

Review article

Robotic-assisted total knee arthroplasty for post-traumatic osteoarthritis following tibial plateau fractures: A narrative review

F. Granata ^a, F. Nasca ^{a,b}, C.D. Cobisi ^{a,b}, M.G.L. Bellia ^{a,b}, C. Burgio ^c, F. Bosco ^{a,b,*}

^a Department of Orthopaedics and Traumatology, G.F. Ingrassia Hospital Unit, ASP 6, Palermo, Italy

^b Department of Precision Medicine in Medical, Surgical and Critical Care (Me.Pre.C.C.), University of Palermo, Palermo, Italy

^c Adult Reconstruction and Joint Replacement Service, Hospital for Special Surgery, New York, NY, USA



ARTICLE INFO

Keywords:

Robotic-assisted

Total knee arthroplasty

Post-traumatic osteoarthritis

TKA

PTOA

ABSTRACT

Post-traumatic osteoarthritis (PTOA) following tibial plateau fractures constitutes a demanding indication for total knee arthroplasty (TKA) because of residual deformities, altered joint biomechanics, soft-tissue imbalance, and the potential presence of retained hardware. Conventional TKA in this setting is associated with higher rates of intraoperative complications, suboptimal implant positioning, and increased revision risk. Robotic-assisted (RA) technologies have emerged as potential tools to enhance accuracy, restore alignment, and improve reproducibility in complex knee arthroplasty. The aim of this study is to summarize and critically appraise the current evidence on RA-TKA for PTOA after tibial plateau fractures, highlighting advantages, limitations, and future perspectives. A narrative review was conducted by searching PubMed and Scopus for clinical studies evaluating RA-TKA in the setting of prior tibial plateau fractures. Relevant case series, cohort studies, and comparative analyses were reviewed and synthesized. Preliminary evidence suggests that robotic-assisted TKA may improve the accuracy and reproducibility of component positioning; however, most quantitative accuracy data are derived from primary osteoarthritis cohorts, with limited PTOA-specific evidence currently available. Robotic platforms may also facilitate intraoperative soft-tissue balancing in anatomically distorted knees. However, available literature remains limited to small case series with heterogeneous patient cohorts and short follow-up durations. Functional outcomes and complication rates are inconsistently reported, and robust comparative data are lacking. RA TKA appears to be a promising approach for managing PTOA after tibial plateau fractures. Despite encouraging early results, current evidence is still preliminary. High-quality prospective studies, ideally multicenter with long-term follow-up, are required to substantiate the clinical, functional, and economic benefits of robotics in this challenging population.

1. Introduction

Post-traumatic osteoarthritis (PTOA) of the knee is a frequent long-term consequence of tibial plateau fractures, developing as a result of acute structural injury rather than the chronic degenerative processes characteristic of primary osteoarthritis. Residual malalignment, articular incongruity, and direct chondral damage accelerate joint deterioration and lead to earlier symptom onset ^{1,2} PTOA occurs in approximately 21–44% of patients following tibial plateau fractures, depending on fracture pattern, severity, and quality of reduction, and it often presents nearly a decade earlier than primary osteoarthritis ^{3,4} Considerable debate persists regarding the optimal management

strategy to minimize long-term complications and reduce the need for subsequent surgery, with treatment options ranging from conservative management to operative fixation such as open reduction and internal fixation ^{5,6}

When conservative measures and joint-preserving interventions fail, total knee arthroplasty (TKA) becomes the definitive treatment for symptomatic PTOA. Although conventional TKA has long been the standard option, it is technically demanding in this population due to distorted anatomical landmarks, bone defects, unpredictable soft-tissue balance, and interference from retained hardware ^{7,8} These challenges contribute to higher complication and revision rates compared with TKA performed for primary osteoarthritis, raising concern about the

* Corresponding author. Department of Precision Medicine in Medical, Surgical and Critical Care (Me.Pre.C.C.), University of Palermo, Department of Orthopaedics and Traumatology, G.F. Ingrassia Hospital Unit, ASP 6, 90131, Palermo, Italy.

E-mail addresses: francesco.bosco03@unipa.it, francescobosco@icloud.com (F. Bosco).

<https://doi.org/10.1016/j.jcot.2026.103375>

Received 5 December 2025; Received in revised form 7 February 2026; Accepted 10 February 2026

Available online 10 February 2026

0976-5662/© 2026

reliability of traditional techniques in post-traumatic knees^{9,10} Robotic-assisted TKA (RA-TKA) has emerged as a potential solution to address these limitations. Computed Tomography (CT)-based platforms enable detailed preoperative characterization of deformity, bone loss, joint-line disruption, and retained hardware, supporting highly individualized surgical planning^{11–15}. Intraoperatively, robotic guidance facilitates precise bone resections and real-time soft-tissue evaluation, potentially enhancing the accuracy, reproducibility, and safety of TKA in anatomically distorted knees.

Despite these theoretical advantages, the current literature on RA-TKA for PTOA after tibial plateau fractures remains limited to small case series and single-center reports, with no dedicated registries or randomized controlled trials available^{16–18}. The aim of this narrative review is therefore to summarize the available evidence on RA-TKA in patients with PTOA following tibial plateau fractures, outline potential advantages and limitations, and identify priorities for future research in this complex patient population.

2. Methods

A narrative review of the literature was conducted to provide a descriptive and interpretative overview of the use of RA-TKA in the management of PTOA following tibial plateau fractures. The literature was explored using the PubMed and Scopus databases, focusing on clinical experiences, technical considerations, and reported outcomes in this specific and relatively uncommon clinical scenario.

The search strategy included combinations of the terms “robotic-assisted total knee arthroplasty,” “post-traumatic osteoarthritis,” and “tibial plateau fracture.” Rather than applying predefined inclusion or exclusion criteria or a formal screening process, relevant publications were identified based on their clinical relevance to the topic and their contribution to understanding the role of robotic assistance in complex post-traumatic knee arthroplasty.

Given the limited number of available studies, the heterogeneity of patient populations, and the predominance of small case series and descriptive reports, a narrative synthesis was deemed the most appropriate approach.

3. RA-TKA in post-traumatic settings

TKA performed after tibial plateau fractures presents several technical challenges related to residual deformity, bone loss, ligamentous imbalance, and the possible presence of retained hardware^{6,7}. These factors complicate the restoration of mechanical alignment and soft-tissue balance compared with primary osteoarthritis, and they often render conventional anatomical landmarks unreliable. As a result, intraoperative balancing becomes less predictable and may compromise component positioning¹⁹.

RA-TKA has emerged as a valuable tool in this context, offering advanced preoperative planning, controlled and reproducible bone resections, and real-time assessment of soft-tissue tension. These features are particularly advantageous in joints altered by post-traumatic deformity, where conventional instrumentation may fail to achieve adequate accuracy^{15,19,20}. Early clinical reports and small case series suggest that robotic assistance may facilitate component alignment and reduce variability in complex post-traumatic knees; however, these observations are primarily descriptive and largely extrapolated from primary osteoarthritis populations^{1,2,16–18}. Although these preliminary findings are encouraging, the evidence remains limited by small cohort sizes, heterogeneous patient characteristics, and short follow-up periods. Consequently, robust conclusions regarding functional outcomes, complication rates, and implant survivorship cannot yet be drawn.

3.1. Image-based vs. imageless robotic systems

Robotic platforms for TKA are broadly categorized into image-based

(CT-based) and imageless systems. Image-based platforms, such as the MAKO system, generate a preoperative three-dimensional model derived from CT imaging, enabling precise templating and simulation of component positioning. This technology is particularly advantageous in post-traumatic settings, where the CT-based reconstruction accurately delineates extra-articular deformities, residual fracture morphology, retained hardware, and bone defects, thereby supporting a highly individualized surgical plan^{13–15}.

Imageless systems, in contrast, rely entirely on intraoperative mapping through anatomical landmarks and kinematic assessment without routine preoperative imaging. This eliminates radiation exposure and may simplify perioperative logistics; however, the accuracy of the system is directly dependent on the precision of landmark acquisition and soft-tissue tracking. In complex post-traumatic knees, where anatomical landmarks are distorted due to the prior fractures or inaccessible due to retained hardware, registration may become inherently less reliable^{6,18,20}.

From a practical standpoint, this distinction is particularly relevant in PTOA after tibial plateau fractures: distorted bony anatomy, residual fracture morphology, and retained hardware may compromise landmark acquisition and tracking, increasing susceptibility to registration-related errors. This likely contributes to the current evidence base being predominantly CT-based in post-traumatic scenarios, where preoperative 3D modeling better supports planning in complex anatomy.

The choice between image-based and imageless platforms should therefore be individualized, considering the degree of anatomical complexity, the presence and location of retained implants, available institutional resources, and the surgeon's familiarity with each system. The following section reviews current evidence supporting these considerations in post-traumatic arthroplasty scenarios.

3.2. Clinical evidence

Table 1 provides an overview of the principal clinical studies evaluating the use of a Robotic system in post-traumatic osteoarthritis and other complex knee deformities. Accordingly, outcomes from these series are summarized for contextual purposes only; given the mixed indications and heterogeneous cohorts, they should be interpreted descriptively rather than as PTOA-after-tibial-plateau-specific functional or radiographic benchmarks. Most of the available evidence consists of case reports and small case series, reflecting the novelty and select indication of robotic assistance in this setting^{1,2,8–10,21}.

Notably, the current literature is heavily weighted toward CT-dependent systems, limiting the evaluation of imageless platforms. Collectively, these studies^{1,2,8–10,21} suggest that image-based robotic-assisted TKA can achieve highly accurate component alignment, facilitating intra-articular correction of deformity, and, in selected cases, allowing retention of hardware without compromising implant positioning. However, the small sample sizes, heterogeneous patient characteristics, and short-term follow-up highlight the preliminary nature of current data and underscore the need for larger, prospective studies to confirm these early results^{1,2,8–10,21}. To provide a structured clinical perspective, the key differences between CT-based robotic TKA and conventional techniques in PTOA are summarized in **Table 2**.

4. CT-based RA-TKA: technical advantages

Image-based platforms such as the MAKO system (Stryker, USA) are able to generate a patient-specific three-dimensional model of the knee before surgery. This capability is especially valuable in post-traumatic osteoarthritis, where residual deformities, bone loss, and retained hardware complicate both preoperative planning and intraoperative execution^{13–15}. By integrating high-resolution imaging with intraoperative haptic guidance, the system enables precise bone resections, optimized component positioning, and enhanced management of soft tissues and complex anatomy.

Table 1

Clinical studies on robotic-assisted total knee arthroplasty (RA-TKA) in post-traumatic osteoarthritis (PTOA) or complex deformities.

Author (Year)	Study Design	Population/Cases	Robotic System	Mean FU (months)	Clinical Outcomes (KOOS, KSS, WOMAC, etc.)	Complications
Singh et al. (2022) ¹	Case report series	3 patients with PTOA after tibial plateau fracture	CT-Based	12	KSS improved from ~45 pre-op to ~80 at 1 yr	None reported
Baek et al. (2022) ²	Case series	5 patients (2 with retained hardware)	CT-Based	18 (mean)	WOMAC improved significantly; KSS from ~50 to ~85	1 transient stiffness resolved conservatively
Marchand et al. (2018) ¹⁰	Case series	6 patients with extra-articular deformities (incl. post-traumatic)	CT-Based	24 (mean)	KSS improved in all patients; mean gain ~30 points	No major complications
Sodhi et al. (2019) ²¹	Case series	Patients with post-traumatic and extra-articular deformities	CT-Based	12–24	WOMAC and KOOS improved significantly; alignment within $\pm 3^\circ$	No revisions; 1 superficial wound issue
Kalyan et al. (2025) ⁸	Case series	Patients with valgus deformity (incl. post-traumatic)	CT-Based	24	KSS improved; significant pain reduction	No major complications
Baek et al. (2022) ⁹	Case report	2 patients with PTOA and retained hardware	CT-Based	6–12	Reported satisfactory functional recovery (scores NR)	None

Abbreviations.

RA-TKA, robotic-assisted total knee arthroplasty; PTOA, post-traumatic osteoarthritis; KSS, Knee Society Score; KOOS, Knee Injury and Osteoarthritis Outcome Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; FU, follow-up.

Table 2

Comparative Overview: MAKO CT-based Robotic TKA vs Conventional TKA in Post-Traumatic Osteoarthritis.

Domain	CT-based robotic TKA	Conventional TKA	Evidence/References	Clinical Relevance
Preoperative Planning	3D CT-based patient-specific model; detailed assessment of deformities, bone loss, and hardware	X-ray/landmark-based; less detailed in complex anatomy	33–35	Enables precise surgical planning and anticipation of deformities or retained hardware
Alignment Accuracy	Higher precision; fewer outliers; allows intra-articular corrections	More variability, especially in altered anatomy; higher malalignment risk	34, 35, 37, 28	Reduces risk of malalignment, potentially improving implant longevity and function
Bone Resection Accuracy	Robotic guidance reduces resection errors; real-time intraoperative feedback	Manual instrumentation; higher cumulative error risk	35, 37, 38	Minimizes bone loss and preserves anatomy; reduces technical errors
Management of Deformities/Hardware	Feasible intra-articular corrections; may avoid hardware removal	Often requires hardware removal; less predictable correction	1, 2, 9, 10, 21	Avoids additional surgical trauma; simplifies complex cases
Functional Outcomes (PROs)	Improved KSS, KOOS, WOMAC in small series; short-term trends positive	Good outcomes in standard cases; greater variability in complex PTOA	1, 2, 10, 32, 37	Potential for better short-term patient-reported outcomes, especially in complex knees
Complications	Low short-term complication rate: minor stiffness or wound issues reported	Higher risk in PTOA; stiffness, infection, malalignment more frequent	18, 27, 37, 38	May reduce perioperative complications and need for early interventions
Revision/Survivorship	Long-term evidence insufficient; registries needed	Robust long-term data in primary OA; less evidence in PTOA	22, 31, 33, 37	Uncertain long-term benefit: further studies required
Cost	Higher direct costs (robot, disposables, CT scan)	Lower costs; existing infrastructure	23, 43	Higher upfront investment: potential future savings if revisions reduced
Radiation Exposure	CT scan required; higher radiation, but within safety limits	No CT required	33, 40, 44	Small additional risk; justified by improved preoperative planning
Learning Curve	Longer initially, proficiency reached after ~7–15 cases (primary TKA data)	Predictable for experienced surgeons	25, 26	Surgeons require dedicated training; early cases may take longer
Applicability in PTOA post-TPF	Particularly advantageous in complex deformity or retained hardware; facilitates planning and positioning	Technically feasible, but higher malposition risk	1, 2, 9, 10, 21	Ideal for complex post-traumatic knees; improves confidence in challenging cases

Abbreviations.

TKA, total knee arthroplasty; RA-TKA, robotic-assisted total knee arthroplasty; PTOA, post-traumatic osteoarthritis; TPF, tibial plateau fracture; KSS, Knee Society Score; KOOS, Knee Injury and Osteoarthritis Outcome Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; PROs, patient-reported outcomes.

4.1. Preoperative planning

Preoperative CT imaging allows comprehensive assessment of coronal, sagittal, and axial deformities, joint-line obliquity, bone defects, and the precise location of retained implants, resulting in a full three-dimensional reconstruction of the knee (Fig. 1).

Detailed preoperative templating of component size, orientation, and alignment is particularly advantageous in post-traumatic knees, where conventional anatomical landmarks are often unreliable^{3,10,22,23}. CT-based planning enables accurate evaluation of both intra-articular and extra-articular deformities, quantification of bone loss, and visualization of hardware relative to planned resections, elements that cannot be reliably appreciated on standard radiographs alone. Anticipating technical challenges, such as potential interference between cutting

guides and fixation hardware, supports more accurate surgical planning and facilitates selective hardware removal, when necessary, potentially reducing operative time, blood loss, and morbidity^{2,9}

4.2. Intraoperative accuracy

During surgery, the platform provides haptic boundaries that confine bone resections within the predefined plan, ensuring millimetric precision^{3,21,24} (Fig. 2). Continuous real-time tracking of mechanical and kinematic axes improves the accuracy of deformity correction, even in cases with severe post-traumatic alterations. These features enhance reproducibility compared with conventional instrumentation and may reduce the risk of malalignment, a critical factor in PTOA management^{10,21}



Fig. 1. Computed Tomography (CT) images demonstrating advanced post-traumatic osteoarthritis of the left knee, with marked subchondral sclerosis, severe joint space narrowing, and deformity of the tibial plateau. Irregular articular surfaces and residual post-fracture changes indicate chronic joint incongruity and structural collapse. (A) Coronal CT image. (B) Sagittal CT image.

4.3. Soft-tissue management

Post-traumatic knees frequently exhibit ligamentous imbalance

related to deformity, prior surgery, scarring, or altered joint biomechanics. The robotic system integrates dynamic soft-tissue evaluation, providing real-time gap analysis throughout the procedure. Adjustments to femoral and tibial component positioning can be made to optimize flexion and extension gaps, reducing the need for extensive soft-tissue releases ^{15,19,20}

By promoting more physiologically balanced soft-tissue balancing, robotic assistance may improve early recovery, pain control, and functional outcomes.

4.4. Postoperative radiographic assessment

Postoperative radiographs in patients undergoing TKA for PTOA consistently demonstrate how robotic assistance may transform anatomically complex cases into reproducibly accurate surgical outcomes (Fig. 3). In knees altered by prior tibial plateau fractures—where deformity, bone loss, and distorted anatomical landmarks traditionally increase the risk of malalignment—the precision of CT-based robotic execution enables restoration of coronal alignment, joint-line orientation, and component positioning with remarkable consistency. These radiographic findings highlight the ability of robotic systems to simplify procedures that, at first glance, may appear technically demanding, thereby enhancing surgical confidence and reducing variability in scenarios where conventional instrumentation is often challenged.

4.5. Hardware management

Retained fixation devices, including plates, screws, and intramedullary hardware, can interfere with conventional guides and saw

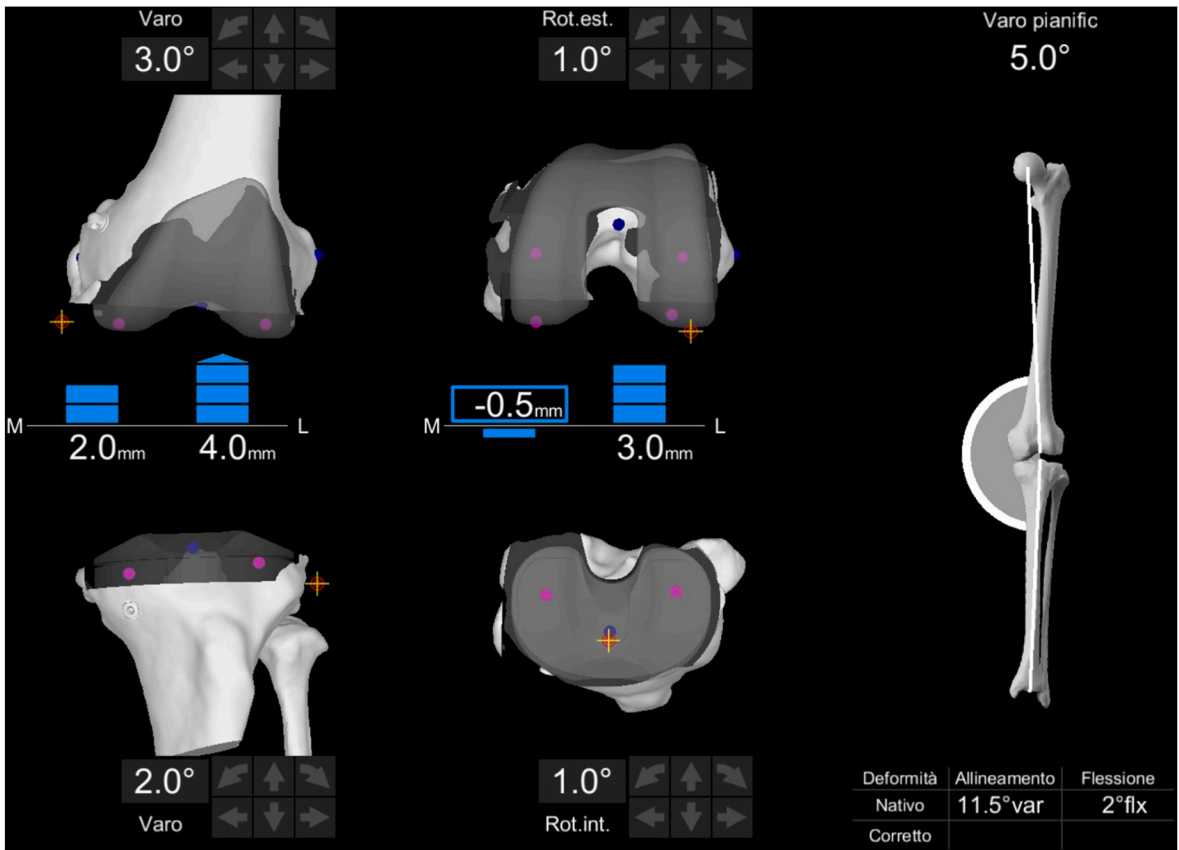


Fig. 2. Intraoperative robotic planning corrected the native 11.5° varus deformity to a targeted 5° functional varus alignment. Coronal and rotational adjustments with compartment-specific resections were performed to optimize soft-tissue tension and joint-line orientation. In post-traumatic knees, planning accounted for residual deformity, asymmetric bone loss, and altered joint-line anatomy, requiring individualized alignment targets. Medial and lateral gaps in flexion and extension were quantitatively assessed through robotic gap analysis to achieve balanced ligament tension and knee stability.

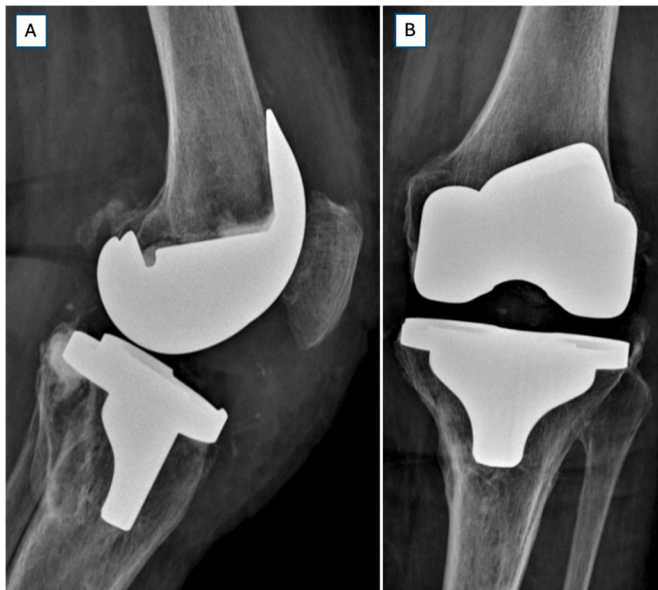


Fig. 3. Postoperative radiographs following image-based robotic-assisted total knee arthroplasty (TKA). The anteroposterior and lateral views demonstrate appropriate implant positioning, restoration of coronal alignment, and balanced tibiofemoral component orientation, consistent with the preoperative robotic plan. (A) Lateral postoperative radiograph. (B) Anteroposterior postoperative radiograph.

blades. The image-based system leverages the preoperative CT model to locate implants and, when feasible, plan resections around them precisely. In selected cases, this capability allows retention of hardware without compromising component alignment, thereby minimizing additional surgical trauma, reducing operative time, and potentially lowering postoperative morbidity.^{2,9}

4.6. Learning curve

Although RA-TKA requires specific training, published data indicate a relatively short learning curve. Proficiency in workflow, registration, and robotic execution is generally achieved after approximately 10–15 cases in primary TKA.^{25,26} In post-traumatic settings, operative time may initially increase due to greater anatomical complexity, and specific learning-curve data for PTOA after tibial plateau fractures are currently unavailable.

No dedicated studies have evaluated the learning curve in post-traumatic scenarios. Given the greater anatomical complexity, early cases in this population may require longer operative times and additional intraoperative support; however, improved reproducibility and accuracy are expected to offset these limitations as experience increases.

5. Clinical outcomes and evidence

Current evidence on CT-Based RA-TKA for post-traumatic osteoarthritis is limited and predominantly consists of case reports and small case series.^{1,2,8–10,21} Despite this constraint, early clinical experiences consistently indicate that robotic assistance enables accurate component positioning, effective correction of extra-articular or intra-articular deformities, and reliable management of retained hardware.^{2,10,21}

Functional outcomes reported across the available literature demonstrate clinically meaningful improvements. Singh et al.¹ documented increases in Knee Society Score (KSS) from 45 to 85 and WOMAC from 65 to 85 at 12-month follow-up in three patients. Baek et al.² reported improvements in KSS from 48 to 88 and KOOS from 60 to 82 in five patients, including two who retained hardware. Marchand et al.¹⁰ and Sodhi et al.²¹ described postoperative functional scores

generally exceeding 80, with results maintained up to 24 months. Kalyan et al.⁸ further demonstrated that MAKO-assisted TKA is safe and reproducible even in moderate-to-severe valgus deformities, reporting a mean postoperative KSS of 88.

Reported complications in the available robotic-assisted series were infrequent and typically minor; however, these findings are based on small cohorts and short follow-up, and do not allow reliable comparison with conventional TKA complication rates in PTOA. Transient stiffness managed with physiotherapy and superficial wound complications were occasionally observed, but no early revisions were required in any series.^{2,9,10} This compares favorably to conventional TKA performed for PTOA, which has historically been associated with postoperative stiffness rates of approximately 10–15%, infection rates of 2–4%, and an increased risk of malalignment in post-traumatic cohorts treated with conventional techniques.^{6,20,27–30}

Nevertheless, these encouraging findings must be interpreted with caution. Available studies are characterized by small sample sizes, heterogeneous case complexity, and short follow-up intervals (12–24 months). No randomized controlled trials or large multicenter cohorts directly comparing robotic-assisted and conventional TKA in PTOA have been published. The use of variable functional outcome scores further limits comparability and generalizability.^{1,2,10,21}

In summary, robotic-assisted TKA demonstrates promising early clinical results, with advantages in alignment accuracy, deformity management, soft-tissue balancing, and early functional recovery. However, robust evidence is still lacking. Larger, prospective, multicenter studies with long-term follow-up are warranted to validate these preliminary findings and assess implant survivorship, complication rates, and functional durability.^{22,31}

6. Discussion

This narrative review highlights the growing role of RA-TKA in the management of PTOA following tibial plateau fractures, one of the most technically demanding indications for knee arthroplasty. Early case series consistently demonstrate that CT-based robotic assistance enhances the accuracy of preoperative planning, improves the precision of bone resections, and supports reliable deformity correction, even in the presence of retained hardware or extra-articular malalignment.^{1,2,10,21,32} Compared with conventional instrumentation, robotic platforms have been associated with improved alignment accuracy and fewer outliers in primary osteoarthritis, while corresponding PTOA-specific data remain limited and should be interpreted cautiously.^{33–35}

From a clinical standpoint, PTOA following tibial plateau fractures presents distinct challenges compared with primary osteoarthritis. These include higher rates of postoperative stiffness, wound complications, and infection, as well as an increased likelihood of requiring stems, augments, or higher levels of constraint to address bone loss and ligamentous insufficiency.^{6,20,27–30} Bone defects are frequently asymmetric and related to prior fracture patterns or hardware removal, often necessitating careful preoperative planning and intraoperative flexibility.^{9,11,15} Additionally, revision risk in PTOA is influenced not only by implant alignment but also by compromised bone stock, altered soft-tissue envelopes, and previous surgical scars.^{16–18,30} Importantly, these factors represent intrinsic limitations of post-traumatic osteoarthritis that are largely independent of the surgical technology employed. Even with optimized implant positioning, outcomes in PTOA remain strongly influenced by the quality of residual bone stock, soft-tissue balance, and prior surgical trauma, which partly explains the historically inferior results of TKA in post-traumatic knees compared with primary osteoarthritis.^{36,37} While robotic-assisted planning may support more accurate anticipation of these issues, it does not eliminate the need for sound surgical judgment in implant selection and reconstruction strategy. In this context, the principal clinical value of robotic planning may lie not solely in alignment accuracy, but in its ability to assist

surgeons in preoperatively anticipating reconstruction strategies, including the potential need for augments, stems, or increased constraint in the presence of bone loss and ligamentous insufficiency.

Image-based platforms are particularly advantageous in post-traumatic knees, where preoperative CT scans delineate deformities, bone defects, and hardware interference, enabling individualized surgical strategies. These features have been associated with improved accuracy of implant positioning and more predictable restoration of the mechanical axis, as confirmed by CT-based postoperative validation studies^{34,35}. In PTOA, robotic planning differs substantially from that performed in primary osteoarthritis. Rather than relying on relatively preserved and symmetric anatomical landmarks, planning in PTOA requires individualized compensation for residual intra-articular deformity, asymmetric bone loss, and altered joint-line orientation related to the prior fracture. Alignment targets and component positioning are therefore adapted to fracture-related anatomy and soft-tissue imbalance, often prioritizing functional alignment and gap balancing over standardized mechanical alignment strategies commonly applied in primary osteoarthritis. This predominance of CT-based evidence in PTOA is likely related to the limitations of imageless systems in anatomically distorted knees. In PTOA following tibial plateau fractures, altered bony landmarks, residual fracture morphology, and retained hardware may compromise intraoperative registration and kinematic mapping, increasing susceptibility to cumulative registration errors. These potential failure modes reduce reproducibility and may limit the reliability of imageless platforms in complex post-traumatic scenarios. Comparative studies performed mainly in primary osteoarthritis populations suggest differences in alignment reproducibility between robotic platforms; however, PTOA-specific comparative data, particularly after tibial plateau fractures, remain insufficient³⁸.

Functional outcomes after RA-TKA appear encouraging, with multiple small series reporting meaningful improvements in KSS, KOOS, and WOMAC, and postoperative scores generally exceeding 80 at short-term follow-up^{1,2,10,21}. Meta-analytic evidence suggests that RA-TKA improves component alignment and patient-reported outcomes compared with conventional TKA, although most published data derive from primary osteoarthritis, not specifically from post-traumatic cohorts³⁹. A recent study published by Strafford et al.⁴⁰ further supports this distinction, reporting that outcomes of total knee arthroplasty in post-traumatic settings remain inferior to those observed in primary osteoarthritis, largely due to residual deformity, compromised bone stock, and soft-tissue imbalance. Importantly, the authors did not demonstrate a reduction in complication or revision rates attributable to advanced surgical technologies, underscoring that patient- and injury-related factors remain dominant determinants of outcome in post-traumatic knees. A recent randomized trial further demonstrated superior prosthesis alignment and improved joint-line restoration after RA-TKA compared with manual TKA, reinforcing the potential clinical value of robotic execution in anatomically challenging knees⁴¹. While imageless systems may be effective in selected cases, their accuracy is more variable in severe deformities, and early reports suggest that imageless RA-TKA may achieve reliable corrections but with greater sensitivity to registration errors^{42,43}.

The potential benefits of robotic assistance, however, must be weighed against important non-technical considerations. Image-based RA-TKA requires a preoperative CT scan, which adds to costs and radiation exposure. Nevertheless, modern low-dose CT protocols and recent comparative analyses confirm that radiation levels remain within established safety limits and are comparable across most widely used robotic systems^{33,44–47}. Cost remains a key barrier: CT-based robotic procedures entail higher direct operative costs compared with conventional TKA and imageless systems^{23,46}. Despite this, economic models based on primary osteoarthritis populations suggest that improved alignment accuracy could enhance long-term cost-effectiveness; however, no PTOA-specific data currently support the cost benefits of RA-TKA after tibial plateau fractures.

Future research should prioritize prospective multicenter PTOA cohorts with standardized outcome reporting, direct platform comparisons, and predefined subgroup analyses (e.g., extra-articular deformity, retained hardware, and bone loss patterns), alongside cost and workflow metrics. Integration of advanced technologies—including artificial intelligence (AI), predictive analytics, and augmented reality—may further optimize preoperative planning, surgical decision-making, and postoperative rehabilitation⁴⁸. Emerging interest in primary arthroplasty for selected acute tibial plateau fractures could expand the role of robotics beyond the post-traumatic setting, potentially reducing the need for secondary procedures and improving early recovery³. Furthermore, large registry datasets and prospective multicenter studies are essential to validate the early clinical promise of RA-TKA, clarify its economic impact, and determine long-term survivorship outcomes.

From a surgical perspective, RA-TKA should be interpreted as an enabling technology that may support decision-making in anatomically complex post-traumatic knees rather than as an independent driver of outcomes. Its potential relevance appears greatest when preoperative planning must account for asymmetric bone loss, altered joint-line orientation, ligamentous imbalance, and the possible need for stems or increased constraint. Nevertheless, current evidence remains insufficient to determine whether these technological advantages translate into superior long-term clinical results in PTOA. Until robust comparative data become available, the role of robotics in post-traumatic knee arthroplasty is likely to remain complementary to—rather than a substitute for—sound surgical judgment and experience.

This review also underscores limitations in the available literature. Major gaps include the lack of PTOA-specific comparative studies between CT-based and imageless platforms, heterogeneous reporting of radiographic and functional outcomes, limited stratification by deformity severity and hardware status, and the absence of long-term survivorship and revision endpoints. Current evidence is restricted to small case series, retrospective studies, and heterogeneous cohorts, with no randomized controlled trials comparing robotic and conventional techniques specifically in post-traumatic knees. Follow-up is generally short (12–24 months), and functional outcomes are reported using disparate scoring systems, which limits comparability. The lack of multicenter registries dedicated to PTOA further impairs long-term evaluation of implant survivorship and complication profiles. Additionally, early literature in robotic surgery is partly influenced by industry involvement, which may introduce bias.

7. Conclusions

RA-TKA may represent a supportive technology in the surgical management of PTOA following tibial plateau fractures, particularly in anatomically complex cases requiring individualized planning; however, its direct impact on long-term clinical and functional outcomes in PTOA remains insufficiently established. Alongside these technical advantages, important non-technical factors must be considered, including higher upfront costs, the surgeon's learning curve, and limited long-term evidence on implant survivorship and functional outcomes. The adoption of robotic technology should therefore be evaluated within the broader context of healthcare sustainability and the clinical value it adds to patient care pathways. Large multicenter studies, including randomized trials and registry-based analyses, are needed to validate the clinical, functional, and economic benefits of RA-TKA, standardize protocols, and support its wider and sustainable implementation in complex post-traumatic cases. Clarifying which PTOA patients may derive the greatest benefit from robotic assistance should therefore represent a priority for future investigation.

Guardian/patient's consent

Not Applicable.

Ethics approval

Compliant with Helsinki.

Consent

Not applicable.

Code availability

Not applicable.

Ethical statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Credit author statement

FB and FG contributed to the study conception and design. Material preparation and data collection were performed by FN, CDC, and MGLB. Data analyses were performed by CB and FB. The first draft of the manuscript was written by FN, and FB, and all authors commented on previous versions of the manuscript. FB and CB assessed the scientific contents and the writing. All authors read and approved the final manuscript.

Funding

No funding received.

Conflicts of interest

None declared.

Acknowledgement

None.

Data availability

Available on request.

References

- Singh A, Chauhan S, Sen RK, et al. Robotic total knee arthroplasty in post-traumatic osteoarthritis: a report of three cases. *Acta Sci Orthop*. 2022;5(9):100–105. <https://doi.org/10.31080/ASOR.2022.05.0558>.
- Baek JH, Lee SC, Ryu S, Ahn HS, Nam CH. Coronal correction for post-traumatic malalignment using robot-assisted total knee arthroplasty: a case series. *Orthop Res Rev*. 2022;14:445–451. <https://doi.org/10.2147/ORR.S387957>.
- Parratte S, Ollivier M, Argenson JN. Primary total knee arthroplasty for acute fracture around the knee. *Orthop Traumatol Surg Res*. 2018;104(15):S71–S80. <https://doi.org/10.1016/j.otsr.2017.05.029>.
- Boncinelli D, Scalici G, Sangiovanni M, et al. Knee post-traumatic consequences: possible surgical approach and management when everything goes wrong. *Lo Scalpello*. 2022;36:6–12. <https://doi.org/10.36149/0390-5276-234>.
- Lunebourg A, Parratte S, Ollivier M, et al. Lower function, quality of life, and survival rate after total knee arthroplasty for posttraumatic arthritis than for primary arthritis. *Acta Orthop*. 2015;86(2):189–194. <https://doi.org/10.3109/17453674.2014.979723>.
- Haslhofer DJ, Kraml N, Winkler PW, Gotterbarm T, Klasan A. Risk for total knee arthroplasty after tibial plateau fractures: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2023;31(11):5145–5153. <https://doi.org/10.1007/s00167-023-07585-8>.
- Matassi F, Cozzi Lepri A, Innocenti M, Zanna L, Civinini R, Innocenti M. Total knee arthroplasty in patients with extra-articular deformity: restoration of mechanical alignment using accelerometer-based navigation. *J Arthroplast*. 2019;34(4):676–681. <https://doi.org/10.1016/j.arth.2018.12.042>.
- Kalyan K, Singh A, Kumar P, et al. Robotic total knee arthroplasty for moderate to high-grade valgus knee deformity: technique and outcomes. *SICOT J*. 2025;11:12. <https://doi.org/10.1051/sicotj/2025005>.
- Baek JH, Lee SC, Ahn HS, Nam CH. Usefulness of robot-assisted total knee arthroplasty in patients with retained hardware: report of two cases. *Clin Case Rep*. 2022;10(2), e05366. <https://doi.org/10.1002/ccr3.5366>.
- Marchand RC, Khlopas A, Sodhi N, Sultan AA, Mont MA. Difficult cases in robotic arm-assisted total knee arthroplasty: a case series. *J Knee Surg*. 2018;31(1):27–37. <https://doi.org/10.1055/s-0037-1608839>.
- Dexel J, Beyer F, Lützner C, Kleber C, Lützner J. Total knee arthroplasty for posttraumatic osteoarthritis is more complex and requires more surgical resources. *Orthopedics*. 2016;39(3 Suppl):S36–S40. <https://doi.org/10.3928/01477447-20160509-11>.
- Pander P, Fransen BL, Hagemans FJA, Keijsers LCM. Functional outcome of total knee arthroplasty following tibial plateau fractures: a systematic review. *Arch Orthop Trauma Surg*. 2023;143(3):1265–1274. <https://doi.org/10.1007/s00402-021-04188-1>.
- Rattanaprichavej P, Laorueangthana A. Accelerometer-based navigation versus conventional total knee arthroplasty for posttraumatic knee osteoarthritis. *Clin Orthop Surg*. 2022;14(4):522–529. <https://doi.org/10.4055/cios21147>.
- Rieger E, Fuqua A, Shah J, Sinha M, Premkumar A. A systematic review and meta-analysis of total knee arthroplasty after tibial plateau fracture fixation. *J Knee Surg*. 2025. <https://doi.org/10.1055/a-2608-0105>. Published online May 14.
- Benazzo F, Rossi SMP, Combi A, Meena S, Ghiara M. Knee replacement in chronic post-traumatic cases. *EFORT Open Rev*. 2017;1(5):211–218. <https://doi.org/10.1302/2058-5241.1.000025>.
- Lützner C, Postler A, Beyer F, Lange T, Riedel R, Lützner J. Total knee arthroplasty in post-traumatic osteoarthritis is more challenging, but results in similar patient satisfaction: analysis of 1646 cases. *Knee*. 2022;39:116–123. <https://doi.org/10.1016/j.knee.2021.12.005>.
- Saleh H, Yu S, Vigdorchik J, Schwarzkopf R. Total knee arthroplasty for treatment of post-traumatic arthritis: systematic review. *World J Orthoped*. 2016;7(9):584–591. <https://doi.org/10.5312/wjo.v7.i9.584>.
- Syrakas I, Engbäck C, Tsikandylakis G, Karikis I, Desai N. Increased complication rates and inferior patient-reported outcomes following total knee arthroplasty due to post-traumatic osteoarthritis with previous fracture treatment: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2023;31(10):4124–4141. <https://doi.org/10.1007/s00167-023-07407-x>.
- Bonanni S, Scuderi GR. Managing post-traumatic arthritis of the knee with total knee arthroplasty. *Orthop Clin N Am*. 2024;55(4):415–423. <https://doi.org/10.1016/j.ocl.2024.04.002>.
- Fisher ND, Egol KA, Schwarzkopf R. Risk factors for wound complications following conversion TKA after tibial plateau fracture. *Indian J Orthop*. 2022;56(10):1751–1758. <https://doi.org/10.1007/s43465-022-00709-1>.
- Sodhi N, Khlopas A, Ehiorobo JO, et al. Robotic-assisted total knee arthroplasty in the presence of extra-articular deformity. *Surg Technol Int*. 2019;34:497–502.
- Zheng W, Tang J, Li J, et al. Complex primary total knee arthroplasty with constrained condylar knee in post-traumatic arthritis: a retrospective comparison between 3D-printed patient-specific instrumentation and conventional instrumentation. *J Orthop Surg Res*. 2025;20(1):524. <https://doi.org/10.1186/s13018-025-05909-7>.
- Christen B, Tanner L, Ettinger M, Bonnin MP, Koch PP, Callies T. Comparative cost analysis of four different computer-assisted technologies to implant a total knee arthroplasty over conventional instrumentation. *J Personalized Med*. 2022;12(2):184. <https://doi.org/10.3390/jpm12020184>.
- Innocenti B, Bori E. Robotics in orthopaedic surgery: why, what and how? *Arch Orthop Trauma Surg*. 2021;141(12):2035–2042. <https://doi.org/10.1007/s00402-021-04046-0>.
- Zhang J, Ndu WS, Ng N, et al. Robotic-arm assisted total knee arthroplasty is associated with improved accuracy and patient-reported outcomes: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(8):2677–2695. <https://doi.org/10.1007/s00167-021-06464-4>.
- Cacciola G, Bosco F, Giustra F, et al. Learning curve in robotic-assisted total knee arthroplasty: a systematic review of the literature. *Appl Sci*. 2022;12(21), 11085. <https://doi.org/10.3390/app122111085>.
- Softness KA, Murray RS, Evans BG. Total knee arthroplasty and fractures of the tibial plateau. *World J Orthoped*. 2017;8(2):107–114. <https://doi.org/10.5312/wjo.v8.i2.107>.
- Sabatini L, Aprato A, Camazzola D, Bistolfi A, Capella M, Massè A. Primary total knee arthroplasty in tibial plateau fractures: literature review and our institutional experience. *Injury*. 2023;54(Suppl 1):S15–S23. <https://doi.org/10.1016/j.injury.2021.02.006>.
- Howell M, Khalid A, Nelson C, Doonan J, Jones B, Blyth M. Long-term outcomes following tibial plateau fracture fixation and risk factors for progression to total knee arthroplasty. *Knee*. 2024;51:303–311. <https://doi.org/10.1016/j.knee.2024.10.003>.
- Scott CE, Davidson E, MacDonald DJ, White TO, Keating JF. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. *Bone Jt J*. 2015;97-B(4):532–538. <https://doi.org/10.1302/0301-620X.97B4.34789>.
- Assink N, Gonzalez-Perrino MP, Santana-Trejo R, et al. Development of machine learning-based algorithms to predict the 2- and 5-year risk of TKA after tibial plateau fracture treatment. *Clin Orthop Relat Res*. 2025;12. <https://doi.org/10.1097/CORR.0000000000003442>. Published online March.
- Ma N, Sun P, Xin P, Zhong S, Xie J, Xiao L. Comparison of the efficacy and safety of MAKO robot-assisted total knee arthroplasty versus conventional manual total knee arthroplasty in uncomplicated unilateral total knee arthroplasty: a single-centre

- retrospective analysis. *Int Orthop*. 2024;48(9):2351–2358. <https://doi.org/10.1007/s00264-024-06234-0>.
33. Batailler C, Fernandez A, Swan J, et al. MAKO CT-based robotic arm-assisted system is a reliable procedure for total knee arthroplasty: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2021;29(11):3585–3598. <https://doi.org/10.1007/s00167-020-06283-z>.
 34. Sires JD, Wilson CJ. CT validation of intraoperative implant position and knee alignment as determined by the MAKO total knee arthroplasty system. *J Knee Surg*. 2021;34(10):1133–1137. <https://doi.org/10.1055/s-0040-1701447>.
 35. Sires JD, Craik JD, Wilson CJ. Accuracy of bone resection in MAKO total knee robotic-assisted surgery. *J Knee Surg*. 2021;34(7):745–748. <https://doi.org/10.1055/s-0039-1700570>.
 36. Obana KK, Lee G, Lee LSK. Characteristics, treatments, and outcomes of tibial Plateau nonunions: a systematic review. *J Clin Orthop Trauma*. 2020;16:143–148. <https://doi.org/10.1016/j.jcot.2020.12.017>.
 37. Kumar V, Singhroha M, Arora K, Sahu A, Beniwal R, Kundu A. A clinico-radiological study of bicondylar tibial plateau fractures managed with dual locking plates. *J Clin Orthop Trauma*. 2021;21, 101563. <https://doi.org/10.1016/j.jcot.2021.101563>.
 38. Zhou G, Wang X, Geng X, Li Z, Tian H. Comparison of alignment accuracy and clinical outcomes between a CT-based, saw-cutting robotic system and a CT-free, jig-guided robotic system for total knee arthroplasty. *Orthop Surg*. 2024;16(5): 1168–1174. <https://doi.org/10.1111/os.14055>.
 39. Zhang J, Ndou WS, Ng N, et al. Robotic-arm assisted total knee arthroplasty is associated with improved accuracy and patient-reported outcomes: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(8): 2677–2695. <https://doi.org/10.1007/s00167-021-06464-4>.
 40. Strafford M, Biddle M, Rooney B. The requirement for total knee arthroplasty following surgical fixation of tibial plateau fractures. *Bone Jt Open*. 2025;6(12): 1575–1580. <https://doi.org/10.1302/2633-1462.612.BJO-2025-0278.R1>.
 41. Vaidya NV, Deshpande AN, Panjwani T, Patil R, Jaysingani T, Patil P. Robotic-assisted TKA leads to better prosthesis alignment and improved joint-line restoration compared with conventional TKA: a prospective randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(2):621–626. <https://doi.org/10.1007/s00167-020-06353-2>.
 42. Soundarrajan D, Kumar K, Singh R, et al. Imageless robotic-assisted total knee arthroplasty allows intra-articular correction of severe extra-articular deformities using functional alignment and desired under-correction. *Int Orthop*. 2025;49(8): 1869–1878.
 43. Tabatabaee RM, Rasouli MR, Maltenfort MG, Fuino R, Restrepo C, Oliashirazi A. Computer-assisted total knee arthroplasty: is there a difference between image-based and imageless techniques? *J Arthroplast*. 2018;33(4):1076–1081. <https://doi.org/10.1016/j.arth.2017.11.030>.
 44. Winberg TB, Wang S, Howard JL. Imageless optical navigation system is clinically valid for total knee arthroplasty. *Comput Assist Surg (Abingdon)*. 2025;30(1): 2466424.
 45. Hegde V, Stambough JB, Levine BR, Springer BD. Highlights of the 2022 American joint replacement registry annual report. *Arthroplast Today*. 2023;21, 101137. <https://doi.org/10.1016/j.artd.2023.101137>.
 46. Migliorini F, Maffulli N, Schäfer L, et al. Robotic-assisted total knee arthroplasty in clinical practice: protocol for a randomised controlled trial. *J Orthop Surg Res*. 2023; 18(1):623. <https://doi.org/10.1186/s13018-023-04101-z>.
 47. Saad A, Mayne A, Pagkalos J, et al. Comparative analysis of radiation exposure in robot-assisted total knee arthroplasty using popular robotic systems. *J Robot Surg*. 2024;18:120. <https://doi.org/10.1007/s11701-024-01896-9>.
 48. Han F, Huang X, Wang X, et al. Artificial intelligence in orthopedic surgery: current applications, challenges, and future directions. *MedComm*. 2025;6, e70260. <https://doi.org/10.1002/mco2.70260>.