Original Article

Comparative Study Between Radiological Outcome of Robotic-Assisted Total Knee Arthroplasty and Conventional Total Knee Arthroplasty: A Prospective Study

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Abstract

Background: The objective is to compare the radiological outcomes of robotic-assisted total knee arthroplasty and conventional total knee arthroplasty at six months of follow-up. **Material and Methods:** This prospective comparative study was conducted at IMS and SUM Hospital Bhubaneswar, and included 38 patients aged 40–80 years undergoing primary total knee arthroplasty for end-stage osteoarthritis. Patients were allocated to conventional TKA (n = 21) or robotic-assisted TKA (n = 17). Radiological assessment was performed preoperatively, on postoperative day 2, at six weeks, and at six months. **Results:** All 38 patients underwent TKA for osteoarthritis. The conventional group included 12 females (57.1%), while the robotic-assisted group included 10 females (58.8%). The mean body mass index was 31.0 kg/m² in the conventional group and 32.05 kg/m² in the robotic-assisted group. The mean alpha angle improved from 93° preoperatively to 96° at postoperative day 2 and remained stable at six weeks and six months in both groups. The mean beta angle improved from 88° in the conventional group and 89° in the robotic-assisted group preoperatively to 90° in both groups postoperatively. The mean gamma angle was 5.5° in the conventional group and 6° in the robotic-assisted group, while the mean sigma angle was 86° in both groups throughout follow-up. All patients achieved acceptable alpha, beta, and gamma angles, while one sigma-angle outlier was observed. **Conclusion:** It is concluded that robotic-assisted and conventional total knee arthroplasty produced comparable early radiological outcomes at six months of follow-up. Both techniques achieved satisfactory coronal and sagittal component alignment, with no statistically significant difference between the two groups.

Keywords: Total knee arthroplasty, robotic-assisted TKA, conventional TKA, radiological outcome, component alignment, osteoarthritis.

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INTRODUCTION

Knee OA is one of the leading causes of chronic pain, limited mobility, and disability in the world. There are around 595 million people with osteoarthritis in the knee worldwide in 2020, and the number of these people is expected to grow significantly by 2050, driven by population ageing, obesity, and a decrease in physical activity levels.[1] Total knee arthroplasty (TKA) is a well-known procedure for patients with end-stage knee OA who continue to experience symptoms after receiving appropriate conservative treatment.[2] Besides pain relief and restoration of function, restoring the axis of the lower limbs correctly and placing the implants properly, balancing the flexion-extension gaps, and maintaining the orientation of the joint lines are all important factors in the successful TKA.[3] Intramedullary and extramedullary alignment guides are commonly used with conventional TKA. While this technique will yield acceptable results in most patients, anatomical variation, lack of familiarity with landmarks, and technical error during surgery can contribute to component malposition or mechanical-axis outliers after surgery.[4] Malalignment can change the loads on the prosthesis, increase polyethylene wear, impact soft-tissue balance, and impact implant longevity.[5] For this reason, postoperative radiological assessment, such as hip-knee-ankle angle, coronal femoral and tibial alignment, sagittal position of the components, posterior tibial slope, and number of alignment outliers, is still significant to measure the technical accuracy after TKA.[6] To enhance the accuracy/reproducibility of the bone resection and the placement of the prosthesis, the Robotic-Assisted TKA has been introduced.[7] The use of preoperative imaging or imageless intraoperative mapping allows a patient-specific surgical plan to be created and gives real-time guidance during bone preparation and component positioning for robotic systems.[8] Robotic-assisted TKA has been reported to provide better mechanical alignment, joint line, and component position restoration in

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several randomized trials. Another more recent systematic review and meta-analysis further indicate that robotic-assisted TKA results in fewer deviations from optimal hip-knee-ankle alignment and fewer outliers at the end of the procedure.[9] The results of individual femoral or tibial component angles, however, have not been consistently reported, and the increased accuracy of the radiography has not led to a corresponding increase in functional results or implant survival in the short to medium term. Knee OA at its end-stage can be a common cause of pain, deformity, loss of mobility, and poor quality of life.[10] Total knee arthroplasty (TKA) is a well-recognized reconstructive surgery for those patients who have not achieved sufficient pain relief from conservative treatment and who have advanced disease. The success of TKA relies on restoring the lower-limb alignment, positioning of the femoral and tibial components, balancing the soft tissues and restoring the stable lower-limb kinematics.[11] Typically, conventional TKA is conducted with the use of an intramedullary or extramedullary alignment guide. It can achieve satisfactory clinical results in most patients, but may result in technical inaccuracies due to anatomical variations, lack of identification of landmarks, and bone resection errors.[12] If the mechanical axis is misaligned or the components are not positioned correctly, it can result in unequal loading, implant instability, polyethylene wear and potentially early failure of the implant. Thus, the need for a postoperative radiological assessment of mechanical-axis alignment and component positioning for assessing the accuracy of the procedure is important. Robotic-assisted TKA is a relatively new technology that allows for preoperative planning and/or intraoperative assessment of bone cuts, component positioning, and soft-tissue balance.[13] It could enhance the accuracy of mechanical-axis restoration and minimize radiological outliers during mechanical-axis restoration compared with conventional TKA. The use of robotic assistance could also reduce the need for the instrumentation of the femoral intramedullary canal and enable more customized planning.[14] Its use, however, is linked to the cost of doing so, to the need for special equipment and training and to the potential of an extended operative time when first using it, during the learning phase. Robotic assisted TKA is increasingly being used, but its superiority over conventional TKA in routine clinical practice is still being evaluated.[15] The available evidence indicates that these radiological improvements in alignment accuracy are more pronounced with robotic assistance, but the clinical relevance of these radiological improvements needs to be determined. Therefore, this study is designed to compare the radiological outcomes of robotic-assisted total knee arthroplasty and conventional total knee arthroplasty, particularly regarding restoration of the mechanical axis and postoperative component alignment.

Materials and Methods

This prospective comparative observational study was conducted in the Department of Orthopaedic Surgery, at IMS and SUM Hospital Bhubaneswar. A total of 100 consecutive patients undergoing primary unilateral TKA during the study period were included. Patients were allocated to either the robotic-assisted TKA group or the conventional TKA group according to the surgical technique performed. Among the initially enrolled patients, 48 completed the two-year radiological follow-up and were included in the long-term follow-up analysis. All patients who attended the six-month follow-up were included in the primary radiological outcome assessment. Patients aged 40–80 years with end-stage primary osteoarthritis or rheumatoid arthritis of the knee who were planned for primary unilateral TKA were included. Patients with a preoperative mechanical-axis deformity within the predefined range of [insert exact range, for example, 10° varus to 10° valgus] were eligible. Only patients who were able to undergo preoperative and postoperative radiological assessment and agreed to attend scheduled follow-up visits were included. Patients undergoing revision TKA, unicompartmental knee arthroplasty, or bilateral simultaneous TKA were excluded. Patients with previous osteotomy, previous knee arthroplasty, fracture around the knee, severe post-traumatic arthritis, active or previous joint infection, severe extra-articular deformity, neuromuscular disorders affecting gait or limb alignment, severe fixed flexion deformity, or incomplete radiographic records were excluded. Patients who were unable to stand for weight-bearing scannogram assessment or who failed to attend the relevant follow-up visits were excluded from the corresponding longitudinal analysis.

Preoperative Assessment: Demographic and clinical information was collected at baseline, such as age, gender, BMI, side of surgery, diagnosis, comorbidities, preoperatively identified deformity, and preoperatively identified mechanical-axis alignment. Conventional clinical, laboratory, anaesthetic, and radiological evaluation was carried out in all the patients. Radiological examination before the surgery comprised full-length lower-limb anteroposterior scannograms from the hip to the ankle joint. The mechanical axis of the limb was obtained by making a line from the centre of the femoral head to the centre of the ankle joint. The degree of varus or valgus deformity was assessed by measuring the hip-knee-ankle angle.

Surgical Technique: All surgeries were conducted by highly experienced orthopaedic surgeons under spinal or general anaesthetic in a standard medial parapatellar approach in line with institutional protocol. As far as possible, peri-operative antibiotics, thromboprophylaxis, tourniquet use, tranexamic acid, and post-operative analgesia were uniform, as were the rehabilitation protocols, for both groups. The robotic-assisted TKA group underwent robotic-assisted knee replacement surgery with the CUVIS-joint robotic system. Three-dimensional planning was carried out with a computed tomography (CT) scan of the affected lower limb done before surgery. Limb alignment, bone morphology, implant size, component position, bone resection levels, and soft-tissue balance were evaluated using the robotic planning system. During the operation, intraoperatively, femoral and tibial trackers were attached, and anatomical registration was completed. Before using the robot for bone preparation, the surgeon confirmed the planned alignment and positioning of the components. Bone resections were precisely performed with robotic assistance, both according to the plan and according to the soft tissues assessment. Final implant position and balance were investigated before wound closure. Normally, an intramedullary femoral alignment guide and an extramedullary tibial alignment guide were employed in the conventional TKA group. Bone resection, implant positioning, and soft-tissue balancing were done following the standard surgical principles. It was left to the surgeon's discretion, using traditional instrumentation and anatomical landmarks to determine the target coronal alignment, tibial slope, femoral rotation, and implant size.

Postoperative follow-up and radiological assessment: Preoperative and postoperative day 2 and six-week, six-month, and two-year radiological data were collected. On postoperative day 2, standard anteroposterior and lateral knee radiographs were taken to evaluate implant position, fixation, and immediate postoperative complications. During the follow-up period, weight-bearing full-length lower-limb scannograms were obtained to assess the mechanical-axis alignment of the lower limb. All radiographs were taken according to a standard protocol with the patient standing upright, knees fully extended, and patella facing in front, thus minimising any rotation error. The hospital picture archiving and communication system (PACS) was used to review radiographs. The most important radiological result was the mechanical-axis restoration at 6 months, measured by hip-knee-ankle angle. Neutral mechanical alignment was defined as an angle in the hip-knee-ankle line around 180°. Outliers were considered to be mechanical-axis deviations from the planned target axis deviation of >3°. Secondary radiological parameters evaluated included coronal alignment of the femoral component, coronal alignment of the tibial component, posterior tibial slope, sagittal femoral component position, joint-line restoration and radiological outliers of the alignment. All measurements were taken in degrees. The main outcome was the difference in hip-knee-ankle angle at six months between the groups undergoing robotic-assisted and conventional TKA. Secondary outcomes were the percentage of patients with mechanical axis alignment within 5° of the desired alignment, the amount of deviation from the desired alignment, the placement of the femoral and tibial components, the posterior tibial slope, and maintenance of alignment at two years.

Statistical Analysis: The Statistical Package for the Social Sciences version 26.0 was used to enter and analyze the data. Continuous variables were reported as mean ± standard deviation or median (interquartile range) if not normally distributed. Frequency and percentage were used to present categorical variables. The two groups of patients who had robotic-assisted and conventional TKA were compared and analyzed using the independent-samples t-test or Mann-Whitney U test for postoperative radiological results. For the repeated radiological measurements taken at multiple follow-up time points, analysis of variance with repeated measures and/or linear mixed-effects models was used to test for the effect of time, surgical technique, and time-by-group interaction. A p-value < 0.05 was taken as statistically significant.

Results

A total of 38 patients were included, with 21 (55.3%) undergoing conventional TKA and 17 (44.7%) undergoing robotic-assisted TKA. Participants in both groups were aged 40–80 years. Females constituted 12 (57.1%) patients in the conventional group and 10 (58.8%) in the robotic-assisted group, indicating a comparable gender distribution. The mean body mass index was 31.00 kg/m² in the conventional group and 32.05 kg/m² in the robotic-assisted group.

Table 1: Baseline Characteristics of Study Participants

Variable	Conventional TKA (n = 21)	Robotic-Assisted TKA (n = 17)	Total (n = 38)
Age range, years	40–80	40–80	40–80
Female gender, n (%)	12 (57.1)	10 (58.8)	22 (57.9)
Male gender, n (%)	9 (42.9)	7 (41.2)	16 (42.1)
Body mass index, kg/m²	31.00	32.05	—
Time from assessment to surgery	2 weeks	2 weeks	2 weeks
Follow-up duration, months	6	6	6

TKA: Total knee arthroplasty.

The right knee was operated on more frequently than the left knee, accounting for 22 (57.9%) and 16 (42.1%) procedures, respectively. Estimated intraoperative blood loss was 101–200 mL in 8 (21.1%) patients, 201–300 mL in 14 (36.8%), and 301–400 mL in 16 (42.1%) patients. Regarding operative duration, 12 (31.6%) surgeries were completed within 90–110 minutes, 12 (31.6%) required 111–130 minutes, and 14 (36.8%) lasted more than 130 minutes.

Table 2: Clinical and Procedural Characteristics of Study Participants

Variable	Category	n (%)
Indication for surgery	Osteoarthritis	38 (100.0)
	Rheumatoid arthritis	0 (0.0)
Operated knee	Left	16 (42.1)
	Right	22 (57.9)
Estimated intraoperative blood loss	101–200 mL	8 (21.1)
	201–300 mL	14 (36.8)
	301–400 mL	16 (42.1)
Operative time	90–110 minutes	12 (31.6)
	111–130 minutes	12 (31.6)
	>130 minutes	14 (36.8)

At six months, all patients achieved radiological alignment within the accepted range for alpha, beta, and gamma angles. Specifically, 38 (100.0%) patients had alpha angles within 96° ± 3°, beta angles within 90° ± 3°, and gamma angles within 6° ± 3°, with no outliers observed.

Table 3: Distribution of Radiological Alignment Outcomes at Six Months

Radiological angle	Normal reference range	Within normal range, n (%)	Outliers, n (%)	Total, n
Alpha angle	96° ± 3°	38 (100.0)	0 (0.0)	38
Beta angle	90° ± 3°	38 (100.0)	0 (0.0)	38
Gamma angle	6° ± 3°	38 (100.0)	0 (0.0)	38
Sigma angle	86° ± 3°	37 (97.4)	1 (2.6)	38

The mean alpha angle was 93° in both conventional and robotic-assisted TKA groups before surgery. It improved to 96° on postoperative day 2 and remained stable at 96° at six weeks and six months in both groups. Similarly, the mean beta angle was 88° in the conventional group and 89° in the robotic-assisted group preoperatively; it improved to 90° in both groups from postoperative day 2 onwards and remained unchanged until six months.

Table 4: Comparison of Mean Alpha and Beta Angles Between Conventional and Robotic-Assisted TKA

Assessment time	Alpha angle, Conventional TKA	Alpha angle, Robotic-assisted TKA	Beta angle, Conventional TKA	Beta angle, Robotic-assisted TKA
Preoperative	93°	93°	88°	89°
Postoperative day 2	96°	96°	90°	90°
Postoperative 6 weeks	96°	96°	90°	90°
Postoperative 6 months	96°	96°	90°	90°

Figure 1: Alpha angle in Robotic-assisted TKA (preoperative 93°, postoperative 96°)

Figure 2: Beta angle in robotic-assisted TKA (preoperative 88°, postoperative 90°)

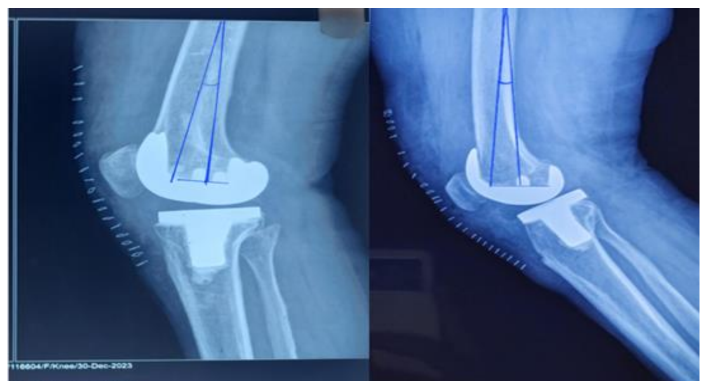

Figure 3: Gamma angle in conventional TKR is 4° and in robotic-assisted TKR is 6

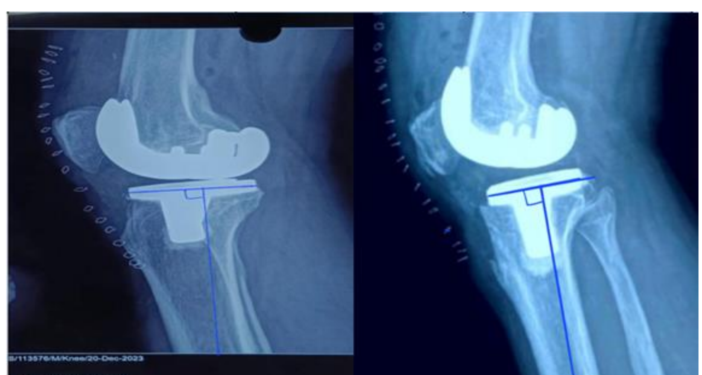

Figure 4: Sigma angle in conventional TKR is 86° and robotic assisted TKR is 88°.

Discussion

In the present study, the radiological results of conventional total knee arthroplasty (TKA) and robotic-assisted total knee arthroplasty (rTKA) were compared in 38 patients; 21 patients received conventional TKA and 17 received rTKA. All operations were done for an OA diagnosis and the age ranges, sex distribution, BMI, time to surgery, and duration of follow-up were similar between both groups. The primary conclusion was that both methods resulted in acceptable component alignment after surgery and there before surgery and 89° after surgery in the conventional group and 90° after surgery in the robotic-assisted group. Both techniques yielded good results in restoring coronal femoral and tibial component alignment in the desired radiologic range. This stability of measurements over the follow-up period is also indicative of good implant positioning within the early postoperative period.[16]

The sagittal alignment was also similar between the two groups. The gamma angle was close to the target angle at each evaluation after the surgery in both groups, with a mean angle of 5.5° in the conventional group and 6° in the robotic-assisted group. Similarly, there were no differences between the two groups in the sigma angle up to six months after surgery.[17] The results indicate that, carefully performed, conventional instrumentation can position the components in the sagittal plane to an acceptable level, within the first postoperative day, like robotic-assisted TKA.[18] The alpha, beta, and gamma angles were acceptable for all patients, and only one patient reported as an outlier on the sigma-angle. The data in the study cannot determine if this outlier was in the conventional or the robotic-assisted group. So, it can not be concluded that one technique is better at reducing radiological outliers. Not only is it important because that is the benefit that is claimed for robotic TKA, but it is also important because it is also about avoiding a deviation from the planned alignment at the patient level.[19]

This is a radiological difference that is not significant, whereas several randomized comparative trials have demonstrated superior mechanical-axis restoration, alignment outlier reduction, and improved component positioning with robotic-assisted TKA.[20] However, this difference could be due to the relatively small sample size in the present study, unequal group sizes, the rounding of mean values, and the possibility that conventional TKA was carried out by experienced surgeons with careful alignment techniques.[21] Perhaps both approaches were successful, creating limited space to prove a further robotic benefit. The total time to operability and intraoperative blood loss were recorded for the entire cohort, but were not reported separately for conventional and robotic-assisted TKA. In the present study, it is not possible to conclude whether robotic assistance extended the procedure or decreased blood loss. Such results need to be reported per treatment group and to account for factors such as surgeon experience, learning curve, extent of deformity before surgery, implant design, and body mass index.[22,23]

Limitations: The fact that the number of patients in this study was small and the distribution of the groups was unequal may have limited their ability to identify small but clinically significant differences between conventional and robotic-assisted TKA. It was an observational study and selection bias due to surgeon preference or patient characteristics and/or the availability of the robotic system cannot be ruled out. The six month follow up was sufficient to assess early radiological outcomes but not long-term implant survival, loosening, wear, revision rates or functional outcomes. Moreover, the radiological results were presented in the form of rounded mean results, with no standard deviation or confidence intervals, further reducing the ability to assess precision of the observed results. The operative time, blood loss, complications, and function outcome were not compared individually between the two groups and the one outlier with a sigma angle was not included in either group.

Conclusion

It is concluded that there was no statistically significant difference in radiological outcomes between conventional total knee arthroplasty and robotic-assisted total knee arthroplasty at six months of follow-up. Both techniques achieved satisfactory coronal and sagittal component alignment within the acceptable radiological range. Larger studies with longer follow-up are needed to determine whether robotic-assisted TKA provides long-term radiological or clinical advantages.

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Conflicts of interest

There are no conflicts of interest.

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