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Is it prime time for robotic-assisted TKAs? A systematic review of current studies

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ABSTRACT

Introduction: Less-than-optimum positioning of femoral and tibial components and improper soft tissue tension, with abnormal loads and reduced range of motion, may cause lower patient satisfaction rates. To reduce surgeon-related variables during TKA, technology-assisted TKA was introduced, including computer navigation and robotic-assisted surgery (RATKA). Although several studies show promising short- and long-term functional and radiological outcomes of RATKA, there are still concerns related to its absolute superiority over conventional TKA.

Methods: This review aims to provide an updated insight into the most recent articles reporting on outcomes (functional, radiological, and complications) of RATKA through a systematic search of major databases. A comprehensive English literature search was performed by both authors through four databases (Embase, PubMed, Web of Science, and Scopus). The full text of the final eligible studies was evaluated for inclusion, resulting in 13 studies that are included in this review.

Results: There were 2112 knees in the 13 studies, with a follow-up ranging from three months to 13 years; only three were randomized controlled trials (RCTs), and nine directly compared the results of RATKA with CTKA technique. Seven studies reported the operative time ranging from 76.8 to 156 min; six reported a longer operative time with RATKA. Length of hospital stay (LOS) was reported in six studies which ranged from 0.48 to 2.1 days; in four studies the LOS was shorter with RATKA. In seven of the nine studies comparing RATKA with CTKA, no difference in functional outcomes was found. Four out of six studies reported that the overall alignment had mechanical alignment within $\pm 3^\circ$ of neutral alignment in all RATKA patients with an HKA ranging from -0.3 to 1.8°. Only one study reported better radiological outcomes in the RATKA group. In six comparative studies, no difference was found in the incidence of complications between RATKA and CTKA.

Conclusion: Although robotic-assisted total knee arthroplasty is a promising technology that provides better component alignment and superior early functional outcomes, the justification for its widespread adoption needs more robust evidence through well-designed and better long-term studies demonstrating superior, predictable, and durable clinical results compared to conventional total knee arthroplasty techniques.

1. Introduction

Despite the considerable annual increase in the number of total knee arthroplasty (TKA) procedures being performed worldwide and improvements in implant designs and perioperative care, patient satisfaction rates remain lower than expected; this is attributed partly to less-than-optimum positioning of femoral and tibial components and improper soft tissue tension, with abnormal loads and reduced range of motion (ROM).[1–4]

Aiming to reduce surgeon-related variables during TKA, technology-assisted TKA was introduced, including computer navigation and robotic-assisted surgery. It was hoped that these technologies would help more accurate implant positioning, alignment, ligament balancing, and preservation of the soft-tissue envelope, thereby leading to improved outcomes and better longevity.[5–7]

Robotic-assisted TKA (RATKA) entails detailed planning intra-operatively or through preoperative three-dimensional CT scans, which are then analyzed by specialized software to convert them into virtual intraoperative navigation; this eventually restricts bony cuts to the preoperative plan and prevents excessive, unnecessary cuts through

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the haptic feedback, which eventually improves components alignment.[8,9]

Although several studies show promising short- and long-term functional and radiological outcomes of RATKA, there are still concerns related to its absolute superiority compared to conventional TKA (CTKA) to justify the additional costs and radiation exposure.[10,11] This review aims to provide an updated insight into the most recent articles reporting on outcomes (functional, radiological, and complications) of RATKA through a systematic search of major databases.

2. Methods

A systematic search on RATKA in adult patients following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[12] The inclusion criteria were English language original studies reporting on the use of RATKA where the following data were presented: patient-reported outcomes (PROMs), functional outcomes, radiological outcomes, and incidence of complications. Studies investigating other procedures such as unicompartmental knee arthroplasty (UKA), cadaveric studies, outcomes of interest, cost analysis studies, other types of publications (reviews, editorials, case reports), and studies not published in the English language were excluded. A comprehensive English literature search was performed by both authors through four databases (Embase, PubMed, Web of Science, and Scopus) till February 28, 2022, using various combinations of the terms "total knee arthroplasty," "total knee replacement," "robotic," and "robotic-assisted." After downloading the results to Endnote 20, duplicates were excluded, followed by screening the title and abstracts for eligibility. The full text of the final eligible studies was evaluated for inclusion, resulting in 13 studies[13–25] which are included in the formulation of this review (Fig. 1). To keep the current review as updated as possible, the included studies are considered the most recent ones (published in 2020 and after) discussing RATKA and including one study published in 2019 which was not included in previous recent reviews.[10,11]

3. Results

3.1. Demographics and operative characteristics

For this review, we included 13 of the most recent studies (Table 1) reporting results of adopting RATKA, with a total of 2112 knees (range 26–724 TKA per study). Most of the patients were females (61%). Follow-up ranged from three months to 13 years; all studies reported a short-term follow-up except two studies, which reported their results at a long-term mean follow-up of eight and 13 years, respectively.[24,25]

Nine (69%) studies were published from the USA, two (15.5%) from China, and two (15.5%) from South Korea. Only three were randomized controlled trials (RCTs)[14,24,25]; the remaining were cohort and case series studies. Nine studies compared the results of RATKA with CTKA technique,[14–18,20–22,24] one study compared RATKA in a group using cruciate retaining (CR) implants with another group using posterior stabilized (PS) implants,[13] while in another study, the authors compared kinematic alignment (KA) with mechanical alignment (MA) during RATKA.[25] All studies, except for one,[15] reported the brand of robot used,

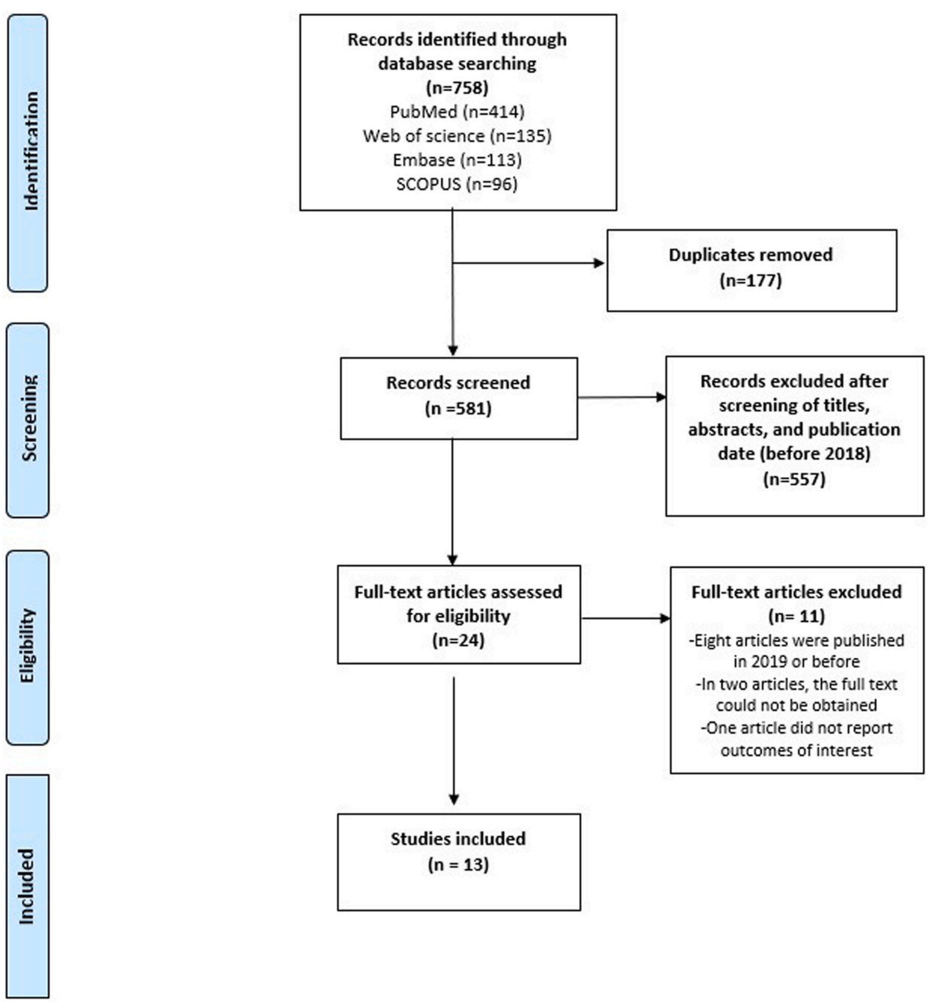

Fig. 1. Flow diagram showing the study search and selection method.

Table 1
Basic characteristics of the included studies.

No.	Author/year	Country	Study	Level of evidence	Sample size (RATKAs)	Sex		Age (years)	Follow up	BMI (kg/m2)	LOS (days)
						Male	Female				
1	Richards et al., 2022 (CR)	USA	Retrospective Cohort (Single surgeon)	LOE III	107	18 (16.8%)	89 (83.2%)	65 ± 10.3	16.4 ± 5.6 Months	30.5 ± 5.5	1.7 ± 1.2
	Richards et al., 2022 (PS)	USA	Retrospective Cohort (Single surgeon)	LOE III	107	56 (52.3%)	51 (47.7%)	66.7 ± 9.6	19.2 ± 6.3 Months	32.9 ± 6.2	1.5 ± 0.8
2	Z. Li et al., 2022	China	RCT (multicenter)	LOE I	73	13 (17.8%)	60 (82.2%)	68 ± 8 (30–86)	3 Months	26.9 ± 3.26 (20–38.5)	NR
3	C. Li et al., 2022	China	prospective cohort (Single surgeon)	LOE II	26	9 (34.6%)	17 (65.4%)	66.4 (50–76)	3 Months	NR	NR
4	Smith et al., 2021	USA	retrospective cohort (Single surgeon)	LOE III	120	48 (40%)	72 (60%)	68 (40–86)	17 (Min:12) Months	31.2 (18–47)	2.1
5	Shaw et al., 2021	USA	prospective cohort	LOE II	260	84 (32.33%)	176 (67.7%)	67.2 (41–91)	NR	32.4 (16.2–48.3)	1.04 (0–5)
6	Samuel et al., 2021	USA	retrospective cohort	LOE III	85	38 (44.7%)	47 (55.3%)	63.3 ± 8.8	Min 12 Months	31.7 ± 5.9	0.48 ± 0.59
7	Nickel et al., 2021	USA	prospective case series	LOE Ⅳ	105	NR		62.4 ± 8.5	NR	30.6 ± 6.1	NR
8	Mitchell et al., 2021	USA	retrospective cohort (Single surgeon)	LOE III	148	72 (48.6%)	76 (51.4%)	65.9 ± 8.2	Min 12 Months	30.6 ± 5.3	1.18
9	Marchand et al., 2021	USA	retrospective cohort (Single surgeon)	LOE III	80	51 (64%)	29 (36%)	67 ± 8 (46–84)	Min 24 Months	31 ± 7	NR
10	Held et al., 2021	USA	retrospective cohort (Single surgeon)	LOE III	111	37 (33%)	74 (67%)	70	Min 24 Months	30.1	2
11	Blum et al., 2021	USA	prospective case series (Single surgeon)	LOE Ⅳ	106	NR		69.6 ± 8.3	Min 24 Months	29.8 ± 4.1	NR
12	Kim et al., 2020	South Korea	RCT (Single surgeon)	LOE I	724	132 (18.2%)	542 (81.8%)	60 ± 7 (49–65)	13 (10–15) years	28 ± 9 (26–36)	NR
13	Yeo et al., 2019 (KA)	South Korea	RCT (Single surgeon)	LOE I	30	5 (16.7%)	25 (83.3%)	72 ± 5.5	Min 8 years	26.1 ± 5	NR
	Yeo et al., 2019 (MA)	South Korea	RCT (Single surgeon)	LOE I	30	3 (10%)	27 (90%)	74 ± 5.2	Min 8 years	26.9 ± 2.1	NR

Data presented as mean ± SD (range) whenever possible. RATKA: robotic assisted total knee arthroplasty, BMI: body mass index, LOS: length of hospital stay, CR: cruciate retaining, PS: posterior stabilized, RCT: randomized controlled trial, NR: not reported, Min: minimum, KA: kinematic alignment, MA: mechanical alignment.

Table 2
Operative details of the included studies.

No.	Author/year	Operative time (Minutes)			Machine used	Implant
		RATKA	CTKA	P value		
1	Richards et al., 2022 (CR)	91.8 ± 20.3			MAKO, Stryker, Mahwah, NJ	Triathlon (CR), Stryker, Mahwah, NJ
	Richards et al., 2022 (PS)	91 ± 16.8			MAKO, Stryker, Mahwah, NJ	Triathlon (PS), Stryker, Mahwah, NJ
2	Z. Li et al., 2022	126 (105–180)			HURWA, BEIJING HURWA-ROBOT Technology Co. Ltd	Legion system (Smith & Nephew, London, UK)
3	C. Li et al., 2022	126.0 (105–180)	75.2 (50–90)	<0.0001	NR	ADVANCE designs (MicroPort Orthopedics Inc., China)
4	Smith et al., 2021	96	86	<0.01	MAKO, Stryker, Mahwah, NJ	Triathlon (PS), Stryker, Mahwah, NJ (110 cementless, 10 cemented)
5	Shaw et al., 2021	76.8	87.2	<0.001	MAKO, Stryker, Kalamazoo, MI	(Cemented and cementless implants)
6	Samuel et al., 2021	113	105	<0.001	MAKO, Stryker, Kalamazoo, MI	Stryker implants (Stryker Corp.)
7	Nickel et al., 2021	NR			MAKO, Stryker, Mahwah, NJ	NR
8	Mitchell et al., 2021	NR			MAKO, Stryker, Mahwah, NJ	Triathlon (CR), Stryker, Mahwah, NJ
9	Marchand et al., 2021	NR			MAKO, Stryker, Mahwah, NJ	Triathlon, cementless (CR), Stryker, Mahwah, NJ
10	Held et al., 2021	123	107	<0.001	NAVIO imageless surgical system; Smith & Nephew, Memphis TN	Journey II BCS; Smith & Nephew, Memphis TN
11	Blum et al., 2021	NR			The OMNIBotics Robotic-Assisted Total Knee System.	OMNI Apex Ultra-Congruent system (Corin USA, Raynham, MA)
12	Kim et al. 2020	97 (81–123)	69 (56–81)	<0.001	ROBODOC system (Integrated Surgical Systems Inc, Davis, CA, USA)	A Duracon (PS) (Stryker Orthopedics, Mahwah, NJ, USA)
13	Yeo et al., 2019 (KA)	NR			ROBODOC system (Integrated Surgical System, Davis, CA, USA).	NexGen, (CR) prosthesis (Zimmer, Warsaw, IN, USA)
	Yeo et al., 2019 (MA)	NR			ROBODOC system (Integrated Surgical System, Davis, CA, USA).	NexGen, (CR) prosthesis (Zimmer, Warsaw, IN, USA)

Data presented as mean ± SD (range) whenever possible. RATKA: robotic assisted total knee arthroplasty, CTKA: conventional total knee arthroplasty, CR: cruciate retaining, PS: posterior stabilized, RCT: randomized controlled trial.

and Mako CT-based robot was the most commonly used (seven studies).[13,16–21] Various implants were used, both cemented and cementless, and PS and CR (Table 2).

Seven studies reported the operative time, which ranged from 76.8 to 156 min.[13,14,16–18,22,24] Six of seven comparative studies reported that the operative time for RATKA was longer than that for CTKA technique.[13,14,16,18,22,24] In one study in which the authors reported a shorter operative time in the RATKA group,[17] most of the implants used were cementless, whereas cemented implants were mainly used in the CTKA group. Furthermore, the length of hospital stay (LOS) was reported in six studies which ranged from 0.48 to 2.1 days.[13,16–18,20,22] In five studies comparing RATKA vs. CTKA, four found LOS was less in RATKA patients compared to CTKA patients,[13,16–18,20] and in one study, the authors found no difference.[22]

Regarding outcomes (Table 3), all studies reported various functional outcomes (PROMs and knee ROM), seven reported the radiological outcomes, and eight reported the complication rates.

3.2. Functional outcomes

Although various measures were used to evaluate the PROMs, all studies reported acceptable outcomes (Table 3). Patient satisfaction rates reported separately in three studies[13,16,23] which were 93.1%, 94.7, 94%, and 100%, respectively. Of the nine studies comparing RATKA with CTKA, no difference at the last follow-up regarding functional outcomes between the two techniques was found in seven studies,[14,15,17,18,20,22,24] while in two studies, the authors reported that RATKA achieved better functional outcomes compared to CTKA.[16,21] Knee ROM was reported in six studies,[14,15,18,23–25] ranging between 106 and 139° of flexion (Table 3).

3.3. Radiological outcomes

These were reported in seven studies (either overall mechanical limb alignment or individual component alignment in the coronal plane).[14,15,19,21,23–25] Six studies reported on the overall alignment; in four studies, all RATKA patients had mechanical alignment within $\pm 3°$ of neutral alignment; and HKA ranged from −0.3 to 1.8°.[14,19,23,25] In two studies, no exact values were reported; however, the mechanical alignment was within $\pm 3°$ of neutral alignment in 80.8 and 86% of the included patients, respectively.[15,24] Two studies reported no difference in the radiological measurements between RATKA and CTKA,[15,24] while in one study,[14] the authors achieved better radiological outcomes in the RATKA group (Table 3).

3.4. Complications

Eight studies reported complications,[13,16,18,19,21–24] details of which are reported in (Table 3); however, the most common complication was stiffness which needed manipulation under anesthesia in most cases. Only one study reported two types of complications related to using the robotic machine[22]; the first was a superficial infection at the pin site, which was reported in three patients, and the second was a unicortical tibial fracture at a pin site in one patient; all were treated conservatively. In six comparative studies,[16,18,20–22,24] the authors reported no difference in the incidence of complications between RATKA and CTKA.

4. Discussion

Although robotic-assisted surgery was introduced to knee arthroplasty surgery as early as 1980, aiming to provide accurate prosthesis alignment and decrease the malpositioning rates, it was not until the last decade that it began to gain popularity during total and partial knee arthroplasties.[11,26]

Several reports have supported the claims for adopting this new technology after proving its ability to drive proper component alignment, aid soft-tissue protection, and increase patient satisfaction.[8,10,27,28] However, some concerns remain and are contentious, such as its cost-effectiveness, the learning curve, and most importantly, the long-term benefit of its usage.[11,26,29]

After a detailed analysis and review of the most recent publications on RATKA, we find that most of the studies have reported similar functional outcomes when comparing RATKA with CTKA; furthermore, radiological results and even complication rates were comparable. Most studies have reported short-term follow-ups, and the only included long-term follow-up RCT study by Kim et al.[24] showed no difference between both techniques. In this review, we have not included studies evaluating the cost of this technology adoption or the learning curve.

We discuss and summarize below additional recent studies which have reported upon various facets of RATKA. Emara et al.[5] evaluated the early perioperative outcomes of technology-assisted (computer navigation and robotic-assisted) knee arthroplasty (including total and partial knee arthroplasty) by examining the US National Inpatient Sample between 2008 and 2018. In over 6.5 million procedures, the authors found that robotic-assisted procedures had a shorter LOS (2.0 ± 1.4 days versus 2.5 ± 1.8 days; $p < 0.001$) and fewer implant-related complications (including dislocation, periprosthetic fractures, wound problems and infection) compared to CTKA. They also found that in-hospital costs were lower for robotic-assisted procedures than for computer navigation. Their study showed an increasing trend of adopting robotic-assisted surgery over the ten-year study period (0.1% in 2008 versus 4.3% in 2018); they predicted that robotic-assisted surgery will represent 50% of all technology-assisted knee arthroplasty by 2030.[5]

This increasing trend of RATKA utilization was similarly echoed in a study by Naziri et al.,[30] who found an increase of 500% between 2009 and 2013 among 27 hospitals in New York State, USA.

In an analysis of 22 studies comparing RATKA with CTKA, Agrawal et al.[10] reported that RATKA resulted in better PROMs and radiological outcomes compared to CTKA. However, they mentioned that this superiority was unclear, and further analysis of complications and cost should be considered when interpreting the present data before the widespread adoption of this technology.

Jeon et al.[7] retrospectively compared the long-term (mean follow up of 11 years) functional and radiological outcomes between 84 RATKAs and 79 CTKAs. They reported significantly longer tourniquet time in the RATKA group; however, there was no significant difference between both groups in terms of Knee Society scores (KSS), SF-36, and ROM. Although RATKA showed fewer outliers for mechanical alignment (measured as HKA angle) than the CTKA group, this did not reach statistical significance. Furthermore, no difference was found regarding complication and revision rates.

In a meta-analysis of 18 studies comparing the results of RATKA with CTKA, Onggo et al.[31] reported the superiority of RATKA for radiological outcomes. While the functional outcomes and rate of overall complications were comparable between both techniques, the rate of periprosthetic infection was higher in two studies with RATKA.

In a meta-analysis evaluating seven studies (six were RCTs) comparing the results of ROBODOC image-based autonomous system with CTKA; Ren et al. [2,31] found that operative time was shorter with CTKA; but there were no differences in functional outcomes based on the Hospital for Special Surgery (HSS) scores and knee ROM; however, WOMAC and KSS scores were superior at six months postoperatively with RATKA. Furthermore, better postoperative lower limb alignment and more precise individual component positioning were observed with RATKA.

Song et al. randomized patients having simultaneous bilateral TKA into a RATKA group and a conventional TKA group. They reported more precision of mechanical axis restoration with RATKA; however, the coronal alignment of the femoral and tibial components was not different in both groups. Also, they reported no difference regarding functional outcomes or implant survivorship between both techniques.[32] At 13 years of follow up, Cho et al.[33] showed similar

Table 3
Outcomes of the included studies.

No.	Study	PROMs			ROM			Radiological			Complications	Revisions
		RATKA	CTKA	P-value	RATKA	CTKA	P-value	RATKA	CTKA	P-value		
1	Richards et al., 2022 (CR)	KSS function: 84.1 ± 14.2 KSS knee: 92.2 ± 9.1 WOMAC: 86.7 ± 13.2 FJS: 65.4 ± 28.9 KOOS-JR: 83 ± 16.9 Satisfaction: 93.1			NR			NR			−2 superficial infection (managed conservatively) −10 stiffness (managed by MUA)	Total 3: 1 instability, 1 for persistent stiffness, 1 periprosthetic fracture
	Richards et al., 2022 (PS)	KSS function: 84.3 ± 16.5 KSS knee: 89.9 ± 11.4 WOMAC: 84.6 ± 19.9 FJS: 66.3 ± 28 KOOS-JR: 83.5 ± 18 Satisfaction: 94.7			NR			NR			−2 superficial infection (managed conservatively) −10 stiffness (managed by MUA)	Total 3: all were for instability
2	Z. Li et al., 2022	KSS function: 58.2 ± 18.19 KSS knee: 70 ± 7.31 WOMAC: 80.6 ± 46.5 SF 36: 61.19 ± 19.9 HSS score: 80.1 ± 12.461	54.7 ± 19.52 67.8 ± 10.06 72.1 ± 44.40 63.05 ± 19.021 79.45 ± 11.52	0.3942 0.1107 0.2559 0.4511 0.9862	114.5 ± 18.41 (60–135) (Measured at 12 weeks)	111.6 ± 18.75 (75–140)	0.2877	HKA: 1.8 ± 1.6 varus (0.15–7.75)	3 ± 2.7 varus (0.2–15.15)	0.0207	NR	NR
3	C. Li et al., 2022	KSS knee: 92.3 (64–99) WOMAC: 8.9 (4–22) (Measured at 90 days)	91.8 (66–98) 8.9 (4–22)	0.8308 0.9552	106 (70–120) (Measured at 90 days)	103.5 (80–120)	0.3613	21 (80.8%) patients were within ±3°	15 (57.7%) patients were within ±3°	0.1318	NR	NR
4	Smith et al., 2021	KSS function: 80 KSS knee: 85 Satisfaction 94%	73 82 84%	0.005 0.046 0.036	119	116	0.02	NR			−9: Stiffness, all underwent MUA, 6 needed arthroscopic lysis. −2: non-fatal PE	0
5	Shaw et al., 2021	KOOS-JR: 71.72 PROMIS: -MH:54.84 -PH: 49.43 (Measured at 8 months)	72.08 51.64 48.62	0.727 0.010 0.471	NR			NR			NR	NR
6	Samuel et al., 2021	KOOS -pain: 42.7 ± 19.7 -PS: 26.2 ± 17.1 -KRQoL: 50.6 ± 21.9 VR-12 -MCS: 0.03 ± 9.80 -PCS: 17.8 ± 9.25 (Measured at 12 months, as differences from baseline (scaled))	42.2 ± 18.5 26.8 ± 16.5 47.1 ± 26.2 0.03 (9.80) 17.8 (9.25)	0.836 0.796 0.283 0.127 0.711	117.8 ± 10.2 (Measured at 90 days)	120.3 ± 9.9	0.043	NR			−2 superficial infection −2 stiffness −1 DVT	0
7	Nickel et al., 2021	KOOS-JR: 89.6 LEAS: 11.9 *NPRS*: 0.7 (Measured at 24 months)			NR			HKA: 0.97 ± 1.79 (−2.4 to 3) (Measured at 12 months)			−5 stiffness (managed by MUA) −1 patellar clunk required arthroscopy	0

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Table 3 (*continued*)

No.	Study	PROMs			ROM			Radiological			Complications	Revisions
		RATKA	CTKA	*P*-value	RATKA	CTKA	*P*-value	RATKA	CTKA	*P*-value		
8	Mitchell et al., 2021	KOOS-JR: 75.8 ± 12.5 VR-12 -MCS: 55.9 ± 9.0, -PCS: 42.9 ± 9.7 UCLA: 6.1 ± 1.7	72.2 ± 13.7 55.4 ± 9.2 41.6 ± 10.6 5.6 ± 2.3	0.072 0.668 0.336 0.059	NR			NR			NR	0
9	Marchand et al., 2021	r-WOMAC -pain: 1 ± 2 (0–10) -Physical function: 2 ± 3 (0–14) -Total: 4 ± 5 (0–24) (Measured at 24 months)	2 ± 3 (0–9) 4 ± 5 (0–28) 6 ± 7 (0–28)	0.024 0.009 0.009	NR			Tibial alignment in the coronal plane was within 3° of varus and valgus in all cases	NR		−2 Stiffness: (one underwent MUA, one underwent 2 arthroscopies then poly exchange at 24 months) −1 DVT −1 PE −1 posterolateral mechanical catching underwent arthroscopic synovectomy at 13 months	0
10	Held et al., 2021	KSS function: 75 WOMAC: -Function:87.30, -Stiffness:82.26, -Pain:90.48 SF 12: -M:44.83 -P:48.57	76.04 81.90 76.09 87.10 45.33 47.11	0.820 0.182 0.232 0.327 0.713 0.220	123	120	0.37	NR			−2 Periprosthetic fracture: (one distal femoral fracture due to a fall required surgical intervention and one unicortical tibial fracture at pin site, treated conservatively) −1 aseptic loosening (stable loose lines and not revised) −10 superficial infection (3 were at pin site, treated conservatively) −2 Deep infection: treated by DAIR −1 stiffness -1 patellar tendon rupture	NR
11	Blum et al., 2021	KOOS (Measured at 24 months) -pain 46.3 ± 15.0 -Symptoms 40.3 ± 15.7 -ADL: 42.9 ± 15.4 -KRQoL 57.2 ± 18.9 -Sports and Rec: 45.2 ± 27.2 Satisfaction 100%			139 ± 4 (Measured immediate postoperatively)			HKA: 0.8 ± 1.1 (Measured immediate postoperatively)			−2 Stiffness: managed by MUA	NR
12	Kim et al., 2020	KSS knee: 93 ± 5 WOMAC: 18 ± 14 points UCLA: 7 points	92 ± 6 19 ± 15 7 points	0.321 0.981 1.000	125 ± 6	128 ± 7°	0.321	−86% were within ±3° of neutral mechanical alignment. -Anatomical TF angle:2 ± 2 (0–6) of valgus -TIBIA: 90 ± 1 (87–94) -FEMUR: 98 ± 2 (94–102)	- 74% - 3 ± 3 (0–8) valgus −89 ± 6 2 (86–92) −97 ± 2 (91–101)	−0.035 −0.897 −0.721 −0.953	−15 knees had aseptic loosening of the femoral and/or tibial component (the authors did not report if they were revised or not). −4 Superficial infection	NR
13	Yeo et al., 2019(KA)	KSS function 90.1 ± 10.5 KSS (pain) 47.5 ± 5.6			125 ± 11.5			HKA: 0.1 ± 2 TIBIA: 87.5 ± 1.7 FEMUR: 91.7 ± 1.9			NR	NR

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Table 3 (*continued*)

No.	Study	PROMs			ROM			Radiological			Complications	Revisions
		RATKA	CTKA	*P*-value	RATKA	CTKA	*P*-value	RATKA	CTKA	*P*-value		
		WOMAC19.3 ± 1.9 HSS score 93.2 ± 8										
	Yeo et al., 2019 (MA)	KSS function 93 ± 9.1 KSS (pain) 47.2 ± 7.5 WOMAC20.4 ± 1.8 HSS score 94.8 5.5			129 ± 11.5			HKA: − 0.3 ± 1.7 TIBIA: 90.1 ± 0.4 FEMUR: 89.5 ± 0.4			NR	NR

PROMS: patient reported outcomes measures, ROM: range of motion, CR: cruciate retaining, PS: posterior stabilized, RATKA: robotic assisted total knee arthroplasty, CTKA: conventional total knee arthroplasty, KSS: knee society score, WOMAC: Western Ontario and McMaster Universities scoring systems, FJS: forgotten joint score, KOOS-JR: Knee Injury and Osteoarthritis Outcome Score for Joint Replacement, NR: not reported, MUA: manipulation under anesthesia, SF 36: short form, HSS: Hospital for Special Surgery, HKA: hip-knee-ankle mechanical angle, PE: pulmonary embolism, PROMIS: Patient-Reported Outcomes Measurement Information System, MH: mental health, PH: physical health, KRQoL: KOOS knee–related quality-of-life sub-score, LEAS: Lower Activity Extremity Score, NPRS: Numeric Pain Rating Scale, VR-12 MCS/PCS: Veterans RAND 12-Item Health Survey–Mental Component/Physical Component Scores, UCLA: University of California at Los Angeles Activity Score, r-WOMAC: reduced Western Ontario and McMaster Universities Osteoarthritis Index, SF-12 M and P: Short Form 12 Mental and Physical scores, DAIR: debridement, antibiotics and implant retention, KA: kinematic alignment, MA: mechanical alignment. N.B. the underlined complications were directly related to the robotic machine use.

survivorship in RATKA *vs.* CTKA, despite the better overall mechanical limb alignment and individual component sagittal alignment with RATKA.

In a network metanalysis evaluating the role of new technologies (including robotics, computer navigation, and patient-specific cutting blocks) during TKA surgery *vs.* CTKA, Bouch'e et al.[34] found that RATKA had the least outliers for postoperative mechanical alignment. The difference however, from other techniques was insignificant, with no difference in the functional outcomes at six, 12, and 24 months postoperatively (using KSS and WOMAC scores). They concluded that new technologies should be adopted cautiously until solid evidence proves their superiority over conventional manual techniques.

The cost-effectiveness of using robotic-assisted technology was not discussed in the studies in the current review. For the sake of completeness of this review, we discuss some recent papers that have shed light on this aspect. To compare the cost burden of RATKA to CTKA, Cool et al.[35] carried out a case-controlled study including a propensity score matching. They demonstrated a significant decrease in the 90-day episode of care costs compared to CTKA; this was mainly attributed to the shorter length of stay and less 90-day acute postoperative services, even after accounting for the preoperative CT scan needed for planning the cost savings were up to US$ 2182. Another study[36] reported a reduction in 90-day costs with RATKA *vs.* CTKA ($28,943 *vs.* $31,028; P = 0.05), owing to a decrease in LOS, 90-days readmission, and non-home discharge. Institutions may be less enthusiastic about adopting robotic technology due to the elevated initial startup costs to obtain a robotic system that could reach up to $1,000,000 and $545,000 in USA and Europe, respectively.[26,37] Even after the justification of using robotic technology from a cost-effectiveness point of view, there is still a concern regarding exposing the patient to excess radiation while obtaining a preoperative CT scan, especially given that the risks do not seem to be mitigated by the enhanced benefit of RATKA over CTKA.[11,37] Ponzio and Lonner found the mean effective radiation dose from preoperative CT scans required for planning of robotic-assisted UKA was 4.8 ± 3.0 mSv (millisieverts), which is equal to 48 chest x-rays; furthermore, a quarter of their patients required one or more further CT scans thus increasing the effective radiation dose to 103 mSv.[38] This needs to be borne in mind given that patients are at an increased risk of radiation-induced cancers when exposed to doses between 10 and 100 mSv.[39]

Soft-tissue preservation is one of the suggested benefits of RATKA. A prospective comparative study by Kalyani et al.[27] showed significantly less medial soft tissue injury and more precise femoral and tibial cuts with RATKA compared to CTKA. However, there are concerns related to the pins used to fix the tracking array, both as a source of postoperative pin tract infection and periprosthetic fracture (if placed in the diaphyseal instead of the metaphyseal segment).[29] Chun et al. have reported a 5% incidence of patellar tendon disruption while using RATKA.[40]

The current review has some limitations; first, in order to keep the current review updated, we included the recently published studies and excluded some of the previously published work, which could have changed the results of the current review. Second, most of the included studies presented relatively short-term follow-ups. Last, we did not perform a thorough statistical analysis of the included studies.

5. Conclusion

Although robotic-assisted total knee arthroplasty is a promising technology that provides better component alignment and superior early functional outcomes, the justification for its widespread adoption needs more robust evidence through well-designed and better long-term studies demonstrating superior, predictable, and durable clinical results compared to conventional total knee arthroplasty techniques.

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Authors' contribution

Both authors contributed equally to the design, research, and writing of the paper.

Declaration of competing interest

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