

Review Article

Robotic-Assisted Unicompartmental Knee Arthroplasty: Component Positioning and Early Outcomes

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Abstract

Background: Robotic-assisted platforms have been increasingly adopted for unicompartmental knee arthroplasty (UKA) to improve component positioning precision beyond conventional jig-based instrumentation.

Objective: To synthesise evidence comparing robotic-assisted and manual UKA on positioning accuracy, soft-tissue balancing, operative time, learning curve, complications, and early functional outcomes.

Methods: Narrative review of randomised trials, comparative cohorts, registry analyses, and meta-analyses of robotic-assisted UKA.

Findings: Robotic assistance reduces coronal, sagittal, and rotational positioning outliers and lowers early revision and complication rates, at the cost of modestly longer operative time and a learning curve of six to eleven cases. Two-year Oxford Knee Score, American Knee Society Score, and Forgotten Joint Score outcomes are comparable to manual UKA, with early functional advantages.

Conclusions: Robotic-assisted UKA improves surgical precision and reduces malposition-related revision without compromising early outcomes, though cost-effectiveness depends on case volume.

Keywords: Unicompartmental knee arthroplasty; Robotic-assisted surgery; Component positioning; Learning curve; Patient-reported outcomes

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Introduction

Unicompartamental knee arthroplasty (UKA) is an established treatment for isolated medial or lateral compartment osteoarthritis, offering faster recovery and more physiological kinematics than total knee arthroplasty in appropriately selected patients. Its principal historic drawback has been a higher revision rate than total knee arthroplasty in national registries, with component malposition, limb malalignment, and inadequate soft-tissue balance consistently implicated as preventable causes of early failure. Conventional jig-based

instrumentation depends on manual bone cuts and visual or mechanical alignment checks, introducing variability that is amplified in the hands of lower-volume surgeons.

Robotic-assisted surgical platforms, first validated for UKA with haptic-guided arm systems and subsequently extended to imageless, handheld burring devices, were developed specifically to address this variability. These systems combine preoperative or intraoperative three-dimensional bone models with real-time tracking to constrain bone resection to a surgeon-approved plan, in principle reproducing the precision of an experienced high-volume surgeon regardless of case volume. Over the past decade this technology has generated a substantial comparative literature spanning cadaveric and dry-bone accuracy studies, randomised controlled trials with radiographic and clinical endpoints, national registry analyses, and multiple systematic reviews and meta-analyses.

Two broad categories of robotic system now dominate clinical practice: semi-active haptic-arm platforms that physically constrain the burr or saw to a predefined resection boundary, and imageless, handheld sculpting systems that provide real-time visual and auditory feedback without mechanically restraining the surgeon's hand. Both approaches share the same underlying rationale of converting a dynamically registered, patient-specific bone and soft-tissue model into a reproducible surgical plan, but they differ in cost, workflow, and the degree of active correction offered intraoperatively.

This review synthesises the published evidence on robotic-assisted UKA relative to manual technique across component positioning accuracy, soft-tissue balancing, operative time and learning curve, complications and revision, and early (one- to five-year) functional and patient-reported outcomes, concluding with a brief

discussion of cost-effectiveness.

Component Positioning Accuracy

The strongest and most consistent finding across the robotic UKA literature is improved radiographic precision. In a prospective randomised trial using the MAKO RIO haptic-arm system, robotic-assisted patients achieved target component position within 2 degrees significantly more often than manual controls across femoral sagittal (57% vs 26%), femoral coronal (70% vs 28%), femoral axial (53% vs 31%), tibial sagittal (80% vs 22%), and tibial axial (48% vs 19%) planes [1], a finding the accompanying editorial commentary noted was of uncertain clinical significance pending longer follow-up [2]. Tibial-specific analysis confirmed markedly smaller posterior slope and coronal angulation errors with robotic assistance (0.41 degrees and 0.43 degrees) than with conventional jig-based instrumentation (2.47 degrees and 2.12 degrees) [3]. A Korean cohort study similarly found that robotic assistance halved the proportion of patients with a mechanical femorotibial angle outlier (21.8% vs 42.1%) and increased the proportion of components restored within the Kennedy central alignment zone (67.3% vs 36.8%) (Figure 1) [4]. Component-position benefits extend across surgeon experience: a comparison of high- and low-volume robotic surgeons found no significant difference in coronal or sagittal component positioning between groups, although less experienced surgeons remained slower (86 vs 57 minutes) [5], and low-volume surgeons using robotic assistance avoided valgus overcorrection outliers entirely [6]. Randomised and cohort data corroborate this pattern across implant systems and follow-up intervals (Table 1) [1,7,8,9].

Soft-Tissue Balancing and Tibial Slope

Beyond static alignment, robotic platforms allow intraoperative, quantitative assessment of the flexion-extension gap before final implantation, using dynamic tracking of limb position through range of

motion rather than relying solely on surgeon feel. This capability underpins the tibial slope and coronal accuracy advantages reported above, and a recent meta-analysis pooling 22 studies and 8,924 knees confirmed significantly fewer femoral and tibial coronal alignment outliers and lower tibial posterior slope with the MAKO system, at the cost of an additional 19.7 minutes of operative time and with no significant difference in pain, functional scores, or complications [10]. Comparable case-control data found that 86% of conventional UKA revisions were associated with component malposition or limb malalignment, compared with none in the robotic cohort [11], indicating that improved intraoperative soft-tissue and gap assessment translates into a lower burden of malalignment-related early failure.

Table 1: Selected randomised controlled trials comparing robotic-assisted and conventional/manual unicompartmental knee arthroplasty [1,7,8,9].				
Study	Design	n (robotic/manual)	Follow-up	Key finding
Bell 2016	RCT	62/58	Postoperative CT	Robotic superior on all five component-position measures (p<=0.016)
Gilmour 2018	RCT	58/54	2 years	Higher OKS and AKSS in active-subgroup robotic patients
Kayani 2018	Prospective cohort	60/60	Intraoperative	6-case learning curve; no learning-curve effect on accuracy
Banger 2021	RCT (5-yr follow-up of Gilmour cohort)	55/49	5 years	Equivalent OKS/AKSS; 0% vs 12% all-cause reintervention (p<0.001)

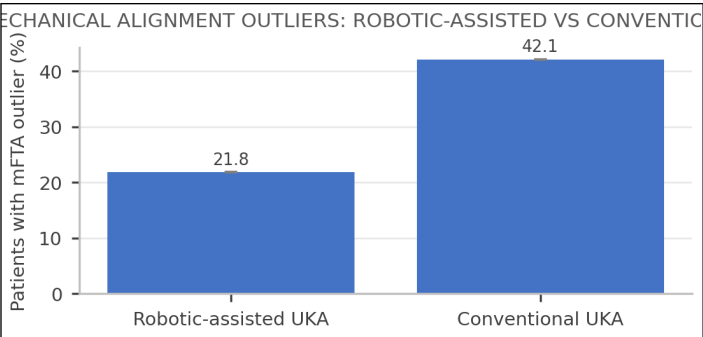


Figure 1: Proportion of patients with a mechanical femorotibial angle (mFTA) outlier after robotic-assisted (21.8%) versus conventional (42.1%) unicompartmental knee arthroplasty [4].

Operative Time and Learning Curve

Robotic assistance reliably increases operative time, particularly during a surgeon's early caseload. Cumulative summation analysis of a single surgeon's early experience identified a learning curve of 11 cases (range 9-15) before operative time and femoral rotation accuracy stabilised, without compromising 36-month implant survivorship (98.2%) [12]. An earlier prospective cohort study reported a shorter six-case learning curve for operative time and surgical-team confidence, with robotic experience having no measurable effect on implant-positioning accuracy at any point in the series [8]. A network meta-analysis of randomised trials found robotic mean operative time of 104 minutes versus 66.7-68.2 minutes for computer-navigated and conventional techniques, a difference that did not reach statistical significance given wide confidence intervals [13]. Despite longer time in theatre, robotic-assisted patients have been discharged from hospital and physiotherapy services significantly sooner than those undergoing conventional navigated UKA (46 vs 74 hours to discharge; 42.5 vs 49 hours to physiotherapy discharge) [14], and achieved straight-leg raise and greater range of motion earlier after surgery (Table 2) [12,6,11,15,16,17,18,19].

Table 2: Selected comparative studies of robotic-assisted unicompartmental knee arthroplasty (UKA) reviewed here [12,6,11,15,16,17,18,19].

Study	Comparison	Design	Follow-up	Key outcome
Tay 2022	Robotic UKA (own learning curve)	Prospective cohort	36 months	11-case learning curve; increased early operating time
Savov 2021	Image-based vs imageless robotic	Comparative cohort	2 years	3.9% combined revision rate; no valgus outliers
Batailler 2019	Robotic vs conventional	Case-control	~20-24 months	Fewer alignment outliers; 5% vs 9% revision
Mergenthaler 2021	Robotic vs conventional	Case-control	Not stated	4% vs 11% revision (p=0.014); no robot-specific complications
Crizer 2021	Robotic vs conventional	Comparative cohort	2 years	Faster early recovery; expectations met more often
Moon 2023	Robotic UKA (own recovery)	Prospective cohort	12 weeks	Quadriceps strength recovers to ~70% of unoperated limb by 12 weeks
Battenberg 2020	Handheld imageless robotic UKA	Case series	2.3 years	99.2% implant survivorship
Gaudiani 2023	Robotic lateral UKA	Case series	5 years	100% survivorship; 94% satisfied

Complications and Revision

Reduced malposition appears to translate into fewer complications and lower revision rates. A systematic review and meta-analysis of the MAKO robotic system pooled revision rates of 1.72% for robotic-assisted UKA versus 3.32% for manual UKA (Figure 2), alongside a significantly higher overall complication odds ratio favouring the manual group (OR 2.18) [20]. A case-control comparison of 200 robotic and 191 conventional UKAs found significantly fewer revisions with robotic assistance (4% vs 11%, p=0.014), with no complications specifically attributable to the robotic system itself [15]. Larger pooled analyses corroborate this signal: a meta-analysis of six studies and 48,091 knees found significantly lower mid- to long-term revision (OR 0.28) and complication rates (OR 0.27), driven principally by reductions in aseptic loosening and periprosthetic fracture [21], while a 15-study

meta-analysis of 29,982 patients found conventional manual UKA carried 1.58-fold higher overall revision risk, with malalignment-related revision nearly seven-fold higher in the manual group [22]. Reassuringly, five-year follow-up of a randomised cohort found zero robotic-group patients required any further surgical intervention, compared with 12% of the manual group ($p < 0.001$), even though patient-reported outcome scores did not differ between arms [9].

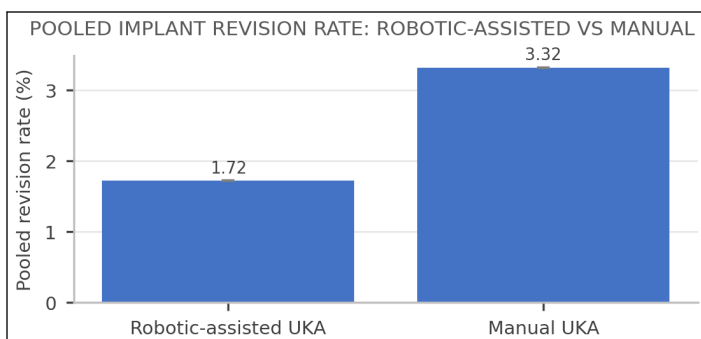


Figure 2: Pooled implant revision rate for robotic-assisted (1.72%) versus manual (3.32%) unicompartmental knee arthroplasty, from a systematic review and meta-analysis of the MAKO robotic system [20].

Early Functional and Patient-Reported Outcomes

Despite clear radiographic and revision advantages, most trials find that robotic assistance does not translate into superior mid-term patient-reported outcome scores. Five-year Oxford Knee Score and American Knee Society Score were statistically indistinguishable between robotic and manual groups in a randomised trial (median OKS 40 vs 41) [9], and a network meta-analysis of randomised trials likewise found no significant difference in tibiofemoral alignment angle or functional recovery between robotic, computer-navigated, and conventional techniques [13]. Where differences do emerge, they are concentrated in the early postoperative weeks: robotic patients reported significantly better Lower Extremity Functional Scale scores at one week, lower visual analogue pain scores at three weeks, and higher Knee Injury and Osteoarthritis Outcome Score-Joint

Replacement at six months, though these differences equilibrated by one year [16]. Quadriceps and hamstring strength after robotic UKA follow a similar trajectory, falling to roughly 80% of baseline at six weeks before recovering to approximately 70% (quadriceps) and 83% (hamstrings) of the unoperated limb's strength by 12 weeks, alongside improved timed-up-and-go and gait-speed performance [17]. Gait analysis at one year found robotic-assisted patients achieved knee flexion excursion statistically indistinguishable from healthy controls, whereas manual UKA gait remained significantly different from normal [23]. Case-series data on the Forgotten Joint Score and satisfaction extend these findings to five years, with 100% survivorship, 94% patient satisfaction, and mean Forgotten Joint Score of 75.8 after robotic lateral UKA [19], and a pooled analysis across the wider literature found a modest but statistically significant Forgotten Joint Score advantage (5.5 points) and Knee Society Score advantage (4.9 points) favouring robotic technique [24]. Imageless handheld robotic systems report comparably favourable early survivorship (99.2% at 2.3 years) [18].

Cost-Effectiveness Considerations

Robotic capital and per-case costs remain a barrier to universal adoption. A Markov decision analysis found robotic-assisted UKA cost-effective only when annual case volume exceeded 94 procedures, at an incremental cost of \$47,180 per quality-adjusted life-year at 100 cases annually, and only if two-year failure rates remained below 1.2% [25]. This volume dependency aligns with the clinical finding that robotic assistance most benefits lower-volume surgeons by narrowing the positioning gap with high-volume peers [5,6], suggesting that the technology's value proposition is strongest in practice settings combining moderate-to-high case volume with a mixed-experience surgical team, rather than as a universal replacement for conventional instrumentation [26].

Conclusion

Across randomised trials, comparative cohorts, and pooled meta-analyses, robotic-assisted UKA delivers consistently superior component-positioning accuracy and lower coronal, sagittal, and rotational outlier rates than conventional manual instrumentation, translating into meaningfully lower early revision and complication rates, particularly malalignment-related revision. These gains come with a modest increase in operative time and a learning curve of roughly six to eleven cases, without any excess of robot-specific complications. Two-year and five-year Oxford Knee Score, American Knee Society Score, and Forgotten Joint Score outcomes are broadly equivalent to manual UKA, though robotic patients recover function, strength, and normal gait somewhat faster in the early postoperative period. Cost-effectiveness remains volume-dependent, favouring high-throughput centres. Longer-term registry follow-up and standardised functional-outcome reporting will further clarify where robotic-assisted UKA offers the greatest value over conventional technique.

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