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Improved precision and Reduced Technical Errors in Total Knee Arthroplasty Using the Velys Robotic-Assisted Solution: Single-Center Comparative Study

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ABSTRACT

Despite advances in total knee arthroplasty (TKA), 7-15% of patients remain dissatisfied with surgical outcomes. Variability in implant positioning and limb alignment are recognized contributors. This study evaluates the surgical precision, coronal alignment, and early clinical safety of an imageless robotic system (VELYSTM Robotic-Assisted Solution) compared to conventional instrumentation.

We retrospectively reviewed 342 consecutive TKAs performed between September 2021 and May 2024: 198 with conventional instrumentation and 144 with robotic assistance. Clinical parameters included anterior femoral notching, tibial stem placement, and insert size. Radiographic outcomes included mechanical hip-knee-ankle axis (HKA), mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), and joint line orientation (JLO). Complication rates within one year were recorded.

Femoral notching was significantly reduced in the robotic group (13.9% vs. 25.3%, $p = 0.04$). Tibial stem extension was less frequently required (15.3% vs. 24.2%, $p = 0.01$). Average insert thickness was reduced (5.7 ± 0.83 mm vs. 6.04 ± 0.98 mm, $p = 0.003$). Radiographic analysis of 225 patients demonstrated reduced variability in postoperative alignment with robotic assistance, including fewer alignment outliers and lower incidence of unintended valgus tibial cuts. Complications occurred in 10 manual and 6 robotic cases, with no events attributable to the robotic system.

The Velys Robotic-Assisted Solution demonstrated improved surgical precision and radiographic outcomes compared to conventional TKA. Through enhanced intraoperative guidance, surgeon decision-making resulted in reduced femoral notching and stem usage, with more consistent implant positioning. These findings support imageless robotic assistance as a safe and effective enabling technology in TKA.

Keywords: TKA, Robotic Surgery, Accuracy, Alignment, VELYSTM Robotic-assisted solution.

INTRODUCTION

Clinical Context

Symptomatic knee osteoarthritis is one of the most common musculoskeletal conditions affecting 10% of men and 18% of women over 60 years of age[1]. It often leads to reduced physical activity and a decreased quality of life. TKA is regarded as the gold standard for treating end-stage knee osteoarthritis with bone-on-bone contact, offering substantial pain relief and functional improvement for the majority of patients[2-4].

Current State of Knowledge

Despite the overall success of TKA, patient dissatisfaction remains a persistent challenge. While historical reports suggested dissatisfaction rates of approximately 20%, more recent systematic reviews indicate rates between 7% and 15%, depending on how dissatisfaction is defined and measured[5-7]. Importantly, patient dissatisfaction is multifactorial, influenced by both patient-related factors (such as preoperative psychological status, comorbidities, and expectations) and surgery-related factors (including implant positioning, alignment, and soft tissue balancing)[8,9].

Variability in surgical execution, particularly regarding implant positioning and limb alignment, has been identified as a modifiable contributor to suboptimal outcomes[10,11]. While the relationship between alignment and patient-reported outcomes remains complex and somewhat controversial, multiple studies have demonstrated that component malalignment, particularly in the coronal and sagittal planes, can negatively impact both implant survival and functional outcomes[10-14]. Precise and reproducible implant positioning is crucial for both short- and long-term outcomes, yet conventional instrumentation often falls short in this regard[15,16].

To address these challenges, enabling technologies such as computer navigation and robotic-assisted systems have been developed to improve surgical precision and reproducibility[17,18]. Recent meta-analyses have demonstrated that robotic-assisted TKA (RA-TKA) is associated with improved radiographic accuracy, reduced alignment outliers, fewer perioperative complications, and modest improvements in patient-reported outcomes compared to conventional instrumentation[19-22]. Specifically, RA-TKA has been shown to reduce rates of intraoperative fracture, postoperative anemia, blood transfusion, manipulation under anesthesia, and overall complication rates[20,23,24]. Furthermore, robotic systems may facilitate individualized alignment strategies that better restore native knee anatomy, potentially addressing the subset of patients whose constitutional alignment deviates from traditional neutral mechanical alignment targets[12,19].

Knowledge Gap and Rationale

While the existing literature supports the theoretical advantages of robotic assistance in TKA, several important questions remain. First, the impact of robotic systems on specific technical parameters, such as the incidence and severity of anterior femoral notching, the need for tibial stem extensions, and polyethylene insert sizing, has not been comprehensively evaluated. These parameters are clinically relevant as they may influence both short-term recovery and long-term implant performance. Second, the ability of robotic systems to maintain native joint line obliquity and avoid the creation of rare, potentially unfavorable coronal plane alignment phenotypes requires further investigation. Third, real-world comparative data from high-volume centers implementing imageless robotic systems are needed to validate findings from controlled trials and assess the technology's practical utility in routine clinical practice.

The VELYS™ Robotic-Assisted Solution (VRAS) represents an imageless robotic platform that does not require preoperative imaging, potentially offering advantages in workflow efficiency and cost-effectiveness. However, comprehensive evaluation of its performance across multiple surgical and radiographic parameters compared to conventional instrumentation is lacking. Understanding whether this technology delivers measurable improvements in surgical precision, component positioning, and early clinical safety is essential for evidence-based decision-making regarding its adoption.

Study Aims and Hypothesis

We hypothesized that implementation of the VRAS imageless robotic system in our high-volume arthroplasty practice would result in more precise implant positioning, reduced technical complications, and more consistent radiographic outcomes compared to conventional instrumentation. The primary objectives of this study were to compare conventional and robot-assisted TKA with respect to: (1) the incidence and severity of anterior femoral notching; (2) the need for tibial stem extension; (3) polyethylene insert thickness; (4) radiographic alignment parameters including HKA, mLDFA, MPTA, JLO*; (5) postoperative Coronal Plane Alignment of the Knee (CPAK) classification distribution[25]; and (6) early complication rates within one year of surgery.

MATERIALS AND METHODS

The authors obtained approval by the institutional ethical committee for this study (AZSJ2025009). In this single-center retrospective analysis, we evaluated 342 consecutive patients who underwent primary TKA for end-stage osteoarthritis or avascular necrosis between September 2021 and May 2024.

Patient allocation was chronological and based on the availability of the robotic system. Before the introduction of the VELYS™ Robotic-Assisted Solution (VRAS), all procedures were performed using conventional instrumentation (first 198 consecutive cases). Following the implementation of the robotic platform at our institution, all subsequent TKAs were performed using VRAS (next 144 consecutive cases). No overlap period occurred, and no patient selection criteria were applied to determine the surgical technique.

All surgeries were performed by a single fellowship-trained arthroplasty surgeon. The ATTUNE Knee (DePuy, Warsaw, Indiana, USA) implant was used in all cases. We included patients undergoing primary TKA due to knee osteoarthritis or avascular necrosis. Patients with posttraumatic osteoarthritis, conversion from unicompartmental to total knee arthroplasty, history of lower limb osteotomy or inadequate postoperative full-leg radiographs were excluded.

Routine data collection included patients' age, gender, body mass index (BMI), operated side (left/right), preoperative HKA axis and insert type. These details were tabulated (Table I). All participants were monitored for at least 1 year post-surgery. No patients were lost to follow up. We specifically reviewed medical records for any complications.

Surgical technique

In every procedure a standard midvastus incision was used. Preference was given to a cruciate retaining implant (CR) whenever possible. If the PCL was insufficient, a posterior-stabilised implant (PS) was used. Patellar resurfacing was selectively performed. All patients were operated under tourniquet at 250 mmHg. In both groups a restricted inverse kinematic alignment philosophy was followed. A short cemented tibial stem extension was used in the presence of an irregular tibial surface, poor tibial bone quality, or in patients with BMI > 35.

In the conventional TKA group, a tibia first technique was performed, type flexion balancing first. Based on the assessment of the flexion gap and the extension gap by ligament balancing, resections of the femur were performed by copying the extension to the flexion gap, obtaining stable flexion and extension gaps.

In the RA-TKA group the VRAS was used. This is an imageless system consisting of an operating table-mounted robotic arm that positions a surgical saw to perform the bony resections. The system is guided by an optical tracking system using two bone-mounted arrays. After landmark registration and assessment of initial alignment and joint stability , surgical planning was performed (see addendum for the required landmarks). In this phase the surgeon's desired component position, knee balance and leg alignment are virtually displayed before engaging the device to perform the bony resections. Validation of the accuracy of tibial and femoral resections was then followed by testing range of motion, alignment and ligament balance with trial components. When satisfactory results were obtained definitive components were implanted.

One reviewer analyzed both the medical records, operation reports and pre- and postoperative radiographs. The medical files were screened for complications. Early complications were defined as those occurring within 1 year after surgery. The final component and insert sizes were retrieved from the operation reports. Anterior femoral notching was evaluated on standardized lateral radiographs using the Tayside classification. Notching was defined as a violation of the anterior femoral cortex by the anterior flange of the femoral component and graded as follows: Grade I, violation of the outer table of the anterior cortex; Grade II, violation of the inner and outer table of the anterior cortex; Grade III, violation up to 25% of the medullary canal; and Grade IV, violation up to 50% of the medullary canal[26]. For statistical analysis, notching was recorded according to grade, and its incidence was compared between groups. Specific angles, like the HKA, mLDFA, MPTA and JLO* were measured on full-leg anteroposterior radiographs. To determine CPAK classification the arithmetic HKA (aHKA) and the joint line obliquity (JLO) were calculated cfr. the paper of MacDessi[25].

Full leg analysis was performed on a subset of the initial series of 342 patients. Due to incomplete imaging 93 patients were excluded, and another 24 patients were excluded because of inferior radiographic quality. Thus, 225 patients (131 conventional versus 94 robot) were left for final radiographic analysis.

Data analysis was carried out using R Statistical Software (v4.3.0; R Core Team, Vienna, Austria). The significance of categorical variables such as

Table I. — Patient characteristics.

Variable	Manual TKA	Robot TKA	P
Number of patients	198	144	
Mean age, yrs (SD)	70 (9.0)	72 (8.9)	0.07**
Women, n (%)	135 (68.2)	84 (58.3)	0.06*
Mean BMI, kg/m² (SD)	29 (5.1)	28 (4.1)	0.14**
Mean preoperative HKA (SD)	177.2 (6.6)	177.9 (7.2)	0.39**
Left knee, n (%)	95 (48.0)	67 (46.5)	0.79*
Insert type (PS/CR)	115/83	49/95	<0.001*

* statistical significant difference based on chi-square testing (Threshold $p < 0.05$)
** statistical significant difference based on unpaired T-testing (Threshold $p < 0.05$).

Table II. — Complications and their management.

anterior femoral notching and tibial stem placement was evaluated using chi-square tests. The significance of continuous variables such as the insert size was evaluated using unpaired Student's T -testing. A significance threshold of $p < 0.05$ was maintained.

RESULTS

Table II showcases the incidence of anterior femoral notching, the incidence of tibial extended stem placement and the average insert size in both the manual and the robot group. Anterior femoral notching was present in 50 (25.3%) of the manual cases as opposed to the robotic cases, where it was only seen in 20 (13.9%) of the cases ($p = 0.04$). An extended tibial stem was implanted in 48 (24.2%) of the manual cases, whereas 22 (15.3%) of the robotic cases required extended tibial stem implantation ($p = 0.01$). Implementation of the robotic system reduced the average insert thickness from 6.04 ± 0.98 mm to 5.7 ± 0.83 mm, which is a statistical significant difference ($p = 0.003$).

Table III showcases average results, with standard deviations (SDs) for the postoperative coronal alignment parameters of both groups. For mLDFA, the following values were measured: average manual 89.3 (SD 2.69) and average robot 89.0 (SD 1.99). The values for MPTA were: average manual 89.5 (SD 1.47) and average robot 88.4 (SD 1.46). JLO measurement in the manual group averaged 0.48 (SD 2.35) with apex pointing proximal, whereas it averaged 0.04 (SD 1.61) with apex pointing distal in the robot group. Finally, HKA values were average manual 180.4 (SD 2.89) and average robot 179.4 (SD 2.68). All these values were measured on full-length radiographs 6 weeks postoperatively.

Figure 1 represents the postoperative CPAK for both the manual and the robot group. In the manual group preoperative CPAK was maintained postoperative in 29 of 131 cases (22,1%), whereas it was maintained in 28 of 93 cases (30.1%) in the robot group ($p = 0.18$).

Within a year of follow-up of all patients, 10 complications were observed in the manual group and 6 complications were observed in the robot group, as detailed in Table IV. In the manual group 2 cases necessitated a mobilization under anesthesia, 2 patellar fractures were observed, 1 patient experienced a deep venous thrombosis, 1 patient was diagnosed with a cerebrovascular accident, 1 patient was

Table II. — Anterior femoral notching, tibial stem placement and insert size.

Parameter	Manual Group N (%)	Robot Group N(%)	P
Anterior femoral notching	50 (25.2)	20 (13.9)	0.04*
Tayside class 1	43 (21.7)	20 (13.9)	
Tayside class 2	7 (3.5)	0 (0)	
Tayside class 3	0 (0)	0 (0)	
Tayside class 4	0 (0)	0 (0)	
Tibial stem placement	48 (24.2)	22 (15.5)	0.01*
Average insert size	6.04	5.72	0.003**
size 5	69 (35.4)	64 (48.1)	
size 6	67 (34.3)	47 (35.3)	
size 7	44 (22.6)	17 (12.8)	
size 8	14 (7.2)	5 (3.8)	
size 10	1 (0.5)	0 (0)	
size 12	0 (0)	0 (0)	

* statistical significant difference based on chi-square testing (Threshold $p < 0.05$)
** statistical significant difference based on unpaired T-testing (Threshold $p < 0.05$).

Table III. — Average values of the postoperative angles in degrees (±SD).

	Manual group: Average angle ± SD	Robot group: Average angle ± SD
mLDFA	89.3 ±2.69	89.0 ± 1.99
MPTA	89.5 ± 1.47	88.4 ± 1.46
JLO*	-0.48 ± 2.35	0.04 ± 1.61
HKA	180.4 ± 2.89	179.4 ± 2.68

Average values of postoperative mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), joint line orientation (JLO*) and Hip-Knee-Ankle axis (HKA) along with standard deviation.

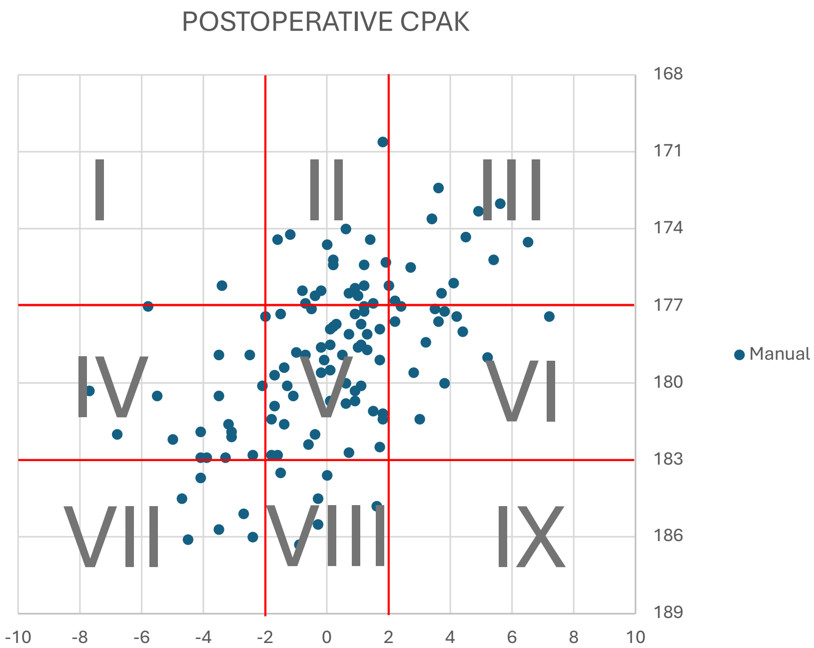

Fig. 1 — Postoperative coronal plane alignment of the knee (CPAK) in the manual group.
X-axis: arithmetic Hip-Knee-Ankle axis (aHKA); Y-axis: joint line obliquity (JLO).

Table IV. — Complications.

Complications	Manual Group	Robot Group
Periprosthetic joint infection	1	0
Superficial wound infection	3	1
Patellar fracture	2	0
Deep venous thrombosis	1	0
Gastro-intestinal bleeding	0	1
Cerebrovascular accident	1	0
Mobilisation under anesthesia	2	4

treated with a debridement, antibiotics and implant retention-procedure because of periprosthetic joint infection and 3 patients exhibited signs of a superficial wound infection that resolved with antibiotics and proper wound management. In the robot group 4 patients underwent mobilization under anesthesia, 1 patient experienced a gastrointestinal bleeding and 1 patient was treated for a superficial wound infection. Notably, none of these complications can be directly related to the robot system usage.

DISCUSSION

This study demonstrates that the use of an imageless robotic system in TKA significantly improves several intraoperative and radiographic parameters compared to conventional instrumentation, including reduced anterior femoral notching, reduced need for tibial stem extension, and thinner insert size.

Anterior Femoral Notching

Anterior femoral notching remains a known risk factor for periprosthetic fractures and has biomechanical implications on implant stability. The reported incidence of anterior femoral notching in primary TKA varies widely in the literature, ranging from 13% to 41% depending on surgical technique, implant design, and use of anterior versus posterior referencing systems[27-29]. While some clinical studies have found no correlation between notching and supracondylar fracture rates, biomechanical investigations have demonstrated that anterior cortical notching significantly reduces load to failure, decreasing bending strength by 18% and torsional strength by 39%[26,29,30].

In our series, the incidence of anterior notching was significantly lower in the robotic group (13.9%) compared to the manual group (25.3%), suggesting that robotic control of femoral resections may mitigate this

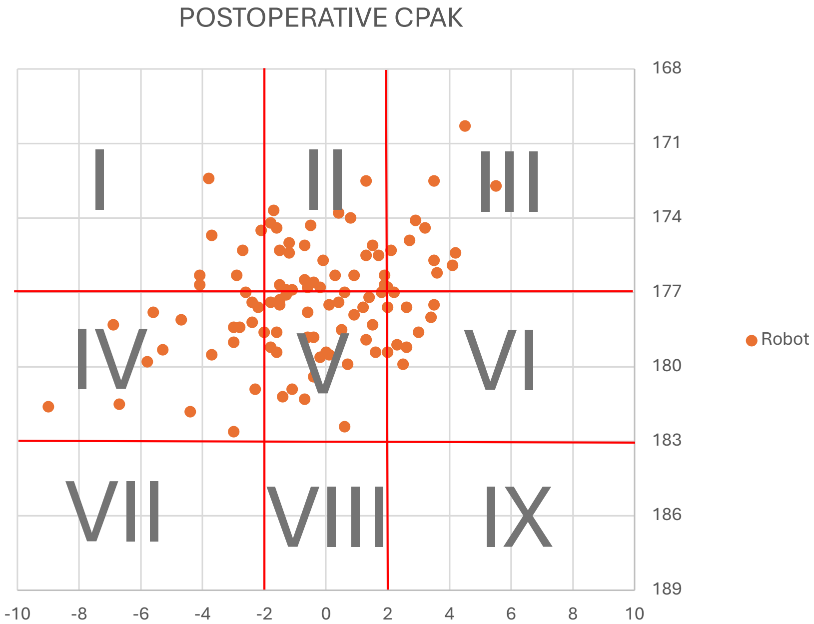

Fig. 2 — Postoperative coronal plane alignment of the knee (CPAK) in the robot group.
X-axis: arithmetic Hip-Knee-Ankle axis (aHKA); Y-axis: joint line obliquity (JLO).

technical complication. Moreover, when notching did occur, its extent was reduced in the robotic group. These findings are consistent with a recent retrospective study demonstrating that robotic-assisted TKA is associated with a reduced incidence of anterior femoral notching[31].

Tibial Stem Extensions

The reduced frequency of tibial stem extension in the robotic group (15.3% vs. 24.2%) suggests that robotic planning may lead to more conservative and precise tibial bone cuts, reducing the need for extended stems to compensate for fixation issues. Recent registry data and meta-analyses have demonstrated that short tibial stem extensions (typically 30 mm) are associated with a significant reduction in revisions due to aseptic loosening, particularly in overweight and obese patients[32-34]. The Australian registry reported that stemmed components had lower rates of all-cause revision beyond 1.5 years and significantly lower rates of aseptic loosening for tibial component-only revision (HR 0.23)[35]. However, stem extensions add operative time, cost, and potential for stem-related complications[36,37].

The lower utilization of stem extensions in our robotic cohort may reflect improved tibial bone preparation. By achieving more precise tibial cuts with optimal coverage and alignment, the robotic system may reduce the surgeon's perceived need for supplemental fixation.

Polyethylene Insert Thickness

A significantly thinner average insert size in the robotic group (5.7 mm vs. 6.04 mm) may indicate improved soft tissue balancing and more accurate bone resection. The clinical significance of polyethylene thickness in TKA remains debated in the literature. Several large registry studies have demonstrated that thicker inserts (≥13-15 mm) are associated with increased revision rates, particularly for aseptic loosening and instability[38,39]]. Conversely, other studies have found no difference in clinical outcomes or survivorship between thick and thin bearings[40,41]. The relationship between insert thickness and outcomes appears complex, as thicker inserts may indicate greater surgical complexity, larger bone resections, or more severe preoperative deformity rather than representing an independent risk factor.

CPAK Classification and Joint Line Obliquity

Radiographically, the robotic group showed more consistent values for HKA, mLDFA, MPTA, and JLO, suggesting greater control over implant positioning. The CPAK classification system categorizes knee phenotypes based on aHKA and JLO, with nine distinct types ranging from constitutional varus with apex distal JLO (Type I, the most common) to rare apex proximal phenotypes (Types VII, VIII, IX)[25]. In healthy populations, Types II, I, and V account for approximately 80% of knees, while apex proximal types (VII, VIII, IX) are exceedingly rare[25].

Notably, in the manual group, we observed postoperative CPAK Types VII, VIII, and IX, which are characterized by an apex proximal joint line orientation. Several studies have identified apex proximal JLO as a negative predictor of patient-reported outcomes following TKA. The restoration of native JLO, particularly apex distal orientation, has been associated with improved WOMAC function scores and Forgotten Joint Scores at 2-year follow-up[42]. Conversely, the creation of non-anatomic apex proximal JLO through mechanical alignment techniques may alter the native knee phenotype in ways that negatively impact functional outcomes [43]. It has been suggested that unintended increases in JLO leading to rare apex proximal phenotypes may negatively impact clinical outcomes, though the evidence regarding CPAK matching and outcomes remains mixed[44-47].

The absence of apex proximal CPAK types in our robotic cohort suggests that the precision of robotic systems may help avoid the creation of these rare, potentially unfavorable alignment patterns. The ability of robotic systems to maintain more physiologic JLO while achieving balanced gaps may represent an important advantage over conventional instrumentation.

Complications

Complication rates were slightly lower in the robotic group, and no adverse events could be attributed to the robotic system itself. This finding is consistent with recent large-scale studies and meta-analyses demonstrating that robotic-assisted TKA is associated with lower perioperative complication rates compared to conventional techniques. A recent meta-analysis of prospective studies found that robotic TKA had significantly lower overall complication rates (11.5% vs. 16.7%, OR 0.62)[19]. Large database studies have reported that robotic TKA is associated with reduced rates of intraoperative fracture, respiratory complications, renal failure, postoperative anemia, blood transfusion, and thromboembolic events[23,48]. Additionally, robotic TKA has been associated with fewer hospital revisits for joint stiffness, chronic pain, and hematomas, as well as reduced rates of manipulation under anesthesia[20,49].

Although our follow-up period was limited to one year, these early findings suggest at least non-inferiority of robotic TKA in terms of safety.

Limitations

Several limitations should be acknowledged. First, this was a retrospective analysis conducted at a single high-volume center, which may limit generalizability. Second, although radiographic alignment and surgical parameters were assessed objectively, patient-reported outcomes were not included, limiting our ability to correlate the observed technical improvements with functional outcomes. Third, the robotic group represents a more recent cohort, potentially introducing bias from evolving surgical proficiency or institutional protocols. Finally, only one observer performed the radiographic measurements. No intra- or interobserver coefficients were calculated, but the literature has shown good reliability for analysis of full leg radiographs[51].

CONCLUSION

Our findings support the clinical utility of imageless robotic systems in enhancing surgical accuracy and consistency in TKA. The observed reductions in anterior femoral notching, tibial stem extension use, and insert size variability, combined with more consistent radiographic alignment and avoidance of rare apex proximal CPAK phenotypes, suggest that robotic assistance may help surgeons achieve more predictable and potentially more anatomic reconstructions. Future studies with longer follow-up and comprehensive patient-reported outcome measures will be necessary to determine whether these technical advantages translate into meaningful improvements in clinical outcomes and implant longevity.

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