Robotic-assisted unicompartmental knee arthroplasty improves functional outcomes, complications, and revisions

a systematic review and meta-analysis

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Aims
Robotic-assisted unicompartmental knee arthroplasty (R-UKA) has been proposed as an approach to improve the results of the conventional manual UKA (C-UKA). The aim of this meta-analysis was to analyze the studies comparing R-UKA and C-UKA in terms of clinical outcomes, radiological results, operating time, complications, and revisions.

Methods
The literature search was conducted on three databases (PubMed, Cochrane, and Web of Science) on 20 February 2024 according to the guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Inclusion criteria were comparative studies, written in the English language, with no time limitations, on the comparison of R-UKA and C-UKA. The quality of each article was assessed using the Downs and Black Checklist for Measuring Quality.

Results
Among the 3,669 articles retrieved, 21 studies on 19 series of patients were included. A total of 3,074 patients (59.5% female and 40.5% male; mean age 65.2 years (SD 3.9); mean BMI 27.4 kg/m^2 (SD 2.2)) were analyzed. R-UKA obtained a superior Knee Society Score improvement compared to C-UKA (mean difference (MD) 4.9; $p < 0.001$) and better Forgotten Joint Score postoperative values (MD 5.5; $p = 0.032$). The analysis of radiological outcomes did not find a statistically significant difference between the two approaches. R-UKA showed longer operating time (MD 15.6; $p < 0.001$), but reduced complication and revision rates compared to C-UKA (5.2% vs 10.1% and 4.1% vs 7.2%, respectively).

Conclusion
This meta-analysis showed that the robotic approach for UKA provided a significant improvement in functional outcomes compared to the conventional manual technique. R-UKA showed similar radiological results and longer operating time, but reduced complication and revision rates compared to C-UKA. Overall, R-UKA seems to provide relevant benefits over C-UKA in the management of patients undergoing UKA.

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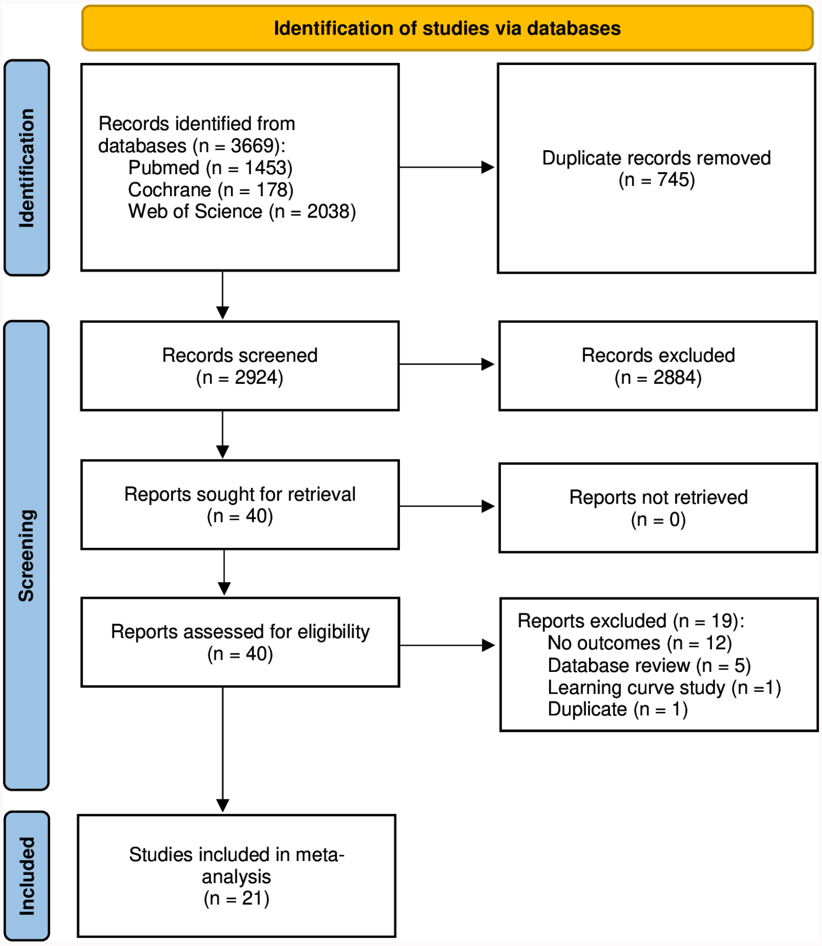

Fig. 1
Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram.

Take home message

- This meta-analysis showed that robotic-assisted unicompartmental knee arthroplasty (R-UKA) provided a significant improvement in functional outcomes compared to the conventional manual technique (C-UKA).
- R-UKA showed similar radiological results and longer operating time, but reduced complication and revision rates compared to C-UKA.
- Overall, R-UKA seems to provide relevant benefits over C-UKA in the management of patients undergoing UKA.

Introduction

Unicompartmental knee arthroplasty (UKA) is an established and effective treatment for patients affected by unicompartmental osteoarthritis of the knee joint.[1] The popularity of UKA has risen over the past two decades. Currently, UKA covers 10% of all knee arthroplasties worldwide.[2] The potential advantages of UKA include the lower complication rate, reduced operating time, decreased intraoperative blood loss, reduced periarticular soft-tissue trauma, improved preservation of bone stock, better restoration of native kinematics, quicker recovery time, lower perioperative costs, improved functional outcomes, and increased patient satisfaction compared to the whole joint replacement.[1,3,4] However, long-term survival has been the most pressing issue concerning the viability of conventional UKA (C-UKA).[3] In fact, UKA presents concerns with regard to implant survival and revision rates.[5]

Accuracy of component positioning and limb alignment are important prognostic variables affecting implant survival and time to revision surgery following UKA.[6-8] Techniques that improve the accuracy of implant positioning and limb alignment in UKA may help to improve long-term survival and reduce the burden of revisions.[1] Given the sensitivity of UKA survival and functional outcomes to small changes in component position, robotic-assisted UKA (R-UKA) has become an attractive method for ensuring accurate execution of the surgical plan.[3] Robotic technologies have been advanced to increase surgical precision, reduce the amount of soft-tissue and inflammatory response, and improve component alignment and soft-tissue balance, with the expectation that revision rates from technical errors may be mitigated.[4,9] Thus, robotic assistance could enable surgeons to perform UKA with accuracy superior to conventional methods.[10] Despite the potential of R-UKA, the available literature does not provide clear evidence for whether the proposed advantages of this technique translate into better clinical outcomes, and reduce revision rates, compared to C-UKA.

The present systematic review and meta-analysis aims at comparing R-UKA and C-UKA in terms of functional

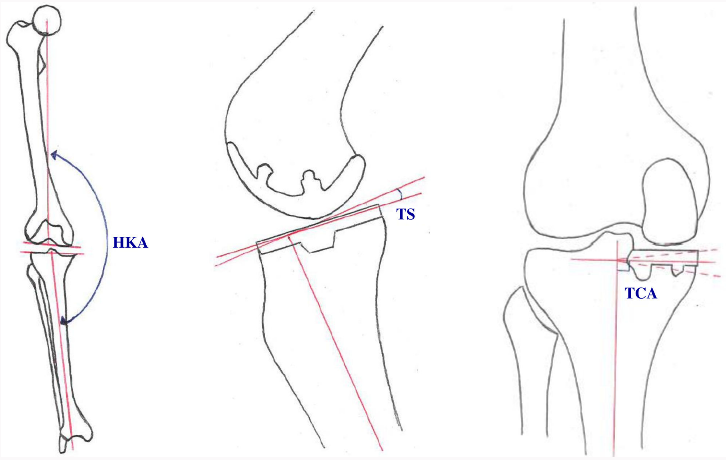

Fig. 2
Illustration of radiological outcomes: hip-knee-ankle angle (HKA; left), tibial slope (TS; centre), and tibial coronal alignment angle (TCA; right).

outcomes, radiological results, operating time, complications, and revisions.

Methods

Literature search

A literature search was conducted on the PubMed, Cochrane, and Web of Science databases on 20 February 2024 using the following criteria: (robot*) AND ((unicompartmental knee arthroplasty) OR (unicompartmental knee replacement) OR (UKA) OR (knee arthroplasty) OR (knee replacement) OR (knee prosthe*)). The trial was registered on PROSPERO (ID CRD42022373129). The guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) were used (Figure 1).[11]

Studies selection and data extraction

The screening process and analysis were conducted by two independent observers (AB, AS), with disagreement resolved by consensus with a third author (AI). First, the articles were screened by title and abstract. The following inclusion criteria were used: comparative studies, written in English, with no time limitations, on the comparison of R-UKA and C-UKA. Exclusion criteria were: non-comparative studies, articles written in other languages, reviews, preclinical studies, case series, case reports, studies not comparing R-UKA and C-UKA, and studies not reporting clinical or radiological outcomes, operating time, revisions, or complications. In the second step, the full texts of the selected articles were screened, with further exclusions according to the previously described criteria. Relevant data (title, author, year of publication, journal, patients' characteristics, follow-up time, clinical outcomes, radiological outcomes, operating time, complications, and revisions) were extracted and collected in a database, to be analyzed for the purposes of the present study.

Radiological outcomes included limb alignment and tibial component alignment parameters. The hip-knee-ankle angle (HKA) is a measure of lower limb alignment, defined as the angle between the mechanical axes of the femur and the tibia. The tibial component alignment was evaluated through two different angles measured on anteroposterior and lateral radiographs of the studied knees. The tibial slope (TS) is the angle formed between the vertical line of the tibial anatomical axis and the tibial plateau tangent, and reflects the tilt of the tibial plateau. The tibial coronal angle (TCA) represents the alignment of the tibial component on the coronal plane. The alignment angles were expressed as the difference from their optimal values to directly reflect the accuracy of the implant position (Figure 2).

Assessment of risk of bias and quality of evidence

The quality of each article was assessed independently by two authors (AB, AS) using the Downs and Black Checklist for Measuring Quality.[12] This is a reliable tool containing 27 'yes' or 'no' questions across five sections, providing a numerical score out of a maximum of 32 points. The five sections include questions about the overall quality of the study (ten items), the ability to generalize the study's findings (three items), the study bias (seven items), the confounding and selection bias (six items), and the power of the study (one item).

Statistical analysis

Statistical analysis and forest plotting were performed according to Neyeloff et al,[13] using the Meta XL tool for Excel (Microsoft, USA). The analysis was performed using random effects (DerSimonian & Laird) for the weighted mean difference (MD) of continuous variables, and the Peto method for odds ratios (ORs) of dichotomous variables. The I^2 statistic for heterogeneity was included, as well as the Q statistic. In the case of continuous outcome, the weighted MD (δ) was used to calculate the Z-test statistic. The 95% confidence intervals (CIs) for the δ were derived and if the 95% CI excludes zero, the meta-analysis has shown a significant treatment effect at 0.05 level of significance. The derived results were used to define the test statistic $z = \delta/SE$ which is $N(0, 1)$, and its corresponding p-value can be used to confirm or negate the result of the same meta-analysis. For dichotomous variables, the OR was used to calculate the test statistic. The 95% CIs for OR were derived; if the 95% CI excludes zero, the meta-analysis has shown a significant treatment effect at 0.05 level of significance. Fisher's exact test was used to check if the OR was statistically different from 1.

Table I. Characteristics and technical aspects of eligible studies.[14–34]

Author	Year	Journal	Study type	Treatment group	Pts, n	M, n	F, n	Mean age, yrs (SD)	Mean BMI, kg/m² (SD)	Medial	Lateral	Robot
Banger et al[16]	2021	*Bone Joint J*	RCT	R-UKA	55	NR	NR	NR	NR	55	0	Mako
				C-UKA	49	NR	NR	NR	NR	49	0	
Batailler et al[14]	2023	*Knee Surg Sports Traumatol Arthrosc*	RCT	R-UKA	33	21	12	65.6 (7.9)	26.4 (3.5)	33	0	Navio
				C-UKA	33	12	21	67.1 (8.1)	28.3 (5.6)	33	0	
Batailler et al[17]	2019	*Knee Surg Sports Traumatol Arthrosc*	Retrospective case-control study	R-UKA	80	53	27	69 (9.6)	26.1 (4.1)	57	23	Navio
				C-UKA	80	53	27	68 (10)	25.5 (3.9)	57	23	
Blyth et al[18]	2017	*Bone Joint Res*	RCT	R-UKA	64	29	35	68 (7.97)	26.9 (3.26)	64	0	Mako
				C-UKA	62	27	35	69 (6)	27.4 (3.38)	62	0	
Canetti et al[19]	2018	*Arch Orthop Trauma Surg*	Retrospective comparative study	R-UKA	11	2	9	66.5 (6.8)	24.2 (4.3)	0	11	Navio
				C-UKA	17	5	12	59.5 (9.9)	26.3 (3.8)	0	17	
Cobb et al[20]	2006	*J Bone Joint Surg Br*	RCT	R-UKA	13	8	5	NR	NR	13	0	Acrobot
				C-UKA	14	NR	NR	NR	NR	14	0	
Cool et al[21]	2019	*J Arthroplasty*	Retrospective longitudinal study	R-UKA	246	114	132	NR	NR	NR	NR	NR
				C-UKA	492	210	282	NR	NR	NR	NR	
Crizer et al[22]	2021	*Adv Orthop*	Retrospective cohort study	R-UKA	50	29	21	63 (11)	28.1 (4.5)	50	0	Navio
				C-UKA	39	22	17	58 (13)	28.3 (4.1)	39	0	
Foissey et al[23]	2022	*Int Orthop*	Retrospective cohort study	R-UKA	197	89	108	66.7 (7.7)	27.5 (3.3)	197	0	Navio
				C-UKA	159	61	98	68.3 (8.1)	27 (3.4)	159	0	
Gilmour et al[24]	2018	*J Arthroplasty*	RCT	R-UKA	58	32	26	61.8 (7.8)	NR	58	0	Mako
				C-UKA	54	28	26	62.6 (7.1)	NR	54	0	
Hansen et al[25]	2014	*J Arthroplasty*	Retrospective comparative study	R-UKA	30	16	14	57.1 (9.8)	32.1 (5.5)	30	0	Mako
				C-UKA	32	11	21	60.7 (11.8)	33.3 (5.7)	32	0	
Kayani et al[26]	2019	*Bone Joint J*	Prospective cohort study	R-UKA	73	32	41	65.3 (8.6)	NR	73	0	Mako
				C-UKA	73	34	39	66.1 (5.8)	NR	73	0	
Lonner et al[27]	2010	*Clin Orthop Relat Res*	Retrospective cohort study	R-UKA	31	15	16	NR	30 (5)	31	0	Mako
				C-UKA	27	17	10	NR	28 (4)	27	0	
MacCallum et al[28]	2016	*Eur J Orthop Surg Traumatol*	Retrospective cohort study	R-UKA	87	NR	NR	NR	NR	87	0	Mako
				C-UKA	177	NR	NR	NR	NR	177	0	
Maritan et al[15]	2023	*Knee Surg Sports Traumatol Arthrosc*	Retrospective cohort study	R-UKA	52	11	41	60.9 (8.4)	26.2 (3.3)	52	0	Mako
				C-UKA	43	6	37	61.5 (8.5)	27 (2.8)	43	0	
Mergenthaler et al[29]	2021	*Knee Surg Sports Traumatol Arthrosc*	Retrospective case-control study	R-UKA	200	78	122	66.7 (9.3)	27 (4.2)	159	41	Navio
				C-UKA	191	58	133	67.1 (10.7)	26.4 (4.2)	135	59	
Negrín et al[30]	2021	*Knee Surg Relat Res*	Retrospective cohort study	R-UKA	16	7	9	NR	NR	16	0	Navio
				C-UKA	18	12	6	NR	NR	18	0	
Park et al[31]	2019	*PLoS One*	Retrospective comparative study	R-UKA	55	11	44	NR	25.5 (2.5)	55	0	Mako
				C-UKA	57	7	50	NR	25.9 (3.7)	57	0	
Rodriguez et al[32]	2005	*Int J Med Robot*	RCT	R-UKA	13	NR	NR	NR	NR	13	0	Acrobot
				C-UKA	15	NR	NR	NR	NR	15	0	
Wong et al[33]	2019	*Knee Surg Sports Traumatol Arthrosc*	Retrospective cohort study	R-UKA	58	30	28	70.4 (9.7)	28.2 (5.6)	58	0	Mako
				C-UKA	118	44	74	67.9 (9.5)	28.7 (4.4)	118	0	
Wu et al[34]	2021	*J Clin Med*	Retrospective cohort study	R-UKA	52	11	41	68.5 (9.8)	NR	52	0	Mako
				C-UKA	61	9	52	69.4 (9.1)	NR	61	0	

C-UKA, conventional unicompartmental knee arthroplasty; NR, not reported; RCT, randomized controlled trial; R-UKA, robotic-assisted unicompartmental knee arthroplasty; SD, standard deviation.

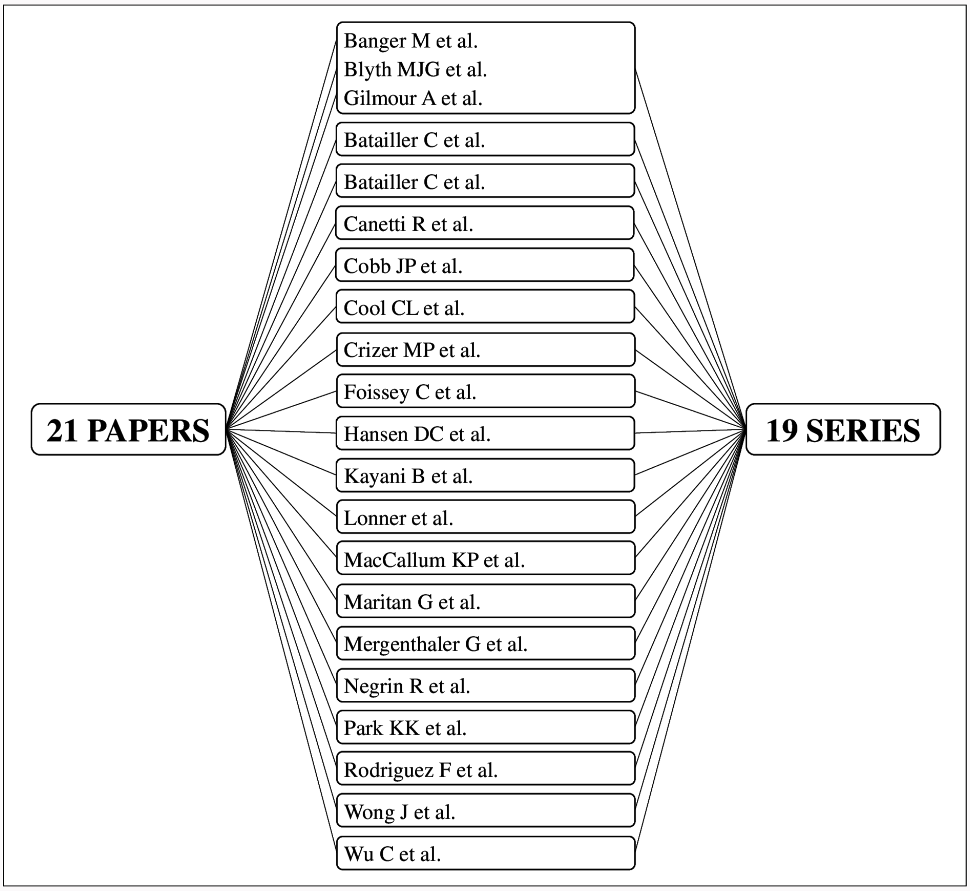

Fig. 3
Correspondence between the 21 articles retrieved and the 19 series of patients analyzed.

Results

Systematic review

A total of 3,669 articles were retrieved; after the removal of duplicates, and screening of the titles, abstracts, and full-texts, 21 studies were included according to the eligibility criteria (Table I). Among the 21 papers included, two were follow-ups of previous papers and therefore referring to the same original patient series: 19 studies were thus identified, and the most updated data extrapolated from the relative papers were included in the qualitative and quantitative data syntheses, as reported in Figure 3. A total of 3,074 patients (59.5% female and 40.5% male; mean age 65.2 years (standard deviation (SD) 3.9); mean BMI 27.4 kg/m^2 (SD 2.2)) was analyzed: 1,352 patients in the R-UKA group and 1,695 in the C-UKA group. Among the studies reporting the knee compartment treated with UKA, 17 studies (15 series of patients) concerned the treatment of the medial compartment and one study the treatment of the lateral compartment, while two studies included both patients treated with medial UKA and patients treated with lateral UKA. Overall, 20 studies on 18 series of patients described the use of three different robotic systems: Mako (11 studies, nine series of patients), Navio (seven studies), and Acrobot (two studies). Only one study did not report the brand of the robotic system employed.

Meta-analysis

Among the outcome measures extracted, a meta-analysis was performed on the following parameters: Knee Society Score (KSS),[35] range of motion (ROM), visual analogue scale (VAS) for pain (0 = no pain, 10 = worst pain), Forgotten Joint Score (FJS),[36] 12-Item Short Form Survey (SF-12) questionnaire,[37] HKA, TS, TCA, operating time, postoperative complications, and revisions. A sub-analysis was performed on the medial UKAs: available parameters that could be meta-analyzed included KSS, HKA, TS, TCA, operating time, postoperative complications, and revisions. Another sub-analysis was performed on the two most documented robotic systems: Mako and Navio. Available parameters that could be meta-analyzed include TS, TCA, operating time, and complications for Mako, KSS, TS, operating time, and revisions for Navio.

Clinical outcomes

KSS: The analysis of KSS improvement from preoperative to postoperative values (Figure 4) demonstrated a statistically significant difference in favour of the R-UKA group ($p < 0.001$; MD 4.9; standard error (SE) 1.3). All the studies included in the meta-analysis of KSS improvement used the Navio robotic system. Similarly, the analysis of KSS postoperative values in the medial UKA subgroup (Figure 4) found a statistically significant difference in favour of R-UKA ($p < 0.001$; MD 5.0; SE 1.0).

FJS: The analysis of FJS postoperative values (Figure 4) demonstrated a statistically significant difference in favour of R-UKA ($p = 0.032$; MD 5.5; SE 2.5).

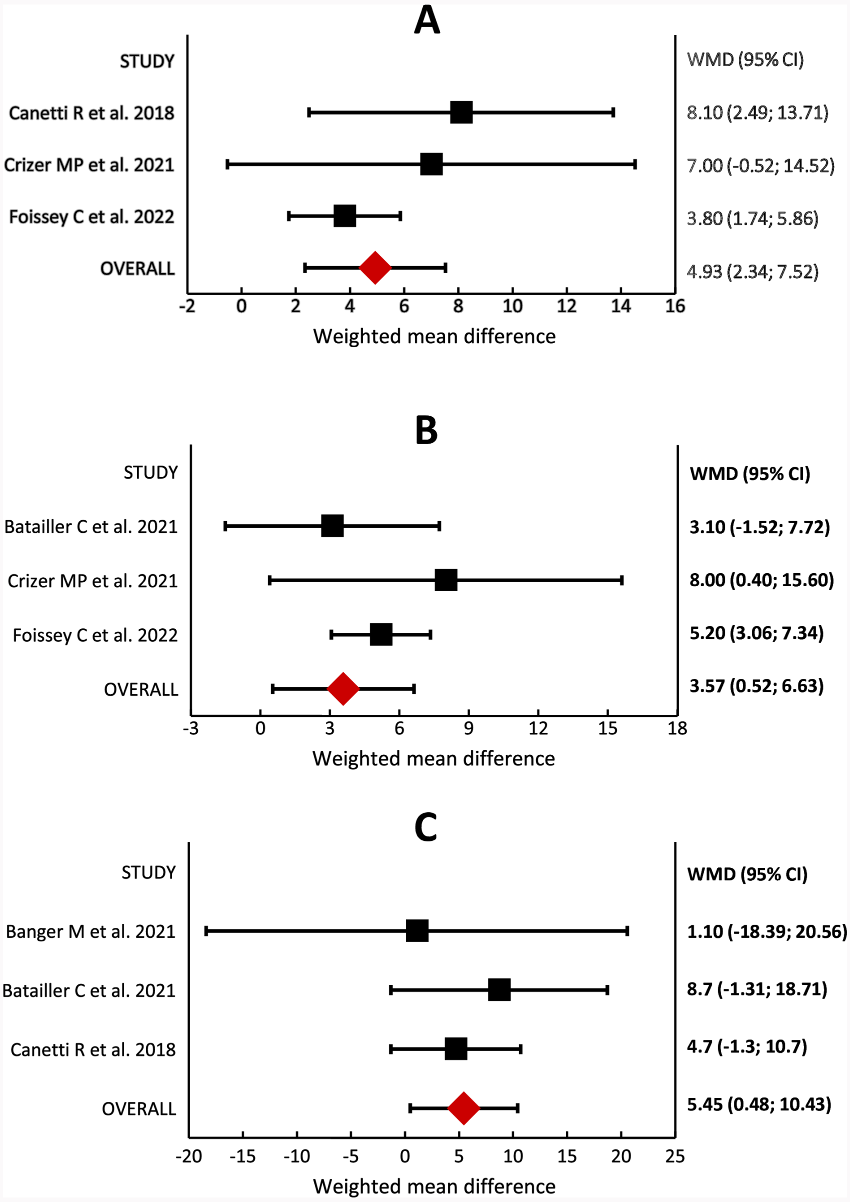

Fig. 4

a) Knee Society Score (KSS): forest plot of the individual studies and weighted mean difference (WMD) for KSS improvement, including a 95% confidence interval (CI). The size of the squares shows the weight of the study. Robotic-assisted unicompartmental knee arthroplasty (R-UKA) showed better KSS values compared to conventional UKA (C-UKA) ($p < 0.001$). b) KSS, medial UKA subgroup: forest plot of the individual studies and WMD for KSS improvement, including a 95% CI. The size of the squares shows the weight of the study. R-UKA showed better KSS values compared to C-UKA ($p = 0.022$). c) Forgotten Joint Score (FJS): forest plot of the individual studies and WMD for FJS values, including a 95% CI. The size of the squares shows the weight of the study. R-UKA showed better FJS values compared to C-UKA ($p = 0.022$).

VAS: The analysis of VAS, ROM, and SF-12 improvements from preoperative to postoperative values did not find a statistically significant difference between R-UKA and C-UKA.

Radiological outcomes

HKA: The analysis of HKA improvement from preoperative to postoperative values did not find a statistically significant difference between R-UKA and C-UKA, nor did the sub-analysis of the medial UKA subgroup.

TS: The analysis of TS postoperative values did not find a statistically significant difference between R-UKA and C-UKA, nor did the sub-analyses of TS postoperative values in the medial UKA subgroup and Mako subgroup. A statistically significant difference was found in the Navio sub-analysis with lower values obtained with the robotic-assisted approach ($p < 0.001$; MD -2.0; SE 0.3).

TCA: The analysis of TCA postoperative values did not find a statistically significant difference between R-UKA and C-UKA, nor did the sub-analyses of the medial UKA subgroup and Mako subgroup.

Perioperative parameters

Operating time: The analysis of operating time (Figure 5) demonstrated a statistically significant difference in favour of the C-UKA group ($p < 0.001$; MD 15.6; SE 3.3). Similarly, the analysis of operating time in the medial UKA subgroup (Figure 5) found a statistically significant difference in favour of C-UKA ($p < 0.001$; MD 16.1; SE 3.5). No statistically significant

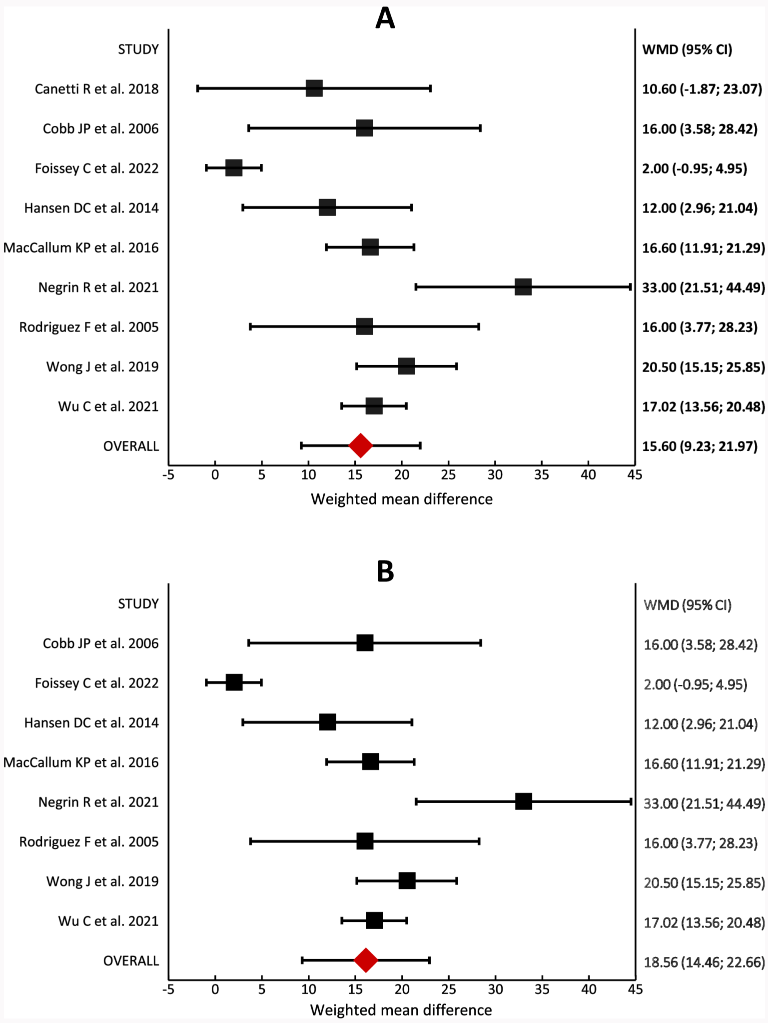

Fig. 5

a) Operating time: forest plot of the individual studies and pooled weighted mean difference (WMD) for operating time, including a 95% confidence interval (CI). The size of the squares shows the weight of the study. Robotic-assisted unicompartmental knee arthroplasty (R-UKA) showed longer operating time compared to conventional UKA (C-UKA) ($p < 0.001$). b) Operating time, medial UKA subgroup: forest plot of the individual studies and pooled WMD for operating time, including a 95% CI. The size of the squares shows the weight of the study. R-UKA showed longer operating time compared to C-UKA ($p < 0.001$).

differences were found in the sub-analyses of Mako and Navio subgroups.

Complications: The analysis of postoperative complications showed a rate of 5.2% for R-UKA and of 10.1% for C-UKA. The sub-analysis of the medial UKA subgroup showed a rate of 6.5% for R-UKA and 9.2% for C-UKA. The sub-analysis of the MAKO subgroup showed a rate of 5.8% for R-UKA and 5.4% for C-UKA. These differences did not reach statistical significance. Details of complications are reported in Table II.

Revisions: The analysis of revision rates showed a rate of 4.1% for R-UKA and 7.2% for C-UKA. The sub-analysis of the medial UKA subgroup showed a rate of 3.2% for R-UKA and 6.6% for C-UKA. The sub-analysis of the Navio subgroup showed a rate of 5.3% for R-UKA and 9.7% for C-UKA. These differences did not reach statistical significance.

Risk of bias

The Downs and Black Checklist for Measuring Quality for assessing the risk of bias assigns each study an 'excellent' ranking for scores ≥ 26, 'good' for scores from 20 to 25, 'fair' for scores between 15 and 19, and 'poor' for scores ≤ 14 points. According to these criteria, none of the included studies was classified as poor, 1 was fair, 16 were good, and 4 were excellent (Figure 6).

Discussion

The main finding of this meta-analysis is that the robotic approach for UKA provided a significant improvement in functional outcomes compared to the conventional manual technique.

Robotic-assisted surgery has become increasingly popular in UKA and is one of the most discussed topics in the current literature. R-UKA provides live intraoperative data on knee kinematics through the arc of flexion, which can be used to fine-tune implant positioning and optimize soft-tissue tensioning.[1] In light of this, R-UKA offers a unique opportunity to achieve high levels of accuracy in implant positioning, which may help to improve implant survival and reduce the number of revisions.[1] The accuracy superior to conventional methods can also translate to a better outcome,[10] as demonstrated by this meta-analysis.

Table II. Complications types and frequency in robotic-assisted versus conventional manual unicompartmental knee arthroplasty.

Complication	R-UKA, n (%)	C-UKA, n (%)
Aseptic loosening	4 (19)	9 (23.1)
Postop knee pain with/without stiffness or swelling	9 (42.9)	3 (7.7)
Limb malalignment	0 (0)	10 (25.6)
Myocardial infarction	0 (0)	9 (23.1)
Implant failure	4 (19)	4 (10.3)
Deep haematoma	1 (4.8)	1 (2.6)
Infection	1 (4.8)	1 (2.6)
Postop cellulitis	1 (4.8)	1 (2.6)
Acute urinary retention	1 (4.8)	0 (0)
Perforated peptic ulcer	0 (0)	1 (2.6)
Total	21 (100)	39 (100)

C-UKA, conventional manual unicompartmental knee arthroplasty; R-UKA, robotic-assisted unicompartmental knee arthroplasty.

The functional result is key in the perspective of patients undergoing UKA surgery, since clinical outcomes and ultimately patient satisfaction remain the fundamental goals of this procedure.[38] Previous meta-analyses on a smaller number of studies have tried to quantify benefits in terms of clinical outcomes. The meta-analysis conducted by Chin et al[39] found significantly superior KSS improvement in R-UKA compared to C-UKA up to three years after surgery. On the other hand, the meta-analysis by Zhang et al[40] failed to find a decisive superiority in functional outcomes when comparing R-UKA with C-UKA, describing similar clinical results for the two approaches. The current meta-analysis, including an up-to-date research of the literature with a higher number of comparative studies, shed new light on this controversial issue, quantifying the clinical benefit. The present meta-analysis found a statistically significant difference in terms of KSS improvement and FJS between R-UKA and C-UKA. Specifically, a mean difference of 4.9 points was found in the analysis of KSS improvement in favour of R-UKA. Although this difference did not reach the minimal clinically important difference (MCID) of 5.4 points reported in the literature for KSS,[41] it is very close to this value and could hardly be interpreted as clinically irrelevant. The results of the FJS analysis showed a MD of 5.5 points in favour of R-UKA. Similarly in this case, while not reaching the MCID of this score (8.8 points),[42] it still represents a considerable functional difference between the two approaches. This is of particular interest in terms of clinical relevance, as well as in terms of clinical indication for using robotic-assisted technology. In fact, robotic assistance showed different results when used for TKA. In a recent systematic review and meta-analysis, Bensa et al[43] investigated the results of 14 randomized controlled trial (RCTs) for a total of 2,255 patients and found that R-TKA did not provide overall superior results compared to C-TKA in terms of clinical and radiological outcomes, while showing longer operating time, thus questioning the benefits of robotic-assisted surgery to improve TKA outcome in the routine clinical practice. An opposite scenario was found instead for UKA, where significant functional advantages of the robotic approach were found.

Another relevant aspect of the comparison between R-UKA and C-UKA is represented by the analysis of the radiological outcomes. This aspect plays a crucial role in the outcome of UKA, especially concerning the long-term survival of the implant.[44] In fact, it is generally believed that UKA survival is mainly related to the original leg alignment,[45] with some authors encouraging only mild under-correction of varus deformities in order to obtain the best results and the longest survival.[46] Overall, there is currently no general agreement on the superiority of the robotic technique in achieving better UKA positioning, with the available studies reporting contrasting results. Hernigou and Deschamps[47] documented that the best clinical and radiological results in UKA were achieved when HKA was between 170° and 180°. The authors underlined that the alignment affects the progression of osteoarthritis in the opposite compartment of the knee and wear in the tibial component, especially when there has been an over-correction of constitutional varus. With regard to posterior tibial slope, Chen et al[48] observed that the best mid-term results for medial UKA were obtained with values ranging from 4° to 7°. This study did not find a statistically significant difference of limb alignment and implant positioning between R-UKA and C-UKA, especially in terms of HKA, tibial slope, and TCA. This result is partially in contrast with previous reviews, which found R-UKA to be more precise than C-UKA in these aspects.[39,49] However, the lack of difference found in the present study may be explained by the fact that, differently from UKA, the aim of UKA is not to correct the limb alignment, but rather to restore the pre-disease anatomy of the knee compartment treated, which increases the complexity of the obtained data interpretation.[50,51]

Perioperative parameters are also important when comparing R-UKA and C-UKA. This meta-analysis found a statistically significant difference between the two approaches in terms of operating time, favouring C-UKA over R-UKA by 15 minutes. This result is confirmed by several studies in the current literature showing similar findings, mainly due to surgical preparation, milling, and registration stages of the R-UKA surgical procedure.[39,40,49] The learning curve of the robotic-assisted procedure may be a relevant aspect affecting the operating time, although R-UKA has a rather flat learning curve, meaning that surgeons with limited experience require a relatively limited number of surgeries before achieving routine efficiency with this approach.[52] Furthermore, R-UKA seems to enable younger or inexperienced surgeons to achieve better accuracy when performing this intervention, suggesting that the use of robotic-assisted technique can also improve the learning curve of performing C-UKA.[10]

Complications and revisions are another important aspect when performing any prosthetic implant. Previous literature analyses showed controversial findings. A meta-analysis conducted by Zhang et al[40] reported a significantly reduced complication rate in R-UKA, and another meta-analysis published by Sun et al[53] showed significantly inferior complication and revision rates in R-UKA, while Chin et al[39] and Fu et al[49] were not able to find robotic assistance advantages in terms of complications and revisions. The present

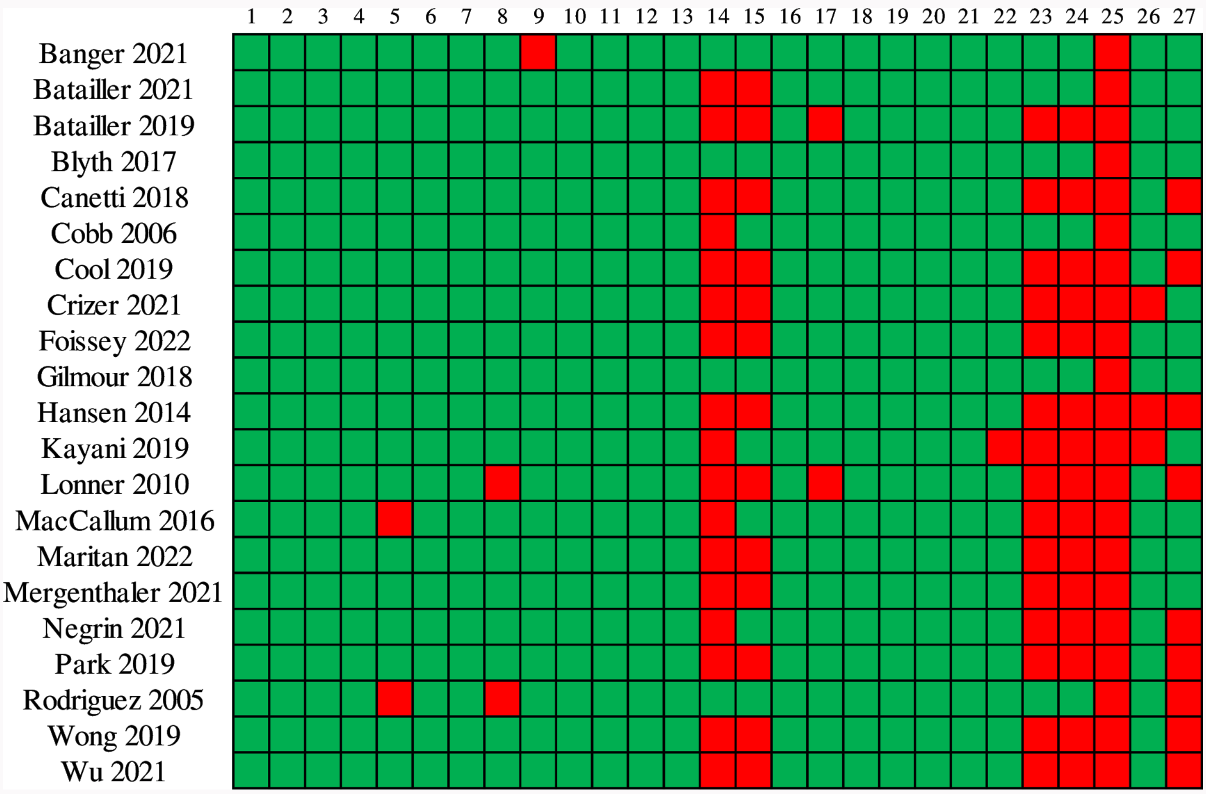

Fig. 6

Downs and Black's tool for risk of bias assessment including the answers to the 27 'yes' or 'no' questions for the each of the included studies.[12] Green: yes. Red: no.

meta-analysis found a considerable difference between R-UKA and C-UKA in terms of complications and revisions, with C-UKA showing both complication and revision rates almost twice as high compared to R-UKA (10.1% vs 5.2% and 7.2% vs 4.1%, respectively). The fact that these differences did not reach statistical significance is probably due to the relatively limited number of patients analyzed from the available literature. For instance, data from the Australian Orthopaedic Association National Joint Arthroplasty Registry and from a large USA database suggested that R-UKA was associated with reduced revision rates compared to C-UKA.[54,55] Additionally, C-UKA was found to have a greater number of risk factors for revision procedures compared to R-UKA: these included high BMI, congestive heart failure, diabetes mellitus, hypertension, hypothyroidism, opioid dependency, and rheumatoid arthritis, suggesting that robotic technology may help in improving the outcomes of UKA in specific patient categories, especially when presenting particular comorbidities.[55] These findings prove that, despite the longer operating time and the increased equipment required in the theatre, the use of robotic technology does not result in increased adverse events and could even help to reduce the complication and revision rates of UKA.

The sub-analysis of the medial UKA subgroup confirmed the results obtained in the main analysis. The analysis of KSS postoperative values showed a statistically significant difference of 5.0 points in favour of R-UKA, once again very close to the MCID value of 5.4 points. No significant difference was found in the analysis of radiological outcomes, while operating time favoured C-UKA of about 16 minutes. Complication and revision rates were considerably higher in C-UKA (9.2% vs 6.5% and 6.6% vs 3.2%, respectively), even if without reaching statistical significance. Unfortunately, it was not possible to perform a sub-analysis on the lateral UKA subgroup due to the limited number of studies focusing on this compartment. On the other hand, a sub-analysis could be performed focusing on the two most used systems: Mako and Navio. Even if both are semiautonomous robotic systems, the main difference between the two lies in the need for preoperative imaging: Mako requires a preoperative CT scan, while Navio is an imageless system. The sub-analysis of the Mako robotic system did not show any statistically significant difference compared to the conventional manual group in terms of TS, TCA, operating time, and complications. The sub-analysis of the Navio robotic system showed a statistically significant difference in favour of the R-UKA group in terms of KSS, confirming the results of the main analysis, and TS, while no difference was found in terms of operating time and revisions. Still, while these data are of interest (as the results could be linked to the specific system used) more data on each specific robotic system are required to clarify the benefits of the different approaches.

This systematic review and meta-analysis presents some limitations that require consideration. First, the studies analyzed presented a considerable heterogeneity of designs, with only six RCTs included (two of which are almost 20 years old). Due to the lack of randomization and retrospective nature of some studies, selection and recall bias cannot be completely excluded. Furthermore, the selected studies lacked standardization in data collection and reporting, particularly in terms of radiological outcomes. The lack of common outcome measures and associated postoperative follow-up timeframes resulted in a limited number of studies analyzed for each outcome. As such, a relatively small number of patients were included for each analysis and hence may not be fully representative of the general population. Not enough data were available for the analysis of surgeons' experience between the two groups, with only one study reporting detailed information on this relevant aspect. Moreover, the included studies used different robotic systems and lacked objective data for the quantification of soft-tissue balancing, which represents a crucial factor for implant durability.[56] Finally, there may be commercial bias in some of the studies: three studies received non-commercial grants, six received commercial funding, and five did not report if external funding or financial support was received. Despite these limitations, this meta-analysis provided important findings by quantifying the advantages and limitations of R-UKA, which reported overall encouraging results for improving the UKA outcome in the routine clinical practice. This is of clinical relevance. Indeed, if confirmed on a larger number of patients and possibly by more randomized controlled trials, the improvement in functional outcomes, complications, and revisions provided by R-UKA would represent a decisive advantage over C-UKA in the management of patients undergoing UKA.

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