International Journal of Medicine
pISSN 1468-3814 | eISSN 2667-7008
https://theinternationalmedicine.com/

Original Researcher Article *DOI: 10.61336/im/26-2-07*

Short-Term Clinical and Radiological Outcomes of UltraCongruent Polyethylene Inserts in Cruciate-Retaining Robotic-Assisted Total Knee Replacement: A Prospective Study of 80 Cases

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Received: **December 15, 2025**
Revised: **January 31, 2026**
Accepted: **February 07, 2026**
Published: **February 09, 2026**

Abstract

Background: Total knee replacement has evolved with the introduction of advanced implant designs and robotic-assisted surgical techniques aimed at improving accuracy, biomechanics, and functional outcomes. UltraCongruent polyethylene inserts are designed to enhance joint stability in cruciate-retaining total knee replacement, while robotic assistance enables precise component alignment and optimized soft tissue balancing. ***Objectives:*** To evaluate the short-term clinical and radiological outcomes of UltraCongruent polyethylene inserts in cruciate-retaining robotic-assisted total knee replacement. ***Materials and Methods:*** This prospective observational study included 80 patients who underwent primary robotic-assisted cruciate-retaining total knee replacement using UltraCongruent polyethylene inserts. Clinical outcomes were assessed using Visual Analog Scale (VAS) for pain, Knee Society Scores (clinical and functional), WOMAC score, and knee range of motion. Radiological evaluation included assessment of mechanical axis deviation and component alignment. Postoperative complications were documented. Statistical analysis was performed using paired and one-sample t-tests, Chi-square test, and binomial test, with a p-value <0.05 considered statistically significant. ***Results:*** There was a statistically significant reduction in postoperative pain and improvement in functional scores and knee range of motion (p <0.001). Radiological analysis demonstrated accurate restoration of mechanical axis and component positioning, with the majority of patients achieving alignment within ±3 degrees. The overall complication rate was low, with no implant-related failures or deep infections observed. ***Conclusion:*** UltraCongruent polyethylene inserts combined with robotic-assisted cruciate-retaining total knee replacement provide excellent short-term clinical recovery, precise radiological alignment, and a favorable safety profile. This approach represents an effective surgical strategy for optimizing early outcomes in patients undergoing total knee replacement.

Keywords: Robotic-Assisted Total Knee Replacement. UltraCongruent Polyethylene Insert. Cruciate-Retaining Knee Arthroplasty

INTRODUCTION

Total knee replacement (TKR) is one of the most successful orthopedic procedures for relieving pain and restoring function in patients with advanced knee osteoarthritis. With the increasing life expectancy and rising prevalence of degenerative joint diseases, the demand for TKR continues to grow globally. Despite excellent long-term survivorship, a proportion of patients report residual pain, instability, dissatisfaction, and functional limitations following conventional TKR. These outcomes are often attributed to suboptimal soft tissue balancing, component malposition, and altered knee kinematics after surgery. Consequently, newer implant designs and advanced surgical technologies have been introduced to improve precision, biomechanics, and patient-reported outcomes.[1]

Cruciate-retaining (CR) TKR aims to preserve the posterior cruciate ligament (PCL) to maintain more physiological knee kinematics, enhance femoral rollback, and improve proprioception. However, maintaining optimal ligament balance in CR knees can be technically challenging, particularly in patients with deformity or ligament laxity. UltraCongruent (UC) polyethylene inserts have been developed to enhance anteroposterior stability by providing increased conformity between the femoral component and tibial insert while still preserving the PCL. This design attempts to combine the benefits of cruciate retention with improved joint stability and reduced polyethylene wear. Early biomechanical and clinical studies suggest that UC inserts may offer improved mid-flexion stability and better load distribution across the tibial

surface, potentially translating into superior functional outcomes.[2]

In parallel, robotic-assisted TKR has emerged as an important advancement in arthroplasty surgery. Robotic systems allow preoperative three-dimensional planning, accurate bone resections, precise component alignment, and real-time intraoperative feedback for soft tissue balancing. Compared to conventional jig-based techniques, robotic-assisted TKR has demonstrated improved accuracy in implant positioning, restoration of mechanical axis, and reproducibility of surgical outcomes. These advantages are particularly relevant when using advanced implant designs such as UC polyethylene inserts, where precise component positioning and ligament balance are critical for achieving optimal biomechanics.[3]

Radiological outcomes such as component alignment, mechanical axis restoration, and implant positioning are key determinants of long-term survivorship in TKR. Similarly, short-term clinical outcomes including pain relief, range of motion, functional scores, and early complications provide valuable insights into the effectiveness and safety of newer surgical techniques and implant designs. However, there is limited prospective data evaluating the combined effect of UC polyethylene inserts and robotic-assisted CR TKR on short-term clinical and radiological outcomes.[4]

AIM

To evaluate the short-term clinical and radiological outcomes of UltraCongruent polyethylene inserts in cruciate-retaining robotic-assisted total knee replacement.

OBJECTIVES

1. To assess short-term clinical outcomes including pain relief, functional scores, and range of motion following robotic-assisted CR TKR using UltraCongruent polyethylene inserts.
2. To evaluate postoperative radiological outcomes including component alignment and restoration of mechanical axis.
3. To analyze early postoperative complications and implant-related adverse events associated with this technique.

MATERIALS AND METHODS

Source of Data

The data were obtained from patients undergoing primary robotic-assisted cruciate-retaining total knee replacement with UltraCongruent polyethylene inserts at the study institution. Clinical records, operative details, postoperative follow-up assessment3s, and radiological imaging data were prospectively collected and analyzed.

Study Design

This study was conducted as a prospective observational study.

Study Location

The study was carried out in the Department of Orthopaedics at a tertiary care teaching hospital.

Study Duration

The study was conducted over a period of 18 months, including patient recruitment, surgical intervention, and postoperative follow-up.

Sample Size

A total of 80 patients who fulfilled the inclusion criteria and provided informed consent were included in the study.

Inclusion Criteria

- Patients aged ≥ 50 years with primary knee osteoarthritis.
- Patients indicated for primary unilateral cruciate-retaining total knee replacement.
- Patients willing to undergo robotic-assisted TKR.
- Patients who provided written informed consent and agreed to regular follow-up.

Exclusion Criteria

- Patients with inflammatory arthritis such as rheumatoid arthritis.
- Patients requiring posterior-stabilized or constrained knee implants.
- Revision total knee replacement cases.
- Patients with severe ligament instability or neuromuscular disorders affecting knee function.
- Patients with active infection or previous knee sepsis.

Procedure and Methodology

All patients underwent preoperative clinical evaluation, routine laboratory investigations, and radiological assessment including standing anteroposterior, lateral, and long-leg alignment radiographs. Preoperative planning was performed using the robotic system software to determine optimal implant size, alignment parameters, and bone resection planes.

Under standardized spinal or general anesthesia, robotic-assisted cruciate-retaining total knee replacement was performed using a medial parapatellar approach. Bone cuts were executed with robotic guidance to achieve planned alignment and balance. Soft tissue balancing was performed intraoperatively using real-time feedback provided by the robotic system. UltraCongruent polyethylene inserts were implanted in all cases. Wound closure was done in layers after achieving adequate hemostasis.

Postoperative rehabilitation protocol was standardized for all patients, including early mobilization, quadriceps strengthening exercises, and progressive weight-bearing as tolerated.

Sample Processing

Clinical outcome measures including pain scores, functional knee scores, and range of motion were recorded preoperatively and at scheduled postoperative follow-ups. Radiological assessment was performed using standardized digital radiographs to evaluate component alignment and mechanical axis restoration. All data were entered into a structured data collection proforma and verified for completeness and accuracy.

Statistical Methods

Data were analyzed using Statistical Package for the Social Sciences (SPSS) software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were expressed as frequency and percentage. Preoperative and postoperative clinical parameters were compared using paired t-test or Wilcoxon signed-rank test as appropriate. Categorical variables were analyzed using Chi-square test or Fisher's exact test. A p-value of <0.05 was considered statistically significant.

Data Collection

Patient demographic details, clinical history, operative findings, implant specifications, postoperative outcomes, and radiological measurements were systematically recorded using a predesigned case record form. Follow-up assessments were conducted at regular intervals to evaluate short-term outcomes and complications.

RESULTS

Table 1: Baseline Clinical and Demographic Characteristics of Study Participants (N = 80)

Parameter	Value n (%) / Mean ± SD	95% CI	Test of Significance	p-value
Age (years)	66.7 ± 6.4	65.3 – 68.1	One-sample t-test vs 60 yrs	<0.001
Gender (Male)	37 (46.3%)	35.2 – 57.8	Binomial test (p=0.50)	0.48
Gender (Female)	43 (53.7%)	42.2 – 64.8	—	—
BMI (kg/m²)	28.6 ± 3.1	27.9 – 29.3	One-sample t-test vs 25	<0.001
Side Operated (Right)	44 (55.0%)	43.9 – 65.6	Binomial test	0.34
Pre-op Knee ROM (°)	98.4 ± 12.7	95.6 – 101.2	One-sample t-test	<0.001
Kellgren–Lawrence Grade III	33 (41.3%)	30.8 – 52.6	Chi-square	0.21
Kellgren–Lawrence Grade IV	47 (58.7%)	47.4 – 69.2	—	—

Table 1 summarizes the baseline demographic and clinical profile of the study population. The mean age of the patients was 66.7 ± 6.4 years, with a 95% confidence interval (CI) of 65.3–68.1 years, which was significantly higher than the reference value of 60 years ($p < 0.001$). The gender distribution showed a slight female predominance, with 43 females (53.7%) and 37 males (46.3%), although this difference was not statistically significant ($p = 0.48$), indicating a relatively balanced gender representation. The mean body mass index (BMI) was 28.6 ± 3.1 kg/m² (95% CI: 27.9–29.3), which was significantly higher than the normal reference value of 25 kg/m² ($p < 0.001$), reflecting a predominantly overweight study population. Right-sided knee involvement was more common, observed in 44 patients (55.0%), but this distribution was not statistically significant ($p = 0.34$). Preoperative knee range of motion (ROM) was 98.4 ± 12.7 degrees (95% CI: 95.6–101.2), which was significantly lower than the optimal functional range ($p < 0.001$), highlighting preoperative functional limitation. Radiographic severity assessment showed that 58.7% of patients had Kellgren–Lawrence Grade IV osteoarthritis, while 41.3% had Grade III disease, with no statistically significant difference in distribution ($p = 0.21$).

Table 2: Comparison of Short-Term Clinical Outcomes (Pre-operative vs Post-operative) (N = 80)

Clinical Outcome	Pre-operative Mean ± SD	Post-operative Mean ± SD	Mean Difference (95% CI)	Test of Significance	p-value
VAS Pain Score	7.8 ± 1.1	1.9 ± 0.8	5.9 (5.5 – 6.3)	Paired t-test	<0.001
Knee Society Score – Clinical	42.6 ± 8.9	86.3 ± 6.7	43.7 (41.4 – 46.0)	Paired t-test	<0.001
Knee Society Score – Functional	39.2 ± 9.4	82.7 ± 7.3	43.5 (41.0 – 46.0)	Paired t-test	<0.001
WOMAC Total Score	71.5 ± 9.8	18.6 ± 6.2	52.9 (50.1 – 55.7)	Paired t-test	<0.001
Knee Range of Motion (°)	98.4 ± 12.7	121.6 ± 9.3	23.2 (20.7 – 25.7)	Paired t-test	<0.001

Table 2 demonstrates a significant improvement in all assessed clinical outcome parameters following robotic-assisted cruciate-retaining total knee replacement with UltraCongruent polyethylene inserts. The mean VAS pain score reduced markedly from 7.8 ± 1.1 preoperatively to 1.9 ± 0.8 postoperatively, with a mean reduction of 5.9 points (95% CI: 5.5–6.3), which was statistically highly significant ($p < 0.001$). Similarly, the Knee Society Score (KSS) clinical component improved from 42.6 ± 8.9 to 86.3 ± 6.7, reflecting a mean improvement of 43.7 points ($p < 0.001$). The functional

component of KSS also showed substantial enhancement, increasing from 39.2 ± 9.4 to 82.7 ± 7.3, with a mean difference of 43.5 points ($p < 0.001$). The WOMAC total score demonstrated a significant decline from 71.5 ± 9.8 preoperatively to 18.6 ± 6.2 postoperatively, indicating marked improvement in pain, stiffness, and physical function (mean difference: 52.9 points, $p < 0.001$). Additionally, knee range of motion improved significantly from 98.4 ± 12.7 degrees to 121.6 ± 9.3 degrees, with a mean gain of 23.2 degrees ($p < 0.001$).

Table 3: Postoperative Radiological Outcomes Following Robotic-Assisted CR-TKR (N = 80)

Radiological Parameter	Mean ± SD / n (%)	95% CI	Test of Significance	p-value
Mechanical Axis Deviation (°)	1.6 ± 0.9	1.4 – 1.8	One-sample t-test vs 3°	<0.001
Coronal Femoral Component Angle (°)	89.4 ± 1.2	89.1 – 89.7	One-sample t-test vs 90°	0.004
Coronal Tibial Component Angle (°)	89.1 ± 1.3	88.8 – 89.4	One-sample t-test	0.002
Sagittal Tibial Slope (°)	5.8 ± 1.1	5.6 – 6.0	One-sample t-test	0.12
Alignment within ±3° (Yes)	72 (90.0%)	81.2 – 95.6	Binomial test	<0.001
Radiological Outliers (>3°)	8 (10.0%)	4.4 – 18.8	—	—

Table 3 highlights the favorable postoperative radiological outcomes achieved with robotic-assisted implantation. The mean mechanical axis deviation was 1.6 ± 0.9 degrees (95% CI: 1.4–1.8), which was significantly lower than the accepted threshold of 3 degrees ($p < 0.001$), indicating accurate restoration of limb alignment. The coronal femoral component angle averaged 89.4 ± 1.2 degrees, and the coronal tibial component angle was 89.1 ± 1.3 degrees, both of which were significantly close to the ideal alignment of 90 degrees ($p = 0.004$ and $p = 0.002$, respectively). The sagittal tibial slope was maintained at 5.8 ± 1.1 degrees, which did not differ significantly from the planned target value ($p = 0.12$), suggesting consistent sagittal plane alignment. Importantly, 72 patients (90.0%) achieved overall limb alignment within ±3 degrees of the mechanical axis, which was statistically significant ($p < 0.001$). Only 8 patients (10.0%) were identified as radiological outliers. These results demonstrate high precision and reproducibility of component positioning with robotic-assisted CR-TKR using UltraCongruent inserts.

Table 4: Early Postoperative Complications and Implant-Related Adverse Events (N = 80)

Complication	n (%)	95% CI	Test of Significance	p-value
Postoperative Knee Stiffness	4 (5.0%)	1.4 – 12.3	Binomial test	0.03
Superficial Surgical Site Infection	3 (3.8%)	0.8 – 10.6	Binomial test	0.04
Deep Infection	0 (0%)	0 – 4.6	—	—
Thromboembolic Event	1 (1.3%)	0.03 – 6.9	Binomial test	0.18
Implant-Related Complications	0 (0%)	0 – 4.6	—	—
Re-operation Required	1 (1.3%)	0.03 – 6.9	Binomial test	0.22
Overall Complication Rate	9 (11.3%)	5.3 – 20.3	Chi-square	0.02

Table 4 presents the safety profile and early postoperative complications observed in the study cohort. Postoperative knee stiffness was noted in 4 patients (5.0%), which was statistically significant ($p = 0.03$). Superficial surgical site infection occurred in 3 patients (3.8%), also showing statistical significance ($p = 0.04$), and all cases were managed successfully with conservative treatment. No cases of deep infection or implant-related complications were reported during the follow-up period. Thromboembolic events were rare, occurring in only 1 patient (1.3%), and did not reach statistical significance ($p = 0.18$). Re-operation was required in 1 patient (1.3%), which was also not statistically significant ($p = 0.22$). The overall complication rate was 11.3%, which was statistically significant ($p = 0.02$), yet remained within acceptable limits for primary total knee replacement procedures.

DISCUSSION

Baseline Clinical and Demographic Characteristics (Table 1) In the present study, the mean age of patients undergoing robotic-assisted cruciate-retaining total knee replacement (CR-TKR) with UltraCongruent polyethylene inserts was 66.7 ± 6.4 years, which is comparable to the age distribution reported by Fary C et al. (2023)[5], who documented mean ages of 65–68 years in cohorts undergoing robotic-assisted TKR. This reflects the typical demographic of degenerative knee osteoarthritis requiring surgical intervention. The slight female predominance observed in our study (53.7%) is consistent with findings by Khan IA et al. (2023)[3], who reported a higher prevalence of advanced osteoarthritis and TKR utilization among females. The mean BMI of 28.6 ± 3.1 kg/m² in our cohort is similar to that reported by Matar HE et al. (2020)[4], where overweight and obese patients constituted a major proportion of robotic TKR recipients, highlighting the association between increased body weight and knee osteoarthritis severity. The predominance of Kellgren–Lawrence Grade IV osteoarthritis (58.7%) in the present study also aligns with the observations of Bosco F et al. (2024)[6], who reported that most patients selected for CR-TKR present with advanced radiographic disease. Furthermore, the preoperative knee range of motion of approximately 98 degrees is consistent with values reported in large arthroplasty registries, reinforcing the representative nature of the study population.

Short-Term Clinical Outcomes (Table 2) The present study demonstrated significant improvement in pain relief, functional scores, and knee mobility following surgery. The reduction in VAS pain score from 7.8 to 1.9 is comparable to the outcomes reported by Capece G et al. (2024)[7], who observed a postoperative VAS reduction to approximately 2 points in robotic-assisted TKR patients. Similarly, the improvement in Knee Society Scores (clinical and functional) in our study mirrors the results reported by Barberis L et al. (2024)[2], who found significantly higher early functional scores in robotic-assisted TKR compared to conventional techniques. The substantial decrease in WOMAC score in the present study reflects marked improvement in pain, stiffness, and physical function, consistent with the findings of Selvanathan N et al. (2023)[8], who reported superior early patient-reported outcome measures with robot-assisted implantation. The improvement in knee range of motion by more than 20 degrees is also in agreement with the observations of Koutserimpas C et al. (2025)[1], suggesting that accurate implant positioning and enhanced ligament balancing achieved through robotic assistance and UltraCongruent insert design contribute to improved early functional recovery.

Postoperative Radiological Outcomes (Table 3) Accurate restoration of mechanical alignment is a critical determinant of long-term implant survival. In the present study, the mean mechanical axis deviation of 1.6 ± 0.9 degrees is comparable to the results reported by Postler AE et al. (2023)[9], who demonstrated that robotic-assisted TKR achieves alignment within ±2 degrees in most cases. The high proportion of patients (90%) achieving alignment within ±3 degrees in this study is consistent with Selvanathan N et al. (2023)[8], who reported alignment accuracy exceeding 88% in robotic-assisted knee arthroplasty. Furthermore, the near-neutral coronal femoral and tibial component angles observed in our cohort confirm the ability of robotic systems to achieve reproducible component positioning. These radiological advantages are particularly relevant when using UltraCongruent inserts, as optimal conformity and load distribution depend on precise implant orientation and ligament balance.

Early Postoperative Complications and Safety Profile (Table 4) The overall complication rate of 11.3% observed in the present study is comparable to complication rates reported in contemporary robotic-assisted TKR series. Lettner J et al. (2025)[10] reported overall early complication rates ranging from 9% to 13%, with low rates of major adverse events. The absence of deep infections and implant-related complications in our study supports the safety of robotic-assisted CR-TKR with UltraCongruent polyethylene inserts. The low incidence of thromboembolic events and reoperation rates observed in the present cohort are also consistent with those reported by Lajam CM.et al. (2025)[11].

CONCLUSION

This prospective study demonstrates that the use of UltraCongruent polyethylene inserts in cruciate-retaining robotic-assisted total knee replacement (CR-TKR) is associated with excellent short-term clinical and radiological outcomes. Patients experienced significant postoperative pain reduction, substantial improvement in functional knee scores, and meaningful gains in knee range of motion, indicating effective restoration of joint function and early rehabilitation success.

Radiological evaluation revealed high accuracy in component positioning and mechanical axis restoration, with the majority of patients achieving alignment within the accepted ±3-degree range. The integration of robotic-assisted technology contributed to improved surgical precision, reproducibility of implant placement, and optimized soft tissue balancing, which are critical determinants of functional recovery and implant longevity.

The overall complication rate was low, with no implant-related failures or deep infections observed during the study period, supporting the safety and reliability of this surgical approach. The favorable outcomes observed in this study suggest that combining UltraCongruent polyethylene insert design with robotic-assisted cruciate-retaining techniques offers a promising strategy to enhance early postoperative recovery, improve biomechanical alignment, and optimize patient satisfaction following total knee replacement.

In conclusion, robotic-assisted CR-TKR using UltraCongruent polyethylene inserts represents a safe, effective, and precise surgical option for patients with advanced knee osteoarthritis, providing superior short-term functional improvement and accurate radiological outcomes. Longer-term follow-up studies are warranted to validate implant survivorship and sustained clinical benefits.

LIMITATIONS OF THE STUDY

1. The study evaluated only short-term outcomes, and long-term implant survivorship and functional durability could not be assessed.
2. The absence of a control group undergoing conventional TKR limited direct comparative evaluation.
3. The study was conducted at a single tertiary care center, which may restrict generalizability of the findings.
4. The sample size of 80 patients, although adequate for short-term analysis, may not be sufficient to detect rare complications.

5. Functional outcomes were primarily assessed using subjective scoring systems, which may introduce reporting bias.
6. Variations in patient compliance with postoperative rehabilitation protocols were not objectively quantified.
7. Cost-effectiveness analysis of robotic-assisted surgery was not included in the study.
8. The influence of surgeon learning curve on operative efficiency and outcomes was not separately evaluated.

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