MENTORS IN ORTHOPEDICS

TOTAL KNEE ARTHROPLASTY IN PRIOR ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: HOW TO MANAGE A PECULIAR CHALLENGE IN THE ROBOTIC ERA

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SUMMARY

Background: Patients with a history of anterior cruciate ligament reconstruction (ACLR) increasingly present with secondary knee osteoarthritis. These cases often exhibit unique anatomical features, such as increased posterior tibial slope and coronal plane deformities, which complicate total knee arthroplasty (TKA) and are associated with higher complication rates and longer operative times compared to primary osteoarthritis.

Objective: This article evaluates the technical challenges of TKA following prior ACLR and assesses the efficacy of imageless robotic-assisted surgery and personalized alignment strategies in managing these complex cases.

Key Points: Clinical data from a prospective study of 70 patients demonstrate that the ACLR group had significantly steeper preoperative tibial slopes (12.55° vs. 9.42°) and higher rates of central pivot laxity (54.3%) than controls. Intraoperatively, the ACLR group required longer surgical durations, more frequent tibial recuts (20% vs. 2.8%), and a lower utilization of medial congruent liners. Despite these baseline anatomical and functional disparities, the use of an imageless robotic system facilitated precise implant positioning and soft tissue balancing. At a mean follow-up of over three years, postoperative outcomes including Knee Society Scores and WOMAC indices were comparable between groups, with the exception of a residual reduction in maximum flexion in the ACLR cohort.

Conclusion: Robotic-assisted TKA using a personalized alignment approach effectively mitigates the technical difficulties associated with post-ACLR altered anatomy. This technology enables intraoperative adjustments to constraint levels and soft tissue balancing, resulting in clinical outcomes and complication rates equivalent to those of primary TKA.

KEYWORDS

Arthroplasty, Replacement, Knee; Robotic Surgical Procedures; Anterior Cruciate Ligament Reconstruction; Osteoarthritis, Knee; Bone Alignment

INTRODUCTION

Anterior cruciate ligament (ACL) injuries have been managed with intra-articular surgical reconstruction since the 1980s [1]. As a result, there is now a growing number of patients presenting with knee osteoarthritis (OA) following prior ACL reconstruction (ACLR) in clinical practice.

It is therefore essential to understand the specific characteristics of these knees, which often present with unique anatomical and functional features. These features can be better interpreted and managed with the use of robotic-assisted total knee arthroplasty (TKA), although a deeper understanding of them can also prove valuable in conventional TKA.

The aim of this article is to highlight the challenges encountered in TKA for patients with OA following prior ACLR, and to evaluate the role of imageless robotic surgery and a personalized approach through clinical data.

OSTEOARTHRITIS IN PRIOR ACL RECONSTRUCTION: CHALLENGES IN TKA

ACL injuries are well recognized as a major risk factor for the later development of knee osteoarthritis (OA). The instability that follows trauma often accelerates damage to both cartilage and menisci, with these degenerative changes becoming more pronounced over time, especially in the absence of appropriate treatment [2],[3].

The biomechanical alterations caused by ACL deficiency, primarily knee laxity, can progressively lead to structural deterioration within the joint. This often manifests as coronal plane deformities and wear-related defects, particularly in the posteromedial region of the tibial plateau, due to abnormal joint loading and altered kinematics [4].

ACLR is currently the treatment of choice to restore stability and protect the knee from further damage during long-term follow-up [5],[6],[7]. However, despite its benefits, ACLR does not eliminate the risk of OA. In fact, data show that individuals with a history of ACLR are seven times more likely to require TKA within 15 years compared to the general population [8].

Recent meta-analyses have highlighted that patients undergoing TKA following ACLR face higher rates of complications and longer operative times compared to those receiving TKA for primary OA [3]. These cases more frequently require the use of revision components and intraoperative soft tissue releases, reflecting the increased complexity associated with previous ligament surgery.

In response to these challenges, robotic-assisted TKA has emerged as a promising tool. By enabling personalized alignment strategies, robotic systems allow surgeons to better accommodate each patient's unique biomechanical, anatomical, and kinematic characteristics. Evidence supports that robotic TKA enhances the precision of implant placement, optimizes component alignment, and provides real-time feedback on ligament balance, factors that may contribute to improved functional recovery and greater implant longevity [9],[10],[11],[12].

CLINICAL EXPERIENCE WITH IMAGELESS ROBOTIC TKA

To investigate the outcomes of robotic-assisted TKA in patients with a history of ACLR, a prospective study was carried out at a high-volume knee arthroplasty center. The study enrolled all consecutive patients undergoing primary TKA after ACLR between January 2021 and February 2023, using the imageless ROSA® Knee System (Zimmer Biomet, Warsaw, IN, USA). A control group of patients undergoing TKA for primary OA was selected randomly to match the study group in terms of demographics, ensuring comparability.

Only younger patients, under the age of 65, were enrolled, with a minimum follow-up period of two years.

In the ACLR group, patients with a history of additional periarticular procedures, such as osteotomies or fractures, were excluded. In the control group, any patient with a prior surgical intervention was excluded. Furthermore, individuals with autoimmune joint diseases were not included. Patients were also excluded if their preoperative, intraoperative, or follow-up data were incomplete or if a comprehensive robotic data report was unavailable.

Demographic data were collected, including age, gender, and body mass index (BMI). For patients with a history of prior ACLR, additional information was recorded, such as the type of graft used, femoral and tibial fixation methods, and the time elapsed since reconstruction.

Additionally, perioperative data were analyzed, including in-hospital complications (such as deep vein thrombosis, pulmonary embolism, urinary tract infection, heart failure, pneumonia, and acute kidney injury), length of hospital stay, and surgical duration. Data were also collected on the type of prosthesis used, including the level of constraint, the use of cones or augments, and the removal of fixation devices from the prior ACLR. Surgical reports were reviewed to assess the need for recuts during the procedure.

The evaluation also included acute complications, such as post-surgical local hematoma, vascular injury, or nerve injury, as well as follow-up complications, including rates of readmission or reoperation and their respective causes, such as infection, aseptic loosening, thromboembolic events, and wound complications.

Radiographic evaluations were performed using anteroposterior, lateral, Rosenberg, sunrise, and full-length weight-bearing X-rays (Figure 1). From these, the mechanical hip-knee-ankle angle (mHKA), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), and arithmetic HKA (aHKA) classification were calculated [13].

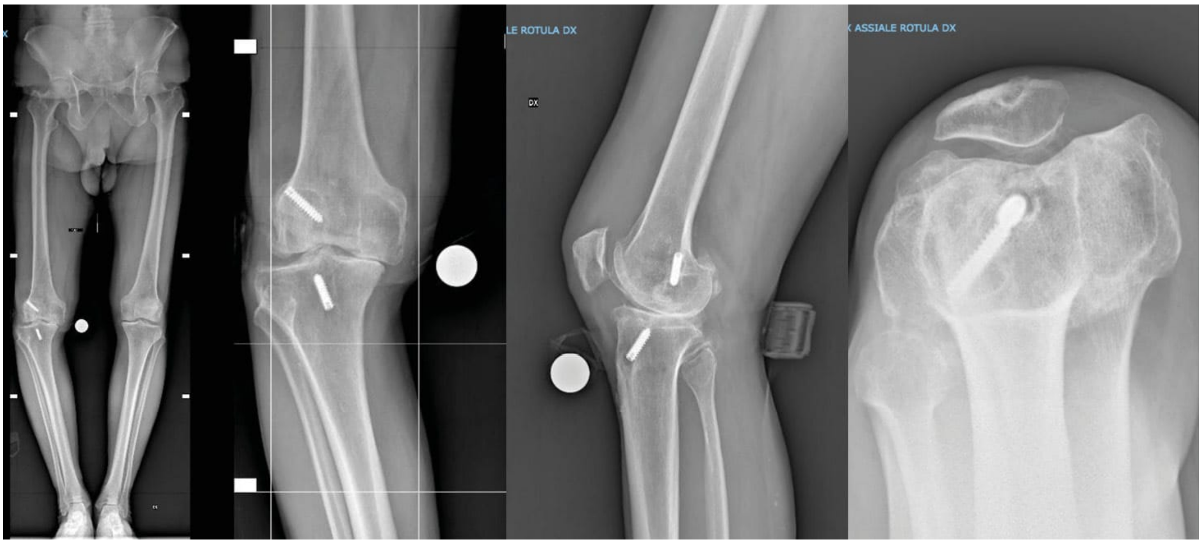


Figure 1 - Preoperative X-rays of a 51-year-old male patient with osteoarthritis of the right knee and a prior anterior cruciate ligament reconstruction performed 29 years ago. The preoperative range of motion was 0-105°, with lateral thrust.

Preoperative data for all patients included knee range of motion (ROM), measured as maximum flexion and extension deficit, as well as the Knee Society Score (KSS) for function and knee components, and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) for pain, stiffness, and function subscales. Pain levels were reported using the Numerical Rating Scale (NRS) (0–100). Additionally, preoperative central pivot stability was assessed using the Lachman test. At the final follow-up, these clinical scores were reassessed, with the addition of the Forgotten Joint Score-12 (FJS-12).

SURGICAL TECHNIQUE

All patients underwent surgery using the same technique, following an individualized alignment approach, as described by Rossi and Benazzo [14]. According to the defined parameters, this technique is based on initial planning of intra-articular corrections with bone resections, followed by a tibial resection, which allows for validation and data implementation in the planning. Next, a re-evaluation of ligament compliance is performed using the FuZion tensioning device (Zimmer Biomet, Warsaw, IN, USA), followed by a distal femoral resection, executed based on ligament constraints after the tibial cut. Finally, FuZion is used for final rotational alignment, and the procedure is completed with 4-in-1 femoral cuts, tibial and patellar preparation, and cementing (Figure 2).

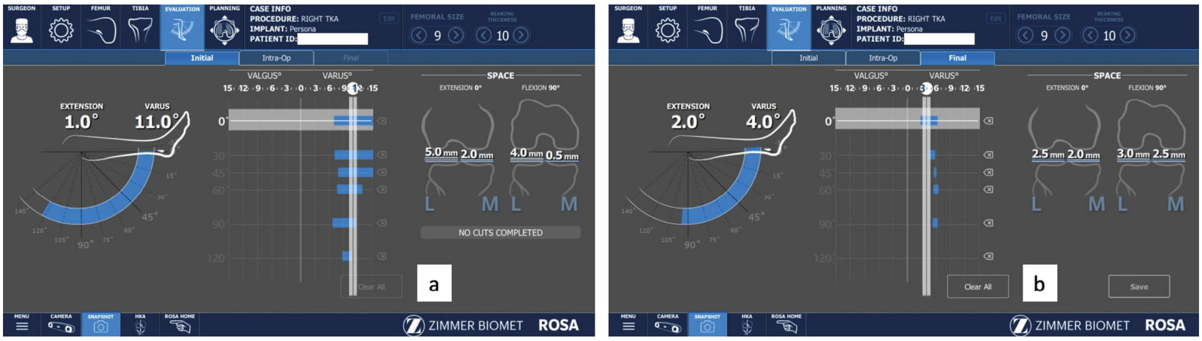


Figure 2 – Intraoperative screenshots of the ROSA Knee System (Zimmer Biomet, Warsaw, IN, USA) of the same patient as in Figure 1. In image (a), an 11° varus deformity in extension is visible, along with significant laxity in both extension and 90° flexion, measuring 5 mm and 4 mm, respectively. In image (b), an improvement in joint kinematics, correction of coronal deformity, and adequate balance in both extension and 90° flexion can be observed.

For standard implants, the Persona® (Zimmer Biomet, Warsaw, IN, USA) was used, while for Varus-Valgus Constrained (VVC) implants, the NexGen® Legacy® Constrained Condylar Knee (LCCK, Zimmer Biomet, Warsaw, IN, USA) was utilized.

RESULTS AND KEY FINDINGS

A total of 70 patients were included: 35 in the OA after ACLR group and 35 in the primary OA control group. The ACLR group had undergone reconstruction an average of 29.2 years prior to TKA (SD ± 7.5). Graft types varied: 20% received synthetic LARS grafts, 34.3% had hamstring autografts, and 45.7% had bone–patellar tendon–bone (BPTB) grafts. Notably, 20% of patients had sustained a second ACL injury requiring revision surgery.

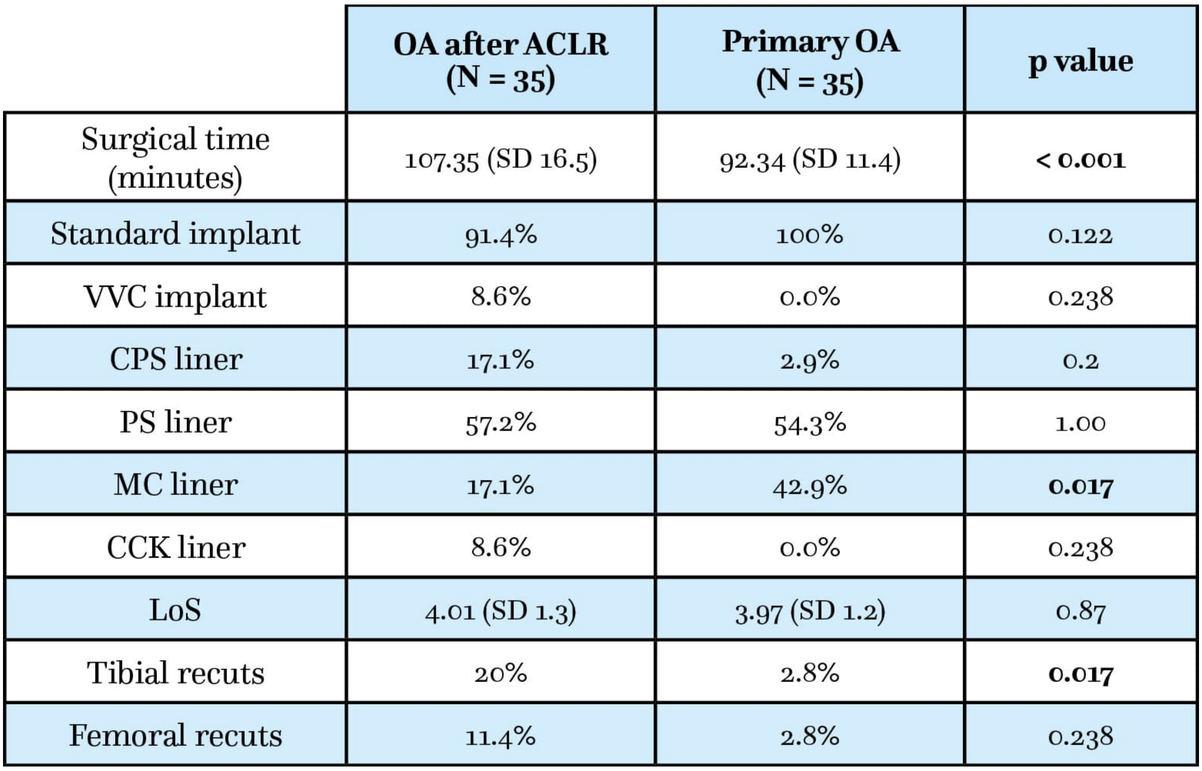
There were statistically significant differences in the anatomical and functional profiles between the two groups. The ACLR group had a steeper tibial slope (12.55° vs. 9.42°, $p = 0.002$), reduced knee flexion (106.47° vs. 118.57°, $p = 0.021$), and greater central pivot laxity (54.3% vs. 17.1%, $p = 0.001$). Functional scores also reflected this impairment: KSS-knee (61.56 vs. 67.81, $p = 0.041$), KSS-function (63.68 vs. 69.16, $p = 0.032$), WOMAC stiffness (6.14 vs. 3.34, $p = 0.017$), and WOMAC function (52.23 vs. 45.56, $p = 0.035$) were all significantly worse in the ACLR group.

The complete preoperative characteristics are reported in Table 1.

	OA after ACLR (N = 35)	Primary OA (N = 35)	p value
Age	55.86 (SD 9.7)	61.7 (SD 8.5)	0.06
Male	88.6%	85.7%	0.73
BMI	27.34 (SD 2.4)	27.0 (SD 2.4)	0.48
mHKA	173.9 (SD 8.8)	174.88 (SD 8.4)	0.57
LDFA	88.46 (SD 4.1)	88.66 (SD 3.6)	0.69
MPTA	86.19 (SD 2.7)	86.9 (SD 4.5)	0.87
aHKA	-2.27 (SD 5.7)	-2.29 (SD 5.4)	0.76
Tibial slope	12.55 (SD 4.0)	9.42 (SD 4.1)	0.002
NRS	43.42 (SD 1.4)	42.13 (SD 1.5)	0.83
Maximum flexion	106.47 (SD 13.3)	118.57 (SD 8.6)	0.021
Extension deficit	7.35 (SD 5.1)	3.78 (SD 2.7)	0.19
Central pivot stability	54.3%	17.1%	0.001
KSS - knee	61.56 (SD 8.1)	67.81 (SD 10.3)	0.041
KSS - function	63.68 (SD 11.3)	69.16 (SD 10.7)	0.032
WOMAC - pain	16.56 (SD 4.5)	15.23 (SD 3.7)	0.45
WOMAC - stiffness	6.14 (SD 1.4)	3.34 (SD 0.9)	0.017
WOMAC - function	52.23 (SD 7.2)	45.56 (SD 9.1)	0.035

Table 1 - Preoperative assessment of the two groups [BMI: Body Mass Index; mHKA: mechanical hip-knee-ankle angle; LDFA: lateral distal femoral angle; MPTA: medial proximal tibial angle; aHKA: arithmetic HKA; KSS: Knee Society Score; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index]

Medial congruent (MC) liners were used less frequently (17.1% vs. 42.9%, p = 0.017). Conversely, tibial recuts were significantly more common in ACLR patients (20% vs. 2.8%, p = 0.017), reinforcing the need to reassess balance after the tibial cut. The detailed perioperative outcomes are reported in Table 2.



	OA after ACLR (N = 35)	**Primary OA (N = 35)**	**p value**
Surgical time (minutes)	107.35 (SD 16.5)	92.34 (SD 11.4)	**< 0.001**
Standard implant	91.4%	100%	0.122
VVC implant	8.6%	0.0%	0.238
CPS liner	17.1%	2.9%	0.2
PS liner	57.2%	54.3%	1.00
MC liner	17.1%	42.9%	**0.017**
CCK liner	8.6%	0.0%	0.238
LoS	4.01 (SD 1.3)	3.97 (SD 1.2)	0.87
Tibial recuts	20%	2.8%	**0.017**
Femoral recuts	11.4%	2.8%	0.238

Table 2 - Perioperative outcomes of the two groups [VVC: Varus-Valgus Constrained; CPS: Constrained Posterior-Stabilized; PS: Posterior-Stabilized; MC: Medial-Congruent; CCK: Constrained Condylar Knee; LoS: Length of Stay]

No patient required an osteotomy of the anterior tibial tuberosity due to reduced flexion and/or a low patella. Additionally, no patients required the use of cones or tibial augments, and no in-hospital complications were recorded in either group. Fixation devices were completely removed at the femoral level in 8 patients (22.9%), while they were left in place in 20 patients (57.1%). The remaining 7 patients (20%) exhibited resorption of the fixation devices (Figure 3).

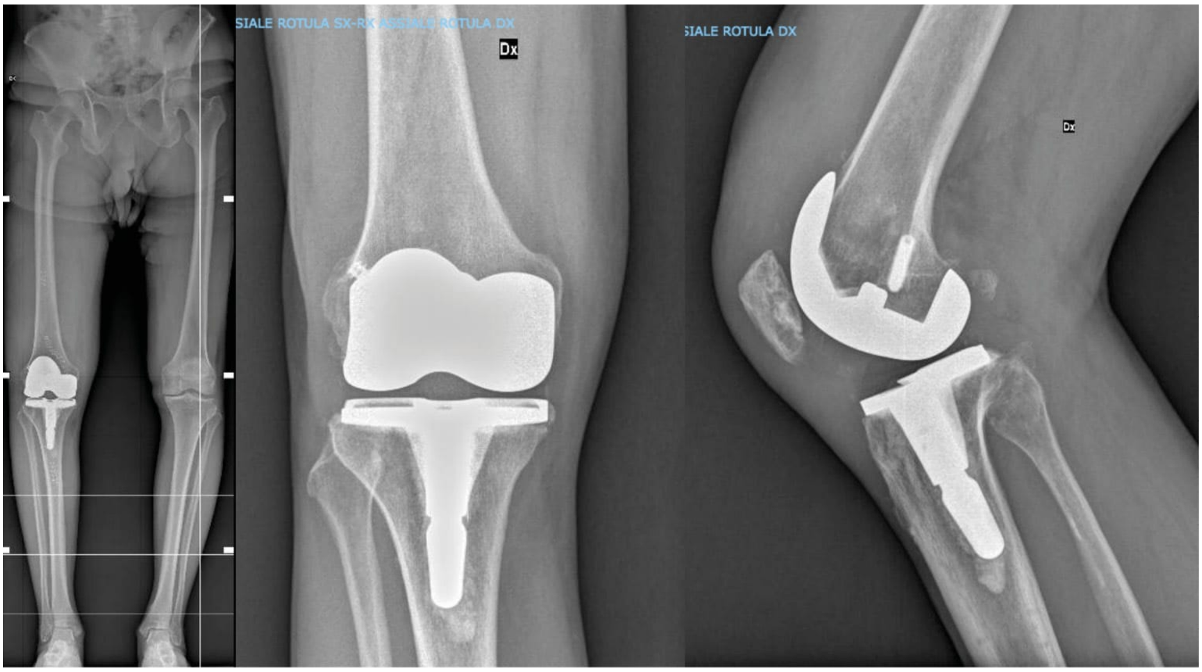


Figure 3 – Postoperative X-rays of the same patient from Figure 1 and Figure 2. A Persona® implant (Zimmer Biomet, Warsaw, IN, USA) with a Posterior-Stabilized insert and a 14 × 30 mm tibial stem was used. The tibial fixation device was removed, while the femoral fixation device was left in place.

At the tibial level, fixation devices were removed in 18 patients (51.4%), either not removed or only partially removed in 10 patients (28.6%), while 7 patients (20%) exhibited resorption of the fixation devices.

The mean follow-up period was 37.78 months (SD 10.5) in the OA after ACLR group and 36.14 months (SD 8.1) in the primary OA group (p = 0.56).

Postoperative outcomes showed a statistically significant difference in maximum flexion, which was lower in the OA after ACLR group compared to the primary OA group (114.41° vs. 128.61°, $p < 0.001$). Complete postoperative outcome data are available in Table 3.

	OA after ACLR (N = 35)	Primary OA (N = 35)	p value
mHKA	175.7 (SD 2.7)	176.3 (SD 2.3)	0.46
LDFA	90.79 (SD 2.6)	90.97 (SD 2.1)	0.81
MPTA	88.85 (SD 2.2)	88.94 (SD 1.6)	0.88
aHKA	-1.86 (SD 3.6)	-2.03 (SD 3.2)	0.31
Tibial slope	4.62 (SD 2.0)	4.9 (SD 2.15)	0.69
NRS	7.65 (SD 8.3)	6.19 (SD 5.4)	0.83
Maximum flexion	114.41 (SD 10.7)	128.61 (SD 9.4)	**< 0.001**
Extension deficit	0.59 (SD 1.7)	1.04 (SD 3.1)	0.83
KSS - knee	91.35 (SD 9.7)	92.43 (SD 10.1)	0.83
KSS - function	91.63 (SD 11.1)	93.45 (SD 8.7)	0.32
WOMAC - pain	3.61 (SD 2.1)	3.29 (SD 1.9)	0.45
WOMAC - stiffness	1.04 (SD 1.8)	1.15 (SD 1.9)	0.51
WOMAC - function	13.45 (SD 9.1)	12.14 (SD 11.5)	0.67
FJS-12	83.27 (SD 15.4)	85.85 (SD 13.17)	0.45
Follow-up (months)	37.78 (SD 10.5)	36.14 (SD 8.1)	0.56

Table 3 - Postoperative outcome data of the two groups [mHKA: mechanical hip-knee-ankle angle; LDFA: lateral distal femoral angle; MPTA: medial proximal tibial angle; aHKA: arithmetic HKA; KSS: Knee Society Score; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; FJS: Forgotten Joint Score]

The prior ACLR group reported a readmission rate of 5.7%, corresponding to two patients with an intra-articular hematoma requiring non-surgical drainage. Additionally, one patient in this group experienced stiffness, with knee flexion limited to 90° due to patella baja (Modified Insall-Salvati Ratio, mISR = 1.67).

The primary OA group had a readmission rate of 2.9%, also due to non-surgical drainage of an intra-articular hematoma. However, the difference in readmission rates between the two groups was not statistically significant (p = 0.99).

No cases of infection, aseptic loosening, thromboembolic events, wound complications, or other major complications were reported, resulting in a 0% revision rate in both groups at the final follow-up.

The main findings of this clinical experience show that, despite preoperative anatomical differences, particularly in native tibial slope, and significant functional disparities in maximum flexion, KSS-knee, KSS-function, and WOMAC stiffness and function, postoperative outcomes remained comparable between the prior ACLR group and patients with primary OA after an average follow-up of over three years. The only exception was a residual reduction in knee flexion in the ACLR group.

These results were achieved using an imageless robotic system combined with a personalized approach, which led to specific intraoperative differences. These included longer surgical times, the use of different liners, and a higher frequency of tibial recuts in patients with prior ACLR. The complication rate is minimized and comparable between patients undergoing TKA after prior ACLR and those with TKA for primary OA.

Several studies have identified tibial slope as a key risk factor for ACL injury, as an increased posterior slope can contribute to greater anterior tibial translation and increased stress on the ligament [15]. A posterior tibial slope exceeding 10.1° has been linked to an 11-fold higher risk of ACL graft failure, suggesting a biomechanical predisposition to instability and recurrent injury [16]. However, an increased posterior tibial slope may not be a significant risk factor for ACL tears in pediatric and adolescent patients [17]. This highlights the importance of tibial slope, even in healthy knees, suggesting that its evaluation may influence surgical outcomes.

Hoxie et al. reported significant preoperative differences between patients with prior ACLR and those with primary OA, findings that mirror the results observed in the total sample of the present study [18]. Systematic reviews have not shown significant differences in post-TKA clinical scores between the previous ACLR group and the control group [19]. The most commonly used scores include the WOMAC score, KSS, and International Knee Society Score (IKS) [3]. Patients with a history of ACLR generally demonstrate postoperative subjective and functional outcomes comparable to those of control patients following TKA [20].

In the two groups evaluated in the present study, statistically significant preoperative differences were found in both WOMAC and KSS scores, suggesting functional heterogeneity between the groups. However, no significant differences were found postoperatively.

Watters et al., in a study conducted on a cohort of 122 patients with prior ACLR, compared to a matched control group, reported higher preoperative KSS scores in the ACLR group [21]. These findings contrast with data of this study, where preoperative KSS scores were significantly lower in patients with a history of ACLR. However, in both studies, no statistically significant differences were observed between the two groups postoperatively.

Several studies have reported greater extension deficits or reduced flexion in the ACLR group. However, at the final follow-up, no significant differences in postoperative range of motion were found between the ACLR and control groups [3],[19].

The literature reports differences in operative times and additional procedures, suggesting that TKA in patients with prior ACLR may involve more complex surgical considerations [22],[23]. Chong et al. found increased surgical duration in the ACLR group [24]. These findings align with the present results, which showed a statistically significant increase in operative time in the group with previous ACLR. Therefore, surgical time and tourniquet duration are consistently longer in patients with a history of ACLR. The increase is primarily due to challenges posed by device removal and the altered knee anatomy resulting from prior surgery, making the procedure more complex compared to patients without prior knee surgery.

Knee deformity is an important factor, especially when TKA is performed with mechanical alignment (MA). The literature reports that when varus or valgus angles exceed certain thresholds, the constraint level of the prosthetic implant is increased to compensate for instability and ensure optimal alignment [11],[25]. In cases of major deformities, the use of more constrained implants, such as VVC or constrained PS (CPS), becomes necessary, as they provide additional stabilization, improve functional outcomes, and reduce the risk of postoperative misalignment [26],[27],[28].

The primary challenge in most ACLR patients was the presence of coronal deformity, accompanied by increased retraction of medial soft tissues, requiring a gradual medial release when using standard techniques such as MA [29],[30]. James et al. found an increased use of constrained implants in patients with a history of ACLR compared to those without previous ligament surgeries [31].

TKA following ACLR carries a higher risk of early reoperation compared to primary TKA in patients without a history of ligament reconstruction. Warren et al. found a significantly higher reoperation risk in the ACLR group, with an incidence more than five times higher than in the control group [21]. The authors also identified a 3.3% infection rate in the ACLR group, whereas no infections were recorded in the matched control cohort.

Lizaur-Utrilla et al., in a study of 74 patients, found that only one patient in the ACLR group reported anterior knee pain at the six-year follow-up [20]. No cases of infection or aseptic loosening were reported in the present study. TKA in patients with prior ACLR appeared more complex and associated with a higher early reoperation risk compared to primary TKA [32].

However, Anil et al. compared postoperative complications between 116 patients undergoing TKA with prior ACLR and 348 patients without prior ACLR. Their results showed no significant differences in wound complications or reoperation rates, suggesting that prior ACLR does not significantly impact perioperative outcomes in TKA [23].

ROBOTIC TKA: HOW TO BETTER UNDERSTAND THE KNEE

In patients undergoing TKA after ACL reconstruction, intraoperative assessment often reveals central pivot insufficiency. In such cases, knee stability may be partially maintained through bony congruence rather than ligamentous integrity. However, significant variations in joint balance can occur following the tibial cut. For this reason, a tibia-first approach is strongly recommended, allowing for accurate reassessment of soft tissue gaps after the proximal tibial resection.

When central pivot deficiency is compounded by collateral ligament laxity, particularly with varus or valgus thrust, a structured, stepwise evaluation becomes essential to guide the degree of soft tissue release and implant constraint.

These knees frequently exhibit hyperextension relative to the contralateral side, often accompanied by flexion contracture, and achieving more than 110° of postoperative flexion may not always be feasible.

Adopting a functional alignment strategy facilitates the creation of well-balanced flexion and extension gaps. Notably, a slightly tighter medial gap in flexion is generally preferred, as it has been associated with improved postoperative outcomes and joint stability.

CONCLUSIONS

Robotic TKA, particularly when combined with a personalized approach, offers significant advantages in managing complex cases such as patients with a history of ACLR. The robot enables greater precision in implant positioning, supports the application of functional alignment, and enhances intraoperative understanding of collateral ligament competence, allowing for real-time adjustments in constraint levels when necessary. This approach not only respects essential pre-robotic surgical principles but also demands a thorough biomechanical interpretation throughout the procedure, especially after the tibial cut, due to possible changes in soft tissue compliance.

Clinical experience confirms that imageless robotic surgery can achieve postoperative outcomes in ACLR patients comparable to those observed in primary OA. Despite potential residual functional differences, robotic assistance has proven to improve soft tissue balancing and mitigate the technical difficulties associated with altered anatomy.

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