

Balancing Precision and Constraint: A Comparative Study of Cruciate-Retaining and Posterior-Stabilized Total Knee Arthroplasty

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Abstract--Total Knee Arthroplasty (TKA) is an established procedure for end-stage knee arthritis, but whether to preserve or sacrifice the posterior cruciate ligament (PCL) remains contentious. Cruciate-Retaining (CR) and Posterior-Stabilized (PS) implants provide different biomechanical benefits, but the relative impact on functional outcomes in everyday living is unknown. The objective of this study was to examine: "Does maintaining the native PCL offer meaningful clinical benefits compared to sacrificing it in primary TKA?" The study aimed to determine whether CR or PS implant designs result in superior functional recovery lower complication rates, or improved subjective outcomes, or whether both perform equivalently in primary TKA. Retrospective study was done in 69 patients (90 knees) who had primary TKA with CR or PS designs at Karuna Medical College and Hospital. Functional outcomes were measured in terms of Knee Society Scores (KSKS, KSFS), Range of Motion (ROM), and WOMAC improvement. Complication rates and deformity patterns were also noted. Independent samples t-tests and Fisher's Exact Test were applied to compare the groups' outcomes. Both implant designs showed great postoperative outcomes. No statistically significant differences were present for ROM, KSKS, KSFS, or complications. The significant difference was increased WOMAC improvement in the PS group ($p = 0.007$). Aside from subjective WOMAC improvement in PS recipients, CR and PS implants are clinically equivalent. Implant selection should be individualized, based on ligament status and surgical condition, and not preference in general.

Key words: total knee arthroplasty, cruciate-retaining, posterior-stabilized, functional outcomes, range of motion, WOMAC, ligament balancing

1. Introduction

Total Knee Arthroplasty (TKA) has revolutionized the treatment of severe osteoarthritis with long-term pain alleviation and restoration of function. Among all the many surgical considerations, the choice between Cruciate-Retaining (CR) and Cruciate-Sacrificing, or Posterior-Stabilized (PS), implants is a controversial topic in orthopedic medicine. Indication for total knee arthroplasty is when nonoperative treatment fails to provide sufficient relief from pain and functional disability from advanced arthritis (D'Ambrosi et al., 2022; Gemayel & Varacallo, 2021)^{1,2}. TKA has become a very frequent and surprisingly effective treatment for advanced knee arthrosis, driven by the rapidly aging population globally, further understanding of the disease mechanism, and ongoing advancements in implant technology, surgical methods, and clinical outcomes.

CR implants preserve the posterior cruciate ligament (PCL), crucial for proprioception, femoral rollback, and natural kinematics. Supporters argue that this design leads to more physiological joint movement and wear reduction. PS implants remove the PCL and employ a cam-post mechanism to replace the rollback function, generally offering superior balancing consistency and greater technical simplicity. While theoretical advantages of both designs are well established, their clinical relevance remains subject to critical challenge. Nikolaou, 2014 stated in his study that it is imperative to study the influence of each design on range of motion, stability, and patient-reported outcomes³. Huang et al. (2007) reported that the choice of the appropriate implant is a complex decision based on individual patient factors and surgeon experience⁴.

The establishment of the appropriate level of constraint in total knee arthroplasty is a critical component of the decision-making process, especially within the realm of revision procedures, as it directly impacts the stability and long-term success of the prosthesis.

There is extensive literature with conflicting results. Some randomized studies show improved function and range of motion with PS implants, yet others have superior or equal results with CR implants. Some high-volume registries and meta-analyses show minimal long-term differences, and patient-specific factors and technique perhaps have more impact than implant mechanics.

This issue is not purely hypothetical. Implant design choices influence surgical exposure, bone cuts, ligament releases, and rehabilitation. Overestimation or underestimation of the PCL's role — to spare it when it is not sufficient or to sacrifice it unnecessarily — can lead to poor balancing, instability, or long-term discontent. Also, variability in cost and implant inventory considerations arise in resource-limited medical systems. Constraint is defined by aspects of the knee implant design, allowing the stability to resist forces around the knee following arthroplasty with an inadequate soft-tissue envelope. Marya & Singh, 2020 demonstrated that since it can be difficult to determine the extent of constraint required, surgeons must prepare preoperatively, but in most instances, the final choices are intraoperative⁵.

Hence, the clinical community needs to pose a more basic question: Is the decision between CR vs PS implants a predictor of patient success — or a procedure option with equivalent results in skilled hands? The aim of this study was to address that question directly.

We retrospectively contrasted outcomes for a group of patients who were receiving primary TKA from a high-volume center between CR and PS designs. We employed validated functional scores (KSKS, KSFS), subjective indicators (WOMAC), deformity correction, ROM, and complication rates to determine whether implant design has an impact on success with surgery.

2. Methodology:

2.1. Study Design and Setting:

This was a retrospective observational study conducted at the Department of Orthopaedics, Karuna Medical College & Hospital situated at Vilayodi, Chittur, Palakkad in the state of Kerala, India. Patients who underwent primary Total Knee Arthroplasty (TKA) using either Cruciate-Retaining (CR) or Posterior-Stabilized (PS) implants between January 2014 and December 2018 were included. The study involved standardized surgical techniques and uniform postoperative rehabilitation. Clinical and functional outcomes were assessed through hospital records and scheduled follow-ups.

2.2. Eligibility Criteria:

Inclusion Criteria:

- Patients undergoing primary total knee arthroplasty for osteoarthritis or rheumatoid arthritis.
- 50–85 years of age
- Either CR or PS implant of the same manufacturer
- Minimum 6-month postoperative follow-up
- 73 patients, or 90 knees, were included in the study.

Exclusion criteria:

- Revision TKAs
- Semi-constrained or constrained implants
- Arthritis following trauma or prior infection
- Limb function or gait neuromuscular disorders

69 of the patients from the original cohort (39 in PS group and 30 in CR group) completed the study with full follow-up.

2.3. Surgical Intervention:

All the procedures were performed by experienced orthopedic surgeons using a uniform medial parapatellar approach with spinal or general anesthesia. PCL status was checked intraoperatively. If the PCL was intact and stable, only a CR implant was used. Otherwise, if PCL insufficiency, narrow flexion gap, or severe deformity was noted, a PS implant was used. The models of implants used in both groups were purchased from the same company to avoid any comparison bias.

Bone osteotomies were performed with intramedullary femoral and extramedullary tibial alignment guides. All of the fixtures were fully cemented using high-viscosity polymethylmethacrylate cement. Tourniquet was applied in all the cases, and intraoperative tranexamic acid was given. Patellar resurfacing was not done as a routine. All patients received standard perioperative antibiotic prophylaxis and DVT prevention as per institutional protocol. Patients were mobilized with walker support on Day 1, and prescribed active quadriceps exercises and progressive weight-bearing under physiotherapy guidelines including active knee range-of-motion and strengthening exercises under guided supervision.

2.4. Study Variables:

Primary variables:

- Implant type: Cruciate-Retaining (CR) vs Posterior-Stabilized (PS) total knee arthroplasty
- Functional Outcomes: All patients underwent standard preoperative clinical evaluation, including assessment of knee alignment (varus/valgus), flexion deformity, ligament status, and functional limitations. Preoperative scores including Knee Society Knee Score (KSKS), Knee Society Functional Score (KSFS), range of motion (ROM) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) were documented prior to surgery by trained clinicians. Radiographic classification of varus or valgus deformity was based on standing anteroposterior and lateral knee X-rays.

Secondary variables:

- Demographics: Age at surgery, gender, body mass index (BMI)
- Radiological and Clinical Assessments: Preoperative knee alignment (varus/valgus), flexion deformity, complications (e.g. superficial infection, DVT, periprosthetic fractures, stiffness, need for revision)
- Follow-up duration: Patients were followed for a minimum of 6 months and up to 10 years, depending on the year of surgery. The data presented in this study includes all available follow-up records until the time of data analysis, ensuring adequate evaluation of long-term outcomes.

2.5. Data sources and Measurement:

- Data were collected retrospectively from hospital records and surgeon logs at Karuna Medical College & Hospital
- Official TKA registry entries and patient outpatient follow-up files were reviewed, with dates spanning January 2014 to December 2018.
- Postoperative outcome data were extracted during structured clinical follow-ups at 6 weeks, 3 months, 1 year, and annually thereafter.
- Knee Society Scores (KSKS/KSFS) and WOMAC questionnaires: Administered by trained clinicians.
- Range of motion (ROM): Measured using a standard 300 mm goniometer, documenting maximum passive flexion and extension.

- Alignment type: Varus or valgus defined based on preoperative radiographs reviewed by two independent observers.

Complications:

- Superficial wound infections confirmed clinically and treated with antibiotics.
- Deep vein thrombosis diagnosed via Doppler ultrasound and treated with anticoagulants.
- Periprosthetic fractures recorded per operative findings and imaging
- Knee stiffness defined as flexion $\leq 45^\circ$ at any follow-up year
- Revision surgery indicated by instability or radiologic loosening and documented in surgical logs
- Time-to-event data: Follow-up duration for each patient calculated from index surgery date to last recorded visit or event date.

2.6. Statistical Analysis

All the data were entered into Microsoft Excel and thereafter analyzed using R Studio. Descriptive statistics were used to report means, standard deviations, and percentages. Independent samples t-tests were used to compare continuous variables across the CR and PS groups. A p-value of ≤ 0.05 was considered statistically significant.

2.7. Ethical Considerations:

Institutional ethical approval was obtained before study initiation. Informed consent was acquired from all patients for data collection and follow-up.

3. Results:

Of the 73 enrolled subjects, 69 were followed up (39 CR, 30 PS). Both groups had significant postoperative functional improvement from baseline, irrespective of implant type.

Baseline Characteristics: To ensure valid comparative analysis, baseline demographic and clinical variables were assessed preoperatively. The inclusion of preoperative data demonstrates that the CR and PS groups were comparable across most parameters, thus validating the internal consistency of the sample. This comparability at baseline reinforces the reliability of postoperative outcome comparisons by minimizing selection bias. The PS group showed a significantly increased preoperative WOMAC score ($p = 0.018$), revealing greater baseline pain and functional limitation (see Table 1).

Table 1: Preoperative demographic and clinical characteristics of CR vs PS groups

Variable	CR Group (n = 39)	PS Group (n = 30)	P-value
Age (years, mean $\pm$ SD)	66.2 $\pm$ 6.1	67.8 $\pm$ 5.4	0.288
BMI (kg/m ² , mean $\pm$ SD)	27.9 $\pm$ 3.4	29.2 $\pm$ 3.0	0.091
Varus Knee (%)	35 (89.7%)	26 (86.7%)	0.671
Valgus Knee (%)	4 (10.3%)	4 (13.3%)	0.661
Pre-op ROM Flexion ($^\circ$)	86.5 $\pm$ 5.8	89.1 $\pm$ 6.2	0.132
Fixed Flexion Deformity ($^\circ$)	10.2 $\pm$ 2.7	9.4 $\pm$ 2.5	0.248
Pre-op KSKS	26.1 $\pm$ 4.2	24.9 $\pm$ 3.6	0.182
Pre-op KSFS	27.4 $\pm$ 3.7	25.8 $\pm$ 4.0	0.115
Pre-op WOMAC Score	50.3 $\pm$ 6.7	54.2 $\pm$ 5.9	0.018*

On between-groups comparison, no statistically significant differences were noted in the majority of the primary functional parameters — postoperative ROM, KSKS, KSFS, and improvement scores. The only statistically significant difference was noted in WOMAC improvement, which was higher in the PS group ($p = 0.007$).

No relationship was found between postoperative complication rates, types, and ROM improvement and implant design. These results suggest that implant type (CR vs PS) was not independently related to clinical outcomes,

validating that other variables may be a more decisive factor. Group-wise results in lollipop plots were compared, clearly indicating that CR and PS designs provide nearly similar functional scores in ROM, KSKS, and KSFS, whereas sole WOMAC improvement was divergent (see Figure 1).

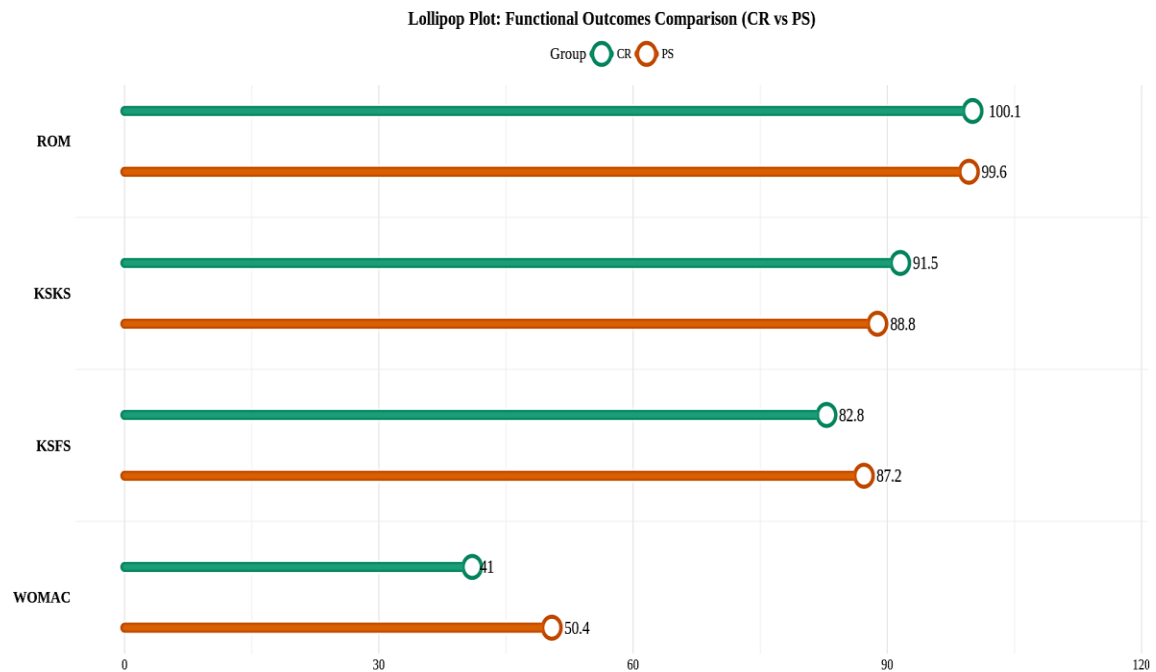


Figure 1: Lollipop chart comparing CR and PS outcomes

Heat map was plotted indicating intensity of mean outcome values, graphically highlighting similarity of CR and PS groups in parameters (see Figure 2).

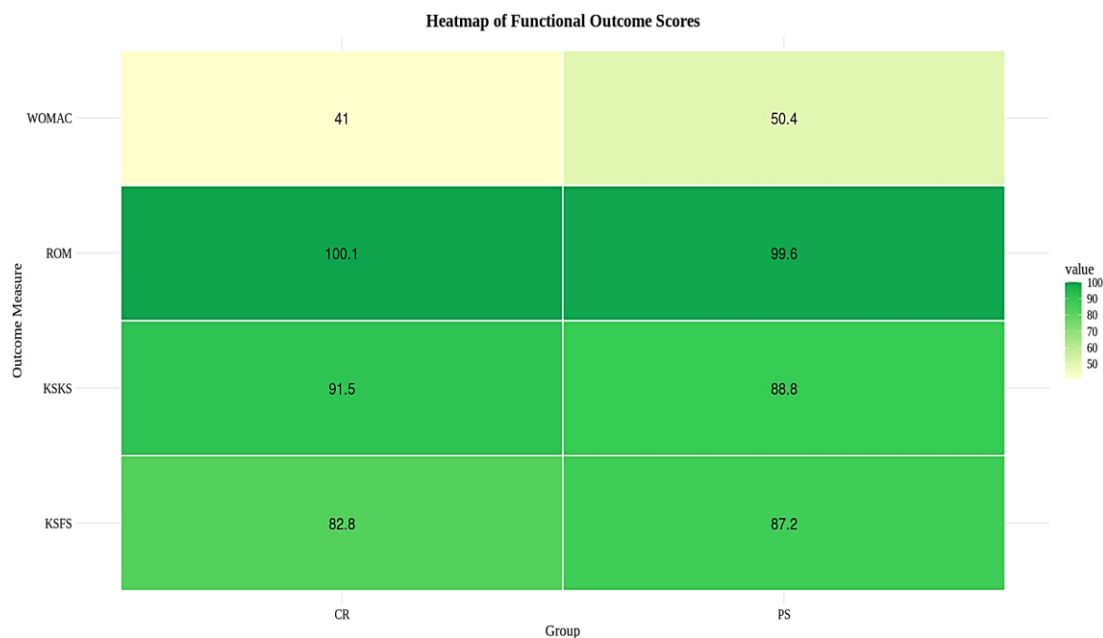


Figure 2: Heat map of functional outcomes scores

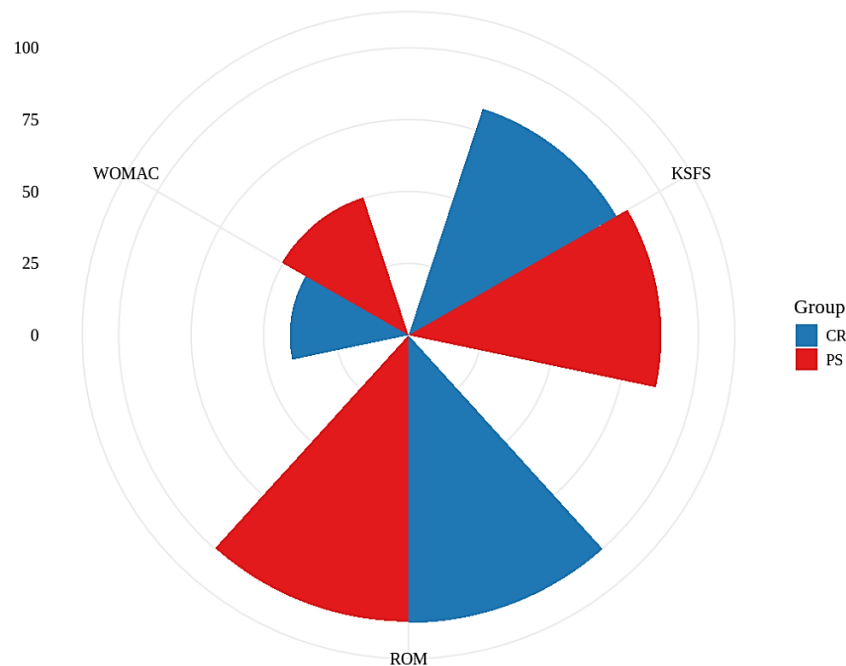
The postoperative functional outcomes including KSKS, KSFS, ROM, and WOMAC improvements between the CR and PS groups were summarized (see Table 2).

Table 2: Comparison of Postoperative Functional Outcomes between CR and PS Groups

Measure	Cr (Mean $\pm$ Sd)	Ps (Mean $\pm$ Sd)	P-Value	Significance
Post-Op Ksks	91.53 $\pm$ 3.21	88.83 $\pm$ 3.91	0.105	NS
Post-Op Ksfs	82.83 $\pm$ 4.51	87.24 $\pm$ 4.23	0.072	NS
Post-Op Rom (°)	100.06 $\pm$ 6.33	99.63 $\pm$ 5.92	0.821	NS
Womac Improvement	41.02 $\pm$ 7.52	50.41 $\pm$ 6.61	0.007	**
Rom Improvement (°)	11.82 $\pm$ 4.72	8.56 $\pm$ 5.13	0.540	NS
Ksks Improvement	66.72 $\pm$ 6.24	69.85 $\pm$ 6.01	0.465	NS

ns = not significant ($p > 0.05$), ** = statistically significant ($p < 0.01$)

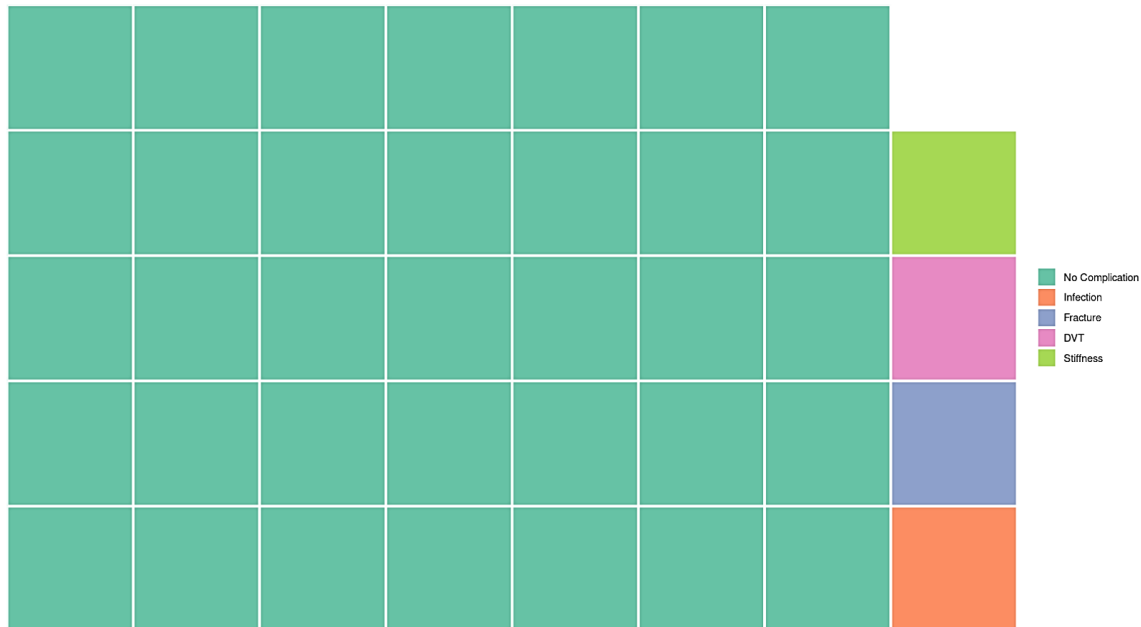
Radial graph was plotted indicating condensing of ROM, KSFS, and WOMAC outcomes in radial bar form, highlighting overlapping recovery patterns in the two groups (see Figure 3).

Radial Plot: Functional Outcome Distribution**Figure 3:** Radial plot showing functional outcome distribution for CS vs PS

Complications were identified through routine clinical follow-up visits and postoperative record reviews, ensuring systematic detection across both implant groups.

Waffle graph plotted illustrated the complication profile with waffle charts, confirming low and similar event frequencies in CR and PS cohorts (see Figure 4).

CR Group: Complication Profile

**Figure 4:** Waffle chart showing CR group complication profile

Postoperative complications were rare and similarly distributed between the Cruciate-Retaining (CR) and Posterior-Stabilized (PS) groups. In the CR group, one patient developed a superficial wound infection that resolved with antibiotics and wound care. A single case of periprosthetic fracture was managed with surgical fixation. One patient experienced deep vein thrombosis (DVT), treated effectively with anticoagulation. In the PS group, one patient sustained a periprosthetic fracture following a minor fall and developed flexion instability, necessitating revision arthroplasty within six months. Additionally, one patient in each group showed postoperative knee stiffness, defined as flexion limited to less than 45°, both of which improved after manipulation under anesthesia. All events were captured during scheduled follow-up appointments as part of our standard surveillance protocol. The overall low and comparable complication rates reflect satisfactory safety outcomes across both implant designs (see Table 3).

Table 3: Complication Frequency between CR and PS Groups

Complication Type	CR (n = 39)	PS (n = 30)	p-value	Significance
Superficial Infection	1	0	1.000	Not significant
Fracture	1	1	1.000	Not significant
DVT	1	0	1.000	Not significant
Revision Surgery	0	1	1.000	Not significant
Stiffness	1	1	1.000	Not significant

The distribution of preoperative varus and valgus deformity patterns between the two groups was tabulated (see Table 4).

Table 4: Distribution of Preoperative Deformity Patterns

Deformity Type	CR Group (n = 39)	PS Group (n = 30)	p-value	Significance
Varus	40	38	0.284	Not significant
Valgus	9	3		Not significant

ROM progression between the CR and PS groups, comparing preoperative and post operative angles was further detailed (see Table 5).

Table 5: ROM Progression Comparison

Measure	CR (mean ± SD)	PS (mean ± SD)	p-value	Significance
Pre-op ROM (°)	88.24 ± 6.72	91.07 ± 6.41	0.626	Not significant
Post-op ROM (°)	100.06 ± 6.33	99.63 ± 5.92	0.821	Not significant
ROM Improvement (°)	11.82 ± 4.72	8.56 ± 5.13	0.540	Not significant

4. Discussion:

This retrospective comparative study aimed to establish the effect of posterior cruciate ligament (PCL) preservation or resection on primary Total Knee Arthroplasty (TKA) clinical results. Our results indicated that both Cruciate-Retaining (CR) and Posterior-Stabilized (PS) implant types achieved acceptable postoperative recovery in most objective outcomes. These were exemplified by the Knee Society Knee Score (KSKS), Functional Score (KSFS), Range of Motion (ROM), and the profile of complications.

This study has verified the growing consensus that CR and PS designs can provide similar functional results, validating that surgical precision, proper tissue selection, and systematic rehabilitation protocols are followed⁶. Several studies have shown that in properly performed primary TKA, the selection of implant does not decide the ultimate result⁷.

The one statistically significant difference we observed in our study was an increased increase in WOMAC scores in the PS cohort. As a patient-reported outcome measure, WOMAC measures symptoms such as pain, stiffness, and physical function—domains that are highly sensitive to patient perception of joint mobility and stability. Better response of WOMAC among PS knee patients is attributed to the consistent rollback and the mechanical stability of cam-post mechanism, especially during the early postoperative period⁸.

Several researchers have provided evidence that indicating PS implants can accommodate flexion gaps better and promote smoother rehabilitation in patients with borderline integrity of PCL or preoperative stiffness of flexion⁹.

The cam-post mechanism of PS implants has been shown to be activated earlier in flexion, enabling stable rollback and minimizing anterior lift-off in deep flexion motion. Although posterior substituting total knee arthroplasty has been extensively used in surgery, whether the cam-post mechanism (posterior substituting mechanism) influences knee joint kinematics and function in patients remains unclear¹⁰.

PS implants may also allow intraoperative balancing, particularly in varus deformity, ligament laxity, or tight flexion space — situations in which CR implants are harder to balance. Posterior impingement effect is preventable in PS TKA¹¹.

Research has shown that incorrect retention of a deficient PCL in CR knees can lead to paradoxical motion, instability, or suboptimal kinematics. Cruciate-retaining TKA designs achieve stability by utilizing the patient's natural posterior cruciate ligament, whereas posterior-stabilized designs replace the function of the PCL with a cam-post system. Retaining or sacrificing the posterior cruciate ligament during total knee arthroplasty is still a significant concern for orthopedic surgeons, dictating the selection of the implant design and the surgical technique.

While the advantage was noted in WOMAC scores, our results did not show substantial differences in complication rates, implying that both designs are safe when well implanted. This corroborates with the results of another study in which no statistical difference in infection rates, revision rates, thromboembolism, or postoperative stiffness was found between CR and PS groups¹². A few large registry series have also reported no difference in rates of reoperation or

complications between PS and CR designs on mid- to long-term follow-up¹³. Furthermore, deformity correction—either in varus or valgus alignment—was successfully performed in both groups, highlighting that the implant design did not limit alignment strategies or surgical objectives. These results are in line with evidence that the correction of deformity in TKA is more a function of surgical technique and position of the implant than degree of constraint per se¹⁴.

Retention of the PCL in CR implants has theoretic advantages like enhanced proprioception, lessened polyethylene wear, and increased physiologic femoral rollback¹⁵. Yet, biomechanical benefits observed may not always be translated into quantifiable clinical advantage, especially in less active or older patient groups. In contrast, PS implants substitute the role of the PCL with a mechanical cam-post system, which could improve flexion stability and decrease the technical demands of procedures¹⁶. Several research studies with strong study design have reaffirmed that intraoperative evaluation should inform the decision-making process for choosing CR and PS implants in place of preoperative preference¹⁷.

Clinical guidelines also suggest that patient anatomy, soft-tissue envelope quality, and ligament status need to dictate the degree of implant constraint at primary TKA¹⁸. In addition, new terms like functional and kinematic alignment moved attention away from fixed implant protocols to restoring patient-specific joint biomechanics irrespective of CR or PS design¹⁹.

Recent advances in robotic support, sensor-based balance, and artificial intelligence-based planning may potentially reduce reliance on implant forms through improving surgical precision and personalized alignment methods²⁰. Robotic-assisted navigation has the potential to provide more accurate implant positioning and soft tissue equilibrium, and ultimately reduce the variation in performance between different implant designs²¹. The results highlight that the mechanics of implants are only a part of a multifaceted, complex process. The surgeon's ability, precision in ligament balancing, handling of soft tissues, and adherence to a methodical rehabilitation program are still the most important determinants of the result²². Notably, some recent research has left open a probe of the disparity in the symmetry of gait and knee kinematics between PS and CR knees, where PS implants tend to present more consistent kinematic profiles after surgery²³.

Anatomical variations related to sex may also play a role in implant selection, since posterior-stabilized designs have been found to better replicate more tapered femoral shapes in specific population cohorts²⁴. There is increased interest in using mobile-bearing platforms in both posterior-stabilized (PS) and cruciate-retaining (CR-type) designs to decrease wear and optimize rotational congruity in active patients. Biomechanical modeling has demonstrated that PS implants have the potential to generate higher contact stresses at deep flexion, a parameter that can affect long-term polyethylene wear—a parameter yet to be investigated²⁵. In addition, the psychological preparation and rehabilitation expectations of patients could affect subjective results, including WOMAC scores, to a great extent regardless of the implant type used²⁶.

Current evidence has placed the study into the impact of metabolic disorders such as diabetes and obesity on the decision for the implant and the functional outcome subsequent to total knee arthroplasty regardless of the constraint used²⁷. Additionally, patient-reported outcome measures (PROMs) are now more prominently seen as the key tools for the evaluation of the functional performance of implant designs, especially in terms of perceiving subtle differences between cruciate-retaining and posterior-stabilized knee prostheses²⁸. Other scholars have proposed incorporating wear sensor data into postoperative evaluation protocols to offer objective and real-time assessment of mobility and gait, possibly revolutionizing future comparison of implant performance²⁹.

In conclusion, since the controversy surrounding cruciate retention versus posterior substitution continues, it is the marriage of careful technique, evidence-based customization, and subjective patient experience that ultimately defines the true success of total knee arthroplasty.

5. Conclusion:

The study addressed whether CR or PS implant designs influence clinical success in primary TKA. This research concludes that no statistically significant correlation exists between implant type (CR vs PS) and most postoperative clinical results in TKA, such as functional scores, range of motion, deformity correction, or complication profile. The lone exception was a statistically higher WOMAC improvement in the PS group, which indicates possible benefit in early subjective symptoms relief.

We suggest that implant selection can be tailored, based on intraoperative findings and not broad assumptions. Future technologies such as artificial intelligence-guided alignment devices, ligament sensing devices, and robotic

procedures can contribute to reducing the dependence on variability in implant designs and can reshape the strategy to truly individualized arthroplasty.

The future lies in integrating kinematic alignment technology, intelligent implant sensors, and artificial intelligence-based surgical planning to personalize TKA. Balancing anatomical variability and implant response, we look forward to the next decade to provide even improved results.

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