addressing early functional metrics in diverse cohorts. Given variations in patient anatomy, healthcare infrastructure, and perioperative practices, it is essential to validate robotic TKA in the Indian context. This study was therefore designed with two objectives: to compare alignment accuracy between conventional and robotic TKA using long-leg standing radiographs, with HKA outliers defined as $>\pm 3^\circ$ from neutral, and to evaluate early functional outcomes using the Oxford knee score (OKS) and KSS.

METHODS

Design and patient selection

A prospective, observational, non-randomised control study was conducted in the Department of Orthopaedics at a G. S. L. Medical College and General Hospital in Rajahmundry, between August 2024 and August 2025.

The sample size was calculated to detect a decrease in mechanical axis outlier rate from 34% in conventional TKA, as reported in prior series of mechanically aligned TKA, to 10% with robotic-assisted TKA, based on previously published improvements in alignment precision with robotic systems.⁸ The necessary sample size was 43 knees in each group (robotic and traditional), for a total of 86 knees, using a two-sided $\alpha=0.05$ and power of 80%.

A sample of 86 patients undergoing primary TKA for advanced osteoarthritis or inflammatory arthritis were recruited. Patients were allocated to either robotic TKA (n=43) or conventional jig-based TKA (n=43) based on surgeon availability and patient preference. Patients aged 50-80 years, with a diagnosis of primary osteoarthritis or inflammatory arthritis requiring TKA, and willing to participate were included. Patients who had prior osteotomy or revision TKA on the ipsilateral limb, post-traumatic deformities requiring augments or hinged implants, severe bone loss (AORI type 2B/3), active infection, neuromuscular disorders affecting gait were excluded.

The study procedure was approved by the institutional ethics committee, and each participant provided signed informed consent. Conventional TKA was done with intramedullary femoral and extramedullary tibial guides. Robotic TKA was performed using a robotic-arm navigation system and preoperative CT-based planning. All instances included the use of standard cemented prostheses. Patellar resurfacing was carried out selectively.

Data collection and statistical analysis

Baseline variables: age, sex, BMI, ASA grade, Kellgren-lawrence (KL) radiographic grade, comorbidities (hypertension, diabetes). Radiographic outcomes: mechanical axis alignment assessed on long-leg standing radiographs. Outliers were defined as having an HKA deviation greater than $\pm 3^\circ$ from neutral. Absolute HKA error was calculated as $|\text{measured HKA} - 180^\circ|$. Functional outcomes, as assessed by OKS and KSS, were evaluated at 0 week, 6 weeks, 3 months and 6 months postoperatively. Perioperative outcomes have been recorded, including operating duration, intraoperative loss of blood, the duration of the hospital stay, pain and complications. Continuous variables were presented as mean $\pm$ SD or median (IQR), whereas categorical variables were reported as N (%). The χ^2 test was used to assess the primary result (outlier proportion) against risk ratios and 95% confidence intervals (CIs). $P<0.05$ was accepted as significant.

RESULT

Baseline characteristics

A total of 86 patients were included, with 43 in each group. Baseline demographic and clinical characteristics-including age, BMI, ASA grade, KL grade, hypertension, and diabetes-were comparable between the two groups (Table 1).

Radiographic outcomes

Robotic TKA demonstrated notably superior alignment performance. Mechanical-axis outliers ($>\pm 3^\circ$) occurred in 25.6% of conventional TKAs compared with 11.6% of robotic TKAs. Although this difference did not reach

statistical significance ($p=0.166$), the absolute HKA error was significantly lower in the robotic group ($1.4^{\circ}\pm 1.1$ versus $2.4^{\circ}\pm 1.7$, $p=0.002$), confirming improved alignment precision with robotic assistance (Table 2 and Figure 1).

Table 1: Baseline demographic and clinical characteristics of patients undergoing conventional and robotic TKA.

Variables	Conventional TKA (n=43)	Robotic TKA (n=43)	P value
Age (years) [#]	63.2 $\pm$ 6.5	64.1 $\pm$ 6.7	0.518
Gender, N (%)			
Male	17 (39.5)	19 (44.2)	0.827
Female	26 (60.5)	24 (55.8)	
BMI (kg/m ²) [#]	28.6 $\pm$ 3.6	28.6 $\pm$ 4.3	1.000
ASA grade, N (%)			0.627
Grade I	4 (9.3)	4 (9.3)	
Grade II	26 (60.5)	24 (55.8)	
Grade III	10 (23.3)	14 (32.6)	
Grade IV	3 (7.0)	1 (2.3)	
Kellgren-Lawrence grade, N (%)			0.202
Grade III	7 (16.3)	13 (30.2)	
Grade IV	36 (83.7)	30 (69.8)	
Comorbidities, N (%)			
Hypertension	27 (62.8)	27 (62.8)	1.000
Diabetes mellitus	7 (16.3)	9 (20.9)	0.782

[#]Mean $\pm$ SD, ^astatistically significant ($p<0.05$)

Table 2: Radiographic outcomes comparing conventional and robotic TKA.

Variables	Conventional TKA (n=43)	Robotic TKA (n=43)	P value
HKA outliers ($>\pm 3^{\circ}$) [*]	11 (25.6%)	5 (11.6%)	<0.166
Absolute HKA error ($^{\circ}$) [#]	2.4 $\pm$ 1.7	1.4 $\pm$ 1.1	0.002 ^a

^aStatistically significant ($p<0.05$), [#]mean $\pm$ SD, HKA=hip-knee-ankle angle

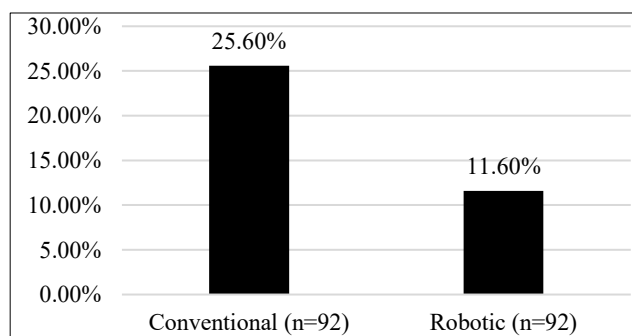


Figure 1: Bar graph showing proportion of alignment outliers in conventional and robotic TKA.

Functional outcomes

Both groups showed substantial functional improvement over time. Robotic TKA yielded higher OKS at 6 weeks (32.2 $\pm$ 3.5 versus 29.9 $\pm$ 4.3, $p=0.009$), with this advantage persisting at 3 months and 6 months. KSS values were also superior in the robotic group at 6 weeks (75.6 $\pm$ 9.7 versus 69.6 $\pm$ 7.9, $p=0.003$) and continued to remain higher at 6 months (90.3 $\pm$ 4.9 versus 85.0 $\pm$ 5.6, $p<0.001$) (Table 3 and Figure 2).

Table 3: Functional outcomes (OKS and KSS) at 0 weeks, 6 weeks, 3 months and 6 months in conventional and robotic TKA.

Variables	Conventional TKA (n=43), mean $\pm$ SD	Robotic TKA (n=43), mean $\pm$ SD	P value
OKS 0 weeks	20.5 $\pm$ 2.8	20.3 $\pm$ 3.1	0.772
OKS 6 weeks	29.9 $\pm$ 4.3	32.2 $\pm$ 3.5	0.009 ^a
OKS 3 months	34.5 $\pm$ 4.0	37.4 $\pm$ 2.9	<0.001 ^a
OKS 6 months	37.8 $\pm$ 2.8	41.5 $\pm$ 2.4	<0.001 ^a
KSS 0 weeks	50.3 $\pm$ 9.7	52.8 $\pm$ 10.2	0.269
KSS 6 weeks	69.6 $\pm$ 7.9	75.6 $\pm$ 9.7	<0.003 ^a
KSS 3 months	82.0 $\pm$ 6.8	84.3 $\pm$ 5.5	0.092
KSS 6 months	85.0 $\pm$ 5.6	90.3 $\pm$ 4.9	<0.001 ^a

OKS=Oxford knee score; KSS=knee society score, ^astatistically significant ($p<0.05$)

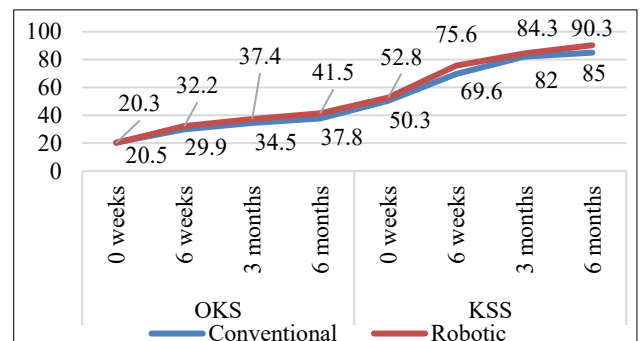


Figure 2: Line graph showing OKS and KSS trend over the follow up.

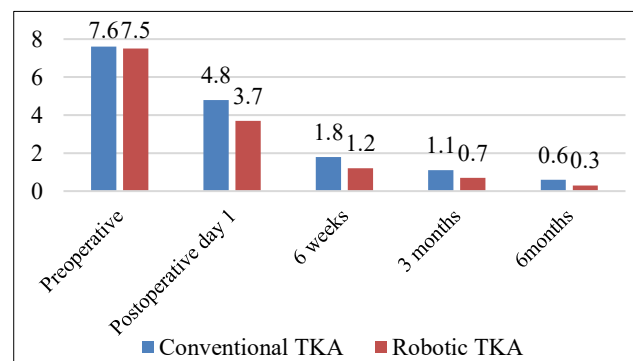


Figure 3: Bar graph showing pain score (VAS) pattern.

Perioperative outcomes

Robotic TKA required longer operative times (94.2 ± 9.4 min versus 81.9 ± 9.7 min, $p < 0.001$). However, robotic procedures resulted in significantly reduced intraoperative blood loss (293.9 ± 52.2 ml versus 350.5 ± 46.3 ml, $p < 0.001$). Length of stay was similar between groups, and complication rates were identical (7 cases in each group) (Table 4).

Table 4: Intraoperative and early postoperative outcomes in conventional and robotic TKA.

Variables	Conventional TKA (n=43), mean $\pm$ SD	Robotic TKA (n=43), mean $\pm$ SD	P value
Operative time (min)	81.9 $\pm$ 9.7	94.2 $\pm$ 9.4	<0.001 ^a
Length of stay (days)	5.9 $\pm$ 2.1	5.7 $\pm$ 2.2	0.508
Blood loss (ml)	350.5 $\pm$ 46.3	293.9 $\pm$ 52.2	<0.001 ^a
Complications*	7 (7.6%)	7 (7.6%)	1.000

^aStatistically significant ($p < 0.05$), *frequency (%)

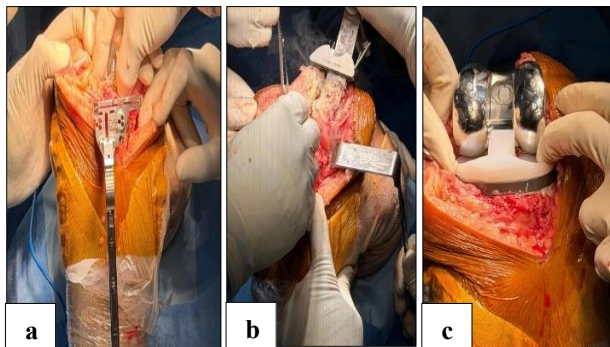


Figure 4: Intraoperative images of conventional total knee arthroplasty, (a) tibial cut, (b) femoral cut, and (c) implant placement.

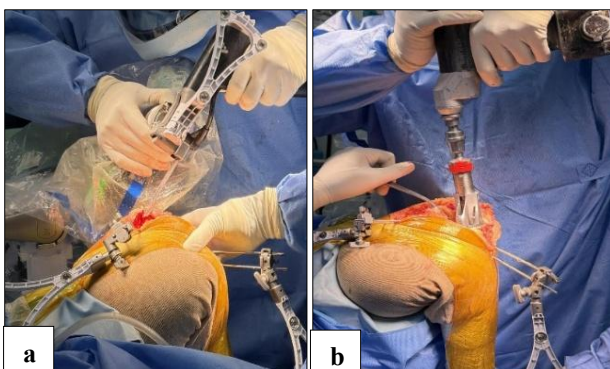


Figure 5: Intraoperative images of robotic assisted total knee arthroplasty, (a) femoral bone preparation, and (b) fibial bone preparation.

Table 5: Pain score (VAS) at pre -op, post-op day 1, 6 weeks, 3 months and 6 months in conventional and robotic TKA.

Variables	Conventional TKA (mean $\pm$ SD)	Robotic TKA (mean $\pm$ SD)	P value
Preoperative	7.6 $\pm$ 1.2	7.5 $\pm$ 1.3	0.749
Postoperative day 1	4.8 $\pm$ 2.1	3.7 $\pm$ 1.5	0.007
6 weeks	1.8 $\pm$ 1.1	1.2 $\pm$ 0.9	0.012
3 months	1.1 $\pm$ 0.9	0.7 $\pm$ 0.8	0.028
6 months	0.6 $\pm$ 0.7	0.3 $\pm$ 0.5	0.039

DISCUSSION

This prospective comparative study evaluated radiographic accuracy, functional recovery, and perioperative metrics between robotic-assisted and conventional TKA. Robotic TKA demonstrated meaningful advantages in alignment precision and early functional improvement, albeit with longer surgical time.

Alignment outcomes

Radiographic evaluation showed a lower proportion of alignment outliers in the robotic group (11.6% versus 25.6%). Although the outlier difference did not reach statistical significance, the robotic cohort displayed a clearly reduced absolute HKA deviation (1.4° versus 2.4° , $p = 0.002$). These findings parallel multicenter RCTs by Geng et al and Asian and Indian datasets, consistently demonstrating enhanced coronal accuracy with robotic systems.^{2,8-11} Meta-analyses likewise affirm robotics as superior for achieving desired alignment.^{1,3,5}

Functional outcomes

Robotic TKA patients exhibited faster functional recovery, with significantly higher OKS at 6 weeks and sustained improvements through 6 months. KSS was superior at both 6 weeks and 6 months, mirroring the accelerated recovery trajectories described by Kayani et al, Marchand et al, and recent Indian studies.^{4,9,12,13} Evidence suggests that while robotics provides clear early functional benefits, long-term functional convergence between techniques remains possible, as shown in long-term analyses by Cho et al and Bensa et al.^{7,15}

Perioperative considerations

Operative time was significantly longer with robotics—consistent with global and Indian trials.^{4,6,8,9} However, reduced intraoperative blood loss mirrored the observations by Song et al and Xu et al, reinforcing the hemostatic advantages of robotic bone preparation.^{14,15} Length of stay and postoperative complication rates did not differ, confirming that robotic TKA maintains a comparable safety profile.

Strengths and limitations

Strengths include prospective data acquisition, strict radiological assessment, and validated functional scoring. Limitations include the single-centre, non-randomised design and short follow-up duration, which may prevent evaluation of long-term survivorship or functional convergence.

CONCLUSION

Robotic TKA improves alignment accuracy and significantly enhances early functional recovery compared with conventional TKA. Although associated with increased operative duration, robotic procedures demonstrated reduced blood loss and comparable complication rates. These results support the safe and effective integration of robotic systems into contemporary TKA practice, with longer-term benefits requiring further follow-up.

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Conflict of interest: None declared

Ethical approval: The study was approved by the Institutional Ethics Committee

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