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# Clinical and Radiological Outcomes in Robotic-Assisted Total Knee Arthroplasty: A Systematic Review and Meta-Analysis

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ABSTRACT

*Background:* The aim of this systematic review is to determine if robotic-assisted total knee arthroplasty (RATKA) results in improved clinical and radiological outcomes, and to elucidate the breadth and depth of studies conducted on this topic.
*Methods:* A Preferred Reporting Items for Systematic Reviews and Meta-Analyses systematic review was conducted using 4 databases (MEDLINE, EMBASE, Cochrane, and Web of Science) to identify all clinical studies that investigate clinical or radiological outcomes using RATKA. The Critical Appraisal Skills Program checklist for cohort studies was employed for critical appraisal and evaluation of all 22 studies that met the inclusion criteria.
*Results:* All studies reviewed determined that knee arthroplasty improved clinical outcomes. Twelve studies found statistically better clinical outcomes with RATKA compared with conventional TKA, whereas 9 studies found no difference. One study did not assess clinical outcomes. When assessing radiological outcomes, 14 studies reported that RATKA resulted in more consistent and accurate postoperative mechanical alignment, whereas 2 studies reported no difference. Six studies did not assess radiological outcomes.
*Conclusion:* Although knee arthroplasty is one of the most commonly performed orthopedic operations, the level of patient satisfaction varies. The meta-analyses conducted in our systematic review shows that RATKA results in greater improvements in postoperative Hospital for Special Surgery score and Western Ontario and McMaster Universities scores compared to conventional TKA. Furthermore, it shows that RATKA results in more accurate postoperative alignment of prostheses. These together can explain the improved postoperative outcomes. More randomized controlled trials must be conducted before this technique is integrated into routine clinical practice.



Osteoarthritis of the knee is an incapacitating disease in which the degradation of articular cartilage results in progressive pain and functional disability. Musculoskeletal disorders including osteoarthritis are the most significant contributor to disability globally, with knee and hip osteoarthritis ranking as the 11th highest contributor [1]. The number of elderly and obese is set to increase in the future, with rates of osteoarthritis set to raise with it. The number of total knee arthroplasties (TKAs) carried out globally is substantial. The National Joint Registry of England, Wales and Northern Ireland and the Scottish Arthroplasty Project have recorded nearly 110,000 TKAs performed across the UK in 2017 [2,3]. In the same year in Canada, 70,502 TKAs were performed [4], and in Australia 53,617 were performed.

Despite the vast number of TKAs performed each year across the world, many studies have shown a variable patient satisfaction following TKA [5,6]. Furthermore, studies have highlighted the importance of femoral and tibial component positioning and soft tissue balance for favorable outcomes in TKA [7–9]. Component malalignment can result in abnormal load and early failure of the knee prosthesis, and is strongly correlated with reduced satisfaction and limited range of motion (ROM) [10]. There is increasing focus on improving surgical techniques in TKA, with the aim to improve the accuracy and precision of tibial and femoral cuts.

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The emergence of computer navigation and, more recently, robotic-assisted total knee arthroplasty (RATKA) has been at the forefront of surgical innovation for TKA. Many different robotic systems have been developed and implemented into clinical practice, including ROBODOC (Curexo Technology, Fremont, CA) [11], CASPAR (URS Ortho GMBH & Co, KG, Rastatt, Germany), and Mako (Stryker, Mahwah, NJ) [12]. However, the production of the CASPAR robotic system ceased in 2001 [13]. These novel interventions use preoperative imaging to create a 3-dimensional anatomical model of patients' knees [14]. Using this information, the surgeon can improve preoperative planning from selection of optimal implant size to ideal component alignment. This has the potential to improve the placement of implants. In addition, the robotic arm used in RATKA is only functional in a predetermined cutting zone that is set before the surgery [15] leading to increased soft tissue and ligament protection.

Although the literature suggests favorable outcomes with RATKA, a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) systematic review looking at the clinical and radiological outcomes of RATKA has not previously been conducted. The aim of this PRISMA systematic review is to determine (1) if RATKA improves clinical and radiological outcomes and (2) the breadth and depth of studies conducted on RATKA.

## Materials and Methods

### *Database and Inclusion Criteria*

This systematic review was carried out by following the guidelines set by the PRISMA checklist [16]. A framework based on the PICOS model (patient, intervention, control, outcome, study) was used for ascertaining the inclusion and exclusion criteria used in this study [17]. Studies in which adults were eligible for TKA with robotic assistance were included. Any studies which investigated use of other surgical interventions such as unicompartmental knee

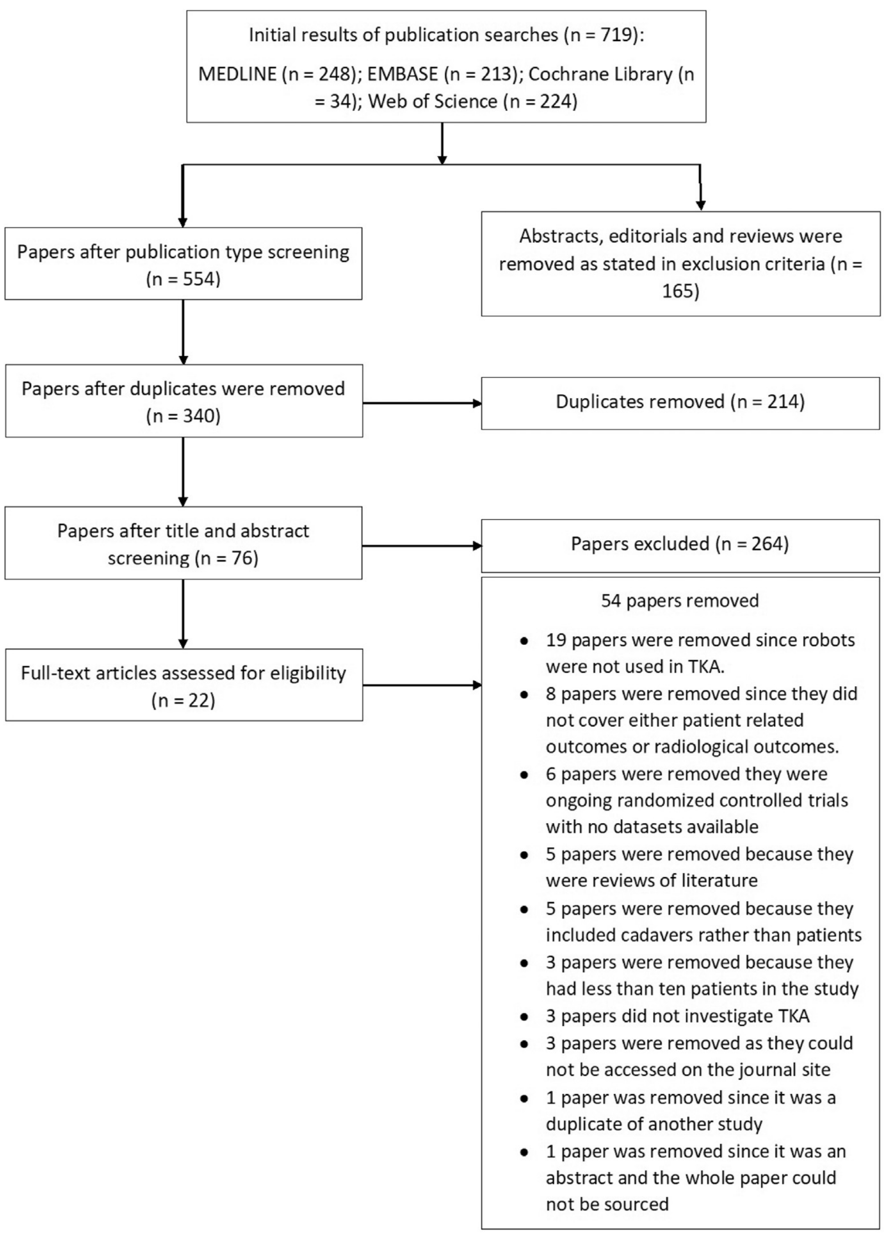


**Fig. 1.** Overview of screening and selection process for the systematic review. TKA, total knee arthroplasty.

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arthroplasty were excluded. Studies which did not include RATKA were also excluded. Studies which measured either clinical or radiological outcomes were included in the review. Consequently, studies which did not include either outcomes were excluded. Studies were included if they used any form of patient data taken from actual patient samples or previous published or unpublished datasets, to determine their conclusions. Accordingly, systematic reviews, methodological studies, index studies, and editorials were excluded. Cadaveric studies were also excluded since conclusions made from these studies could not be applied to clinical practice without making several assumptions. Furthermore, studies in which the data sets were either incomplete or inaccessible such as conference abstracts and ongoing randomized controlled trials (RCTs) were also excluded. Studies in which less than 10 patients were used were also excluded as this was deemed too small a sample size to make reliable conclusions.

A comprehensive literature search was conducted by 2 separate reviewers (N.A. and K.T.) to ensure accuracy. Four databases were included in the search: MEDLINE (1946 to Week 2 of July 2019), EMBASE (1974 to July 22, 2019), Cochrane library (1946 to July 2019), and Web of Science (1900 to 2019).

Using the guidance created by the Cochrane Highly Sensitive Search Strategy, a search strategy was created [18]. This included but was not limited to the following terms: "Arthroplasty, Replacement, Knee," or "Knee Prosthesis" and "Robotics" or "Robotic Surgical Procedures." The specific search strings employed for all 4 of the databases are displayed in Appendix 1. Restrictions were applied to the search to only include studies conducted on humans and in the English language. Although language restriction can be a source of bias, there is no indication that English language restriction has any effect on the information produced in systematic reviews [19]. The combined results of the comprehensive search strategy are shown in Figure 1.

*Quality Assessment*

Each paper was independently appraised by 2 reviewers (N.A. and K.T.) to ensure accuracy, using the Critical Appraisal Skills Program (CASP) checklist for cohort studies [20]. This 12-question checklist was used to assess each of the cohort studies included in the review. Upon completion, the dual analyses of each study were collated to form a table displaying the conclusive appraisal (Table 1). Any disagreements were solved by discussion.

*Data Extraction*

While conducting a critical appraisal for each study, the following study characteristics were also noted: study design, number of patients included in the study, mean follow-up time, type of implant used, type of robot used, types of outcomes measured, and country and year published.

*Statistical Analysis*

Key characteristics from the CASP checklist and inclusion criteria were extracted to describe each study. For each of these characteristics, means were calculated which are expressed as percentages. The studies were also stratified by year conducted, geographical region, design of study, and CASP scores to elucidate any trends. Forest plots were also created for outcome measures which were common to studies including: Hospital for Special Surgery score (HSS), Knee Society Score (KSS), ROM, Western Ontario and McMaster Universities scores (WOMAC). The Review Manager Database was used to extract data to conduct the statistical analysis. The chi-squared test and $I^2$ test were used to test for

**Table 1**
Critical Appraisal of the Papers Included in This Systematic Review, Using the CASP Checklist for Cohort Studies.

| Author (Year, Country) | Question 1 | Question 2 | Question 3 | Question 4 | Question 5a | Question 5b | Question 6a | Question 6b | Question 9 | Question 10 | Question 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yim et al [21] (2013, South Korea) | Yes | Yes | Yes | Yes | Yes | No | Yes | No | Yes | Yes | No |
| Park et al [22] (2007, South Korea) | No | Yes | Yes | Yes | Yes | Yes | Yes | Unspecified | Yes | Unspecified | Unspecified |
| Marchand et al [23] (2018 USA) | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Liow et al [24] (2014, Singapore) | No | No | Yes | Yes | Yes | No | Unspecified | No | Yes | Unspecified | Unspecified |
| Kayani et al [25] (2018, UK) | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Unspecified | Unspecified | Unspecified |
| Naziri et al [26] (2019, USA) | No | No | No | No | Yes | No | Yes | No | Yes | Unspecified | Yes |
| Marchand et al [27] (2019, USA) | No | Yes | Yes | Yes | Yes | Yes | Yes | No | Unspecified | Unspecified | Unspecified |
| Marchand et al [28] (2017, USA) | No | Yes | Yes | Yes | Yes | No | Yes | No | Yes | Yes | Yes |
| Khlopas et al [29] (2019, USA) | No | No | Yes | Yes | Yes | No | Yes | No | Yes | Unspecified | Yes |
| Bellemans et al [30] (2007, Belgium) | No | Yes | No | Yes | Yes | No | Yes | Yes | Yes | Unspecified | Yes |
| Liow et al [31] (2014, Singapore) | No | No | Yes | Yes | No | No | Yes | No | Yes | Unspecified | Unspecified |
| Jeon et al [32] (2019, South Korea) | Yes | Yes | No | Yes | Yes | No | Unspecified | Yes | Yes | Unspecified | Yes |
| Kim et al [33] (2016, South Korea) | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Unspecified |
| Yang et al [34] (2017, South Korea) | Yes | Yes | No | Yes | Yes | No | No | Yes | Yes | Yes | Yes |
| Decking et al [35] (2004, Germany) | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | Unspecified |
| Cho et al [36] (2019, South Korea) | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes | Yes | Yes |
| Kayani et al [37] (2019, UK) | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | Unspecified | Unspecified |
| Kayani et al [14] (2018, UK) | Yes | Yes | Yes | Yes | Yes | No | Yes | No | Yes | Yes | Yes |
| Song et al [38] (2013, South Korea) | Yes | Yes | Yes | Yes | Yes | No | Yes | No | Yes | Yes | Unspecified |
| Liow et al [39] (2017, Singapore) | Yes | Yes | Yes | Yes | Yes | No | Unspecified | No | Yes | Yes | Yes |
| Song et al [40] (2011, South Korea) | Yes | Yes | Yes | Yes | Yes | No | Yes | No | Yes | Yes | Unspecified |
| Siebert et al [41] (2002, Germany) | No | Yes | Yes | Yes | No | No | No | No | Yes | Yes | Unspecified |

Questions 7, 8 and 12 were left out of the table due to the fact that they are not yes/no questions.
CASP, Critical Appraisal Skills Program.

heterogeneity. Since there was no heterogeneity in any of the plots ($I^2$ < 50%), fixed effect models were used for meta-analysis. The weighted mean difference (WMD) was calculated for each of the scores with a 95% confidence interval (CI).

## Results

A summary of the critical appraisal findings is shown in Table 1.

Table 2 summarizes the main characteristics of all the studies included in this systematic review.

Table 3 describes the clinical outcomes measured and the conclusions made for all studies included in the systematic review.

Forest plots were created to analyze the most used clinical outcomes (Fig. 2).

Figure 2A shows that all 4 studies evaluating HSS score [34,36,38,40] demonstrated a statistical difference between RATKA and conventional TKA groups. The pooled WMD was −1.71 (95% CI −2.39 to −1.03) suggesting a significantly better HSS score in the RATKA cohort (Z = 4.92, $P$ < .00001). Figure 2B shows the 5 studies that evaluated KSS [22,24,32,36,39]. Four studies showed a statistical difference [24,32,36,39] with 1 favoring the RATKA group and 3 favoring the conventional TKA group. The pooled WMD was 0.50 (95% CI −0.56 to 1.56) suggesting no statistically significant difference in KSS (Z = 0.92, $P$ = .36) between the cohort groups. Figure 2C shows the 8 studies assessing ROM [22,24,32,34,36,38,40]. Two [22,40] showed there was a greater ROM in the RATKA patient cohort, 4 [24,32,34,39] showed this was better in the conventional TKA cohort, and 2 [36,38] showed no statistical difference. The pooled WMD was −0.42 (95% CI −1.45 to 0.61) suggesting no statistically significant difference in ROM (Z = 0.80, $P$ = .42) between the cohort groups. Figure 2D shows that all 6 studies that assessed WOMAC scores [27,28,34,36,38,40] showed statistically significantly higher WOMAC scores in the conventional TKA cohort. However, since a greater WOMAC score is indicative of poorer clinical outcome, this analysis showed that there are better clinical outcomes in the RATKA cohort. The pooled WMD was 2.81 (95% CI 1.41-4.20) suggesting a statistically significant difference in WOMAC scores (Z = 3.95, $P$ < .0001) favoring the RATKA patient cohort.

Table 4 describes the radiological outcomes measured and conclusions made for each of the studies included in the systematic review.

A forest plot was created to analyze outliers in the coronal mechanical axis alignment (Fig. 3).

Figure 3 shows all 8 studies [26,31,32,34,36,38,40,41], which looked at the number of patients which deviated more than 3° in the coronal mechanical axis alignment. All studies demonstrated a statistical difference between RATKA and conventional TKA groups. The pooled WMD was 5.35 (95% CI 3.52-8.11) suggesting that patients were significantly more likely to get an outlier when undergoing conventional TKA compared to RATKA. This suggests that RATKA is more accurate at aligning prostheses (Z = 7.88, $P$ < .00001).

### *Study Characteristics*

Table 5 provides the study characteristics of all studies included in this review. All studies were cohort studies with 36% (n = 8) [22–24,26,28,32,34,36,38,40] retrospective and 64% (n = 14) [14,21–25,29,31,35,37,41] prospective. All retrospective studies were

**Table 2**
Study Designs, Geographical Region, Year of Publication, Mean Follow-Up Time, Type of Implant Used, and Type of Robot Used for Each of the Studies Included in This Review.

| Author (Year, Country) | Design of Study | Number of Patients Involved | Mean Follow-Up | Implant Used | Robot Used |
|---|---|---|---|---|---|
| Yim et al [21] (2013, South Korea) | Randomized PCS | 117 | 2 y | NexGen CR Zimmer prosthesis | ROBODOC |
| Park et al [22] (2007, South Korea) | Randomized PCS | 72 | 3.9 y | NexGen LPS flex Zimmer prosthesis | ROBODOC |
| Marchand et al [23] (2018, USA) | RCS | 330 | N/A | Triathlon CR system Stryker prosthesis | Mako |
| Liow et al [24] (2014, Singapore) | PCS | 25 | 6 mo | NexGen LPS flex Zimmer prosthesis | ROBODOC |
| Kayani et al [25] (2018, UK) | PCS | 60 | N/A | Triathlon PS Stryker prosthesis | Mako |
| Naziri et al [26] (2019, USA) | RCS | 80 | 3 mo | N/A | Mako |
| Marchand et al [27] (2019, USA) | RCS | 106 | 1 y | Triathlon CR system Stryker prosthesis | N/A |
| Marchand et al [28] (2017, USA) | RCS | 40 | 6 mo | Triathlon CR system Stryker prosthesis | Mako |
| Khlopas et al [29] (2019, USA) | PCS | 252 | 3 mo | Triathlon CR cemented system Stryker prosthesis | Mako |
| Bellemans et al [30] (2007, Belgium) | PCS | 25 | 5 y | N/A | CASPAR |
| Liow et al [31] (2014, Singapore) | Randomized PCS | 60 | 6 mo | NexGen LPS flex Zimmer prosthesis | ROBODOC |
| Jeon et al [32] (2019, South Korea) | RCS | 163 | 9 y | NexGen LPS flex Zimmer prosthesis with RATKA and Triathlon CR system Stryker prosthesis with conventional TKA | ROBODOC |
| Kim et al [33] (2016, South Korea) | RCS | 29 | 3 y | Cemented prosthesis | ROBODOC |
| Yang et al [34] (2017, South Korea) | RCS | 113 | 10 y | NexGen CR Zimmer prosthesis | ROBODOC |
| Decking et al [35] (2004, Germany) | PCS | 13 | 6 mo | P.F.C. Sigma DePuy prosthesis | CASPAR |
| Cho et al [36] (2019, South Korea) | RCS | 351 | 11 y | NexGen Zimmer prosthesis | ROBODOC |
| Kayani et al [37] (2019, UK) | PCS | 120 | 1 mo | Triathlon cruciate substituting knee system and asymmetrical patella resurfacing | N/A |
| Kayani et al [14] (2018, UK) | PCS | 80 | 1 mo | Triathlon posterior stabilized knee system and asymmetrical patella resurfacing | Mako |
| Song et al [38] (2013, South Korea) | RCT | 100 | 65 mo | NexGen posterior CR Zimmer prosthesis | ROBODOC |
| Liow et al [39] (2017, Singapore) | RCT | 60 | 2 y | NexGen LPS flex Zimmer prosthesis | ROBODOC |
| Song et al [40] (2011, South Korea) | Randomized PCS | 30 | 1 y | NexGen posterior CR Zimmer prosthesis | ROBODOC |
| Siebert et al [41] (2002, Germany) | PCS | 120 | 6 mo | LC search evolution knee system in RATKA, and NexGen Zimmer prosthesis in conventional TKA | CASPAR |

RCT, randomized controlled trial; PCS, prospective cohort study; RCS, retrospective cohort study; LPS, legacy posterior stabilized; PS, posterior stabilizing; CR, cruciate retaining; N/A, not applicable; RATKA, robotic-assisted total knee arthroplasty.

**Table 3**
Geographic Location, Publication Year, Types of Clinical Outcomes Measured, and Clinical Outcome Conclusions Made for Each of the Studies Included in This Review.

| Author (Year, Country) | Clinical Outcomes Measured | Clinical Outcome Conclusion |
|---|---|---|
| Yim et al [21] (2013, South Korea) | ROM, HSS, WOMAC | There was no statistical difference in ROM between classical (129 ± 11.5) and anatomical (125 ± 11.5) alignment methods in RATKA ($P = .07$)<br>There was no statistical difference in HSS scores between classical (94.8 ± 5.5) and anatomical (93.2 ± 8.1) alignment methods in RATKA ($P = .28$)<br>There was no statistical difference in WOMAC score between classical (20.4 ± 6.7) and anatomical (19.3 ± 8.6) alignment methods in RATKA ($P = .64$) |
| Park et al [22] (2007, South Korea) | Knee Society Score, Knee Functional Score, ROM | There was no statistical difference in the clinical outcomes between robotic-assisted and conventional manual implantation of primary TKA ($P > .05$)<br>The Knee Society Score was 90.9 ± 4.88 and 62.7 ± 6.51 for conventional and robotic-assisted TKA groups, respectively<br>The Knee Functional Score was 88.5 ± 3.70 and 87.9 ± 4.99 for conventional and robotic-assisted TKA groups, respectively<br>The postoperative ROM was 122 ± 16.9 and 118 ± 9.02 for conventional and robotic-assisted TKA groups, respectively |
| Marchand et al [23] (2018, USA) | N/A | N/A |
| Liow et al [24] (2014, Singapore) | ROM, Knee Function Score, Knee Society Score, Oxford Knee Score | There was better range of motion postoperatively compared to the preoperative status, where extension was 6.3° ± 5.7° preoperatively and 4.4° ± 4.6° postoperatively. Flexion was 120° ± 16.1° preoperatively and 117.2° ± 14.4° postoperatively<br>There was also consistent improvement in functional and pain scores after RATKA surgery. The Knee Function Score was 50.8 ± 19.2 preoperatively and 82.3 ± 17.3 postoperatively<br>The Knee Society Score was 34.5 ± 14.2 preoperatively and 18.8 ± 16.4 postoperatively<br>The Oxford Knee Score was 33.4 ± 8.1 preoperatively and 68.9 ± 5.5 postoperatively |
| Kayani et al [25] (2018, UK) | MASTI score, bony injury score, soft tissue injury | The overall MASTI score was higher in patients undergoing RATKA compared with conventional TKA (30.85 ± 3.1 vs 27.68 ± 3.9, $P < .05$)<br>Patients receiving RATKA had greater grade A scores (10/30 vs 2/30, $P < .05$) and reduced grade C scores (0/30 vs 8/30, $P < .05$) compared with conventional TKA<br>There was no difference in RATKA and conventional TKA in grade B scores (18/30 vs 20/30, $P = .21$) and no patients in either group received grade D scores<br>There was reduced iatrogenic bone injury scores in RATKA compared with conventional TKA. The use of RATKA was linked with more pristine type A femoral (30/30 vs 12/30, $P < .05$) and tibia (26/30 vs 15/30, $P < .05$) bone cuts compared with conventional TKA. Type B bone cuts were not as common in RATKA for both femur (0/30 vs 18/30, $P < .05$) and tibia (4/30 vs 15/30, $P < .05$) compared to conventional TKA. No patients in either group had type C femoral or tibial bone resection surfaces<br>In patients with both correctable and noncorrectable deformities there was no complete medial zone soft tissue release (0/30). There were patients in which there was complete medial zone soft tissue release (10/30) in the conventional TKA group. There was a statistical reduction in soft tissue damage with use of RATKA compared to conventional TKA ($P < .05$)<br>Patients undergoing RATKA are far more likely to have reduced bone and soft tissue injury |
| Naziri et al [26] (2019, USA) | Length of stay, operating time, ROM, Knee Society Scores, complication rates, LEAS | Length of stay was longer for patients with conventional TKA (1.92 d) compared to robotic (1.27) ($P < .001$)<br>When comparing the overall surgical time between conventional TKA (78.3 min) and RATKA (82.5), RATKA surgery was statistically significantly longer ($P = .002$). However, when looking at the latter 20 cases operated on by RATKA compared to conventional TKA, there was no statistical difference in overall surgical time ($P = .254$). This reflects the early learning curve with RATKA<br>There was a statistical significance in the ROM at 90 d when comparing preoperative to postoperative differences when looking at the RATKA cohort (+3.8) compared to the conventional TKA cohort (−8.7) ($P = .039$)<br>There was however no statistical significance in the KSS at any of the follow-up times when comparing preoperative to postoperative differences when looking at the RATKA cohort (+6.7) compared to the conventional TKA cohort (+12.2) ($P = .353$)<br>There was no statistical difference in complication rates, whether they were major (n = 1 for conventional TKA, n = 0 in RATKA) or minor (n = 0 in both TKA groups)<br>There was no difference in LEAS between RATKA (8.47) and conventional TKA (8.27) during the preoperative period ($P = .529$) or at any of the follow-up times of 30 ($P = .736$), 60 ($P = .271$), or 90 ($P = .519$) days, where it was 11.63, 12.06, and 12.18 in the RATKA cohort respectively, and 11.50, 11.65, and 11.94 in the conventional TKA cohort respectively |
| Marchand et al [27] (2019, USA) | WOMAC scores | The RATKA cohort had significantly improved mean total (6 ± 6 vs 9 ± 8 points, $P = .03$) and physical function scores (4 ± 4 vs 6 ± 5 points, $P = .02$) when compared with the conventional TKA cohort. The mean pain score for the RATKA cohort (2 ± 3 points, range 0-14) was also lower than that for the conventional TKA cohort (3 ± 4 points, range 0-11) ($P = .06$) |
| Marchand et al [28] (2017, USA) | WOMAC scores | The mean pain score and range for the conventional and robotic-assisted TKA cohorts were 5 ± 3 (range 0-10) and 3 ± 3 (range 0-8, $P < .05$), respectively<br>The mean physical function score and range for the conventional and robotic-assisted TKA cohorts were 9 ± 5 (range 0-17) and 4 ± 5 (range 0-4, $P = .055$), respectively<br>The mean total patient satisfaction score and range for the conventional and robotic-assisted TKA cohorts were 14 points (range 0-27) and 7 ± 8 points (range 0-22, $P < .05$), respectively |

(*continued on next page*)

**Table 3** (*continued* )

| Author (Year, Country) | Clinical Outcomes Measured | Clinical Outcome Conclusion |
|---|---|---|
| | | There was a statistical improvement in pain and better satisfaction with patients in the RATKA cohort compared to the conventional TKA cohort |
| Khlopas et al [29] (2019, USA) | Knee Society Score | At 4-6 wk postoperatively, RATKA patients were found to have significantly larger improvements in walking and standing (1.4 vs −1.2 points, $P = .019$)<br>RATKA patients were also found to have larger improvements in advanced activities (1.3 vs 2.3 points), pain with walking (3.3 vs 3.2 points), satisfaction score (12.4 vs 12 points), and expectations score (5.1 vs 4.4 points) when compared with conventional TKA patients<br>At 3 mo, RATKA patients were also found to have larger improvements in walking and standing (6.0 vs 4.8 points), standard activities (11.4 vs10.1 points), advanced activities (6.2 vs 4.6 points), functional activities total score (22.8 vs 21.2 points), pain with walking (4.3 vs 4.1 points), total symptoms score (10.5 vs 10.3 points), satisfaction score (17.0 vs 15.5 points), and expectations score (4.8 vs 4.0 points) when compared with conventional TKA patients. However, none of these were statistically significant ($P > .05$) |
| Bellemans et al [30] (2007, Belgium) | American Knee Society Knee and Function Score, ROM, operating time | The preoperative Knee Society Knee Score was on average 48 points (range 14-85) and improved to an average of 91 (range 75-100). Eleven patients (50%) had a final score in the 90-100 point range, 10 patients (45%) in the 80-89 range, and 1 (5%) in the 70-79 range<br>The preoperative Knee Society Function Score was on average 37 (range 5-70) and improved to an average of 81 (range 50-100)<br>Preoperative flexion mean was 111° (range 70°-125°). Postoperative flexion mean was 105° (range 65°-125°)<br>Mean operating time was 195 min (range 130-255) |
| Liow et al [31] (2014, Singapore) | Length of stay, operating time, ROM, Oxford Knee Score, Knee Society Score, Knee Society Function Score, SF-36, complications | There was no statistically significant difference in the mean length of stay with 5.2 ± 2.3 d in the RATKA cohort and 5.8 ± 3.8 d in the conventional TKA cohort ($P = .457$)<br>There was no statistically significant difference in the mean operating time with 91 ± 10 min in the RATKA cohort and 93 ± 14 min in the conventional TKA cohort ($P = .432$)<br>There was no statistically significant difference in the preoperative and postoperative ROM. Extension was 6.8 ± 6.4 and 7.9 ± 7.1 for RATKA and conventional TKA groups respectively preoperatively ($P = .508$). Extension was 5.3 ± 4.8 and 4.5 ± 4.0 for RATKA and conventional TKA groups respectively postoperatively ($P = .499$)<br>Flexion was 121.0 ± 17.4 and 119.8 ± 17.9 for RATKA and conventional TKA groups respectively preoperatively ($P = .792$).<br>Flexion was 116.0 ± 17.8 and 122.4 ± 10.7 for RATKA and conventional TKA groups respectively postoperatively ($P = .112$)<br>Oxford Knee Society Score was 34.4 ± 7.8 and 37.4 ± 8.7 for RATKA and conventional TKA groups respectively preoperatively ($P = .322$). Oxford Knee Society Score was 18.8 ± 5.7 and 19.6 ± 6.8 for RATKA and conventional TKA groups respectively postoperatively ($P = .619$)<br>Knee Society Function Score was 55.9 ± 16.9 and 51.0 ± 20.4 for RATKA and conventional TKA groups respectively preoperatively ($P = .360$). Knee Society Function Score was 71.3 ± 18.5 and 70.0 ± 15.6 for RATKA and conventional TKA groups respectively postoperatively ($P = .791$)<br>Knee Society Knee Score was 34.2 ± 14.6 and 34.0 ± 17.1 for RATKA and conventional TKA groups respectively preoperatively ($P = .943$). Knee Society Knee Score was 80.8 ± 17.1 and 82.6 ± 14.7 for RATKA and conventional TKA groups respectively postoperatively ($P = .684$)<br>Nine aspects of the SF-36 were investigated: physical function, role physical, bodily pain, general health, vitality, social function, role emotional, and mental health<br>Physical function was 41.8 ± 21.6 and 33.1 ± 23.7 for RATKA and conventional TKA groups respectively preoperatively ($P = .144$).<br>Physical function was 69.2 ± 22.6 and 60.0 ± 23.8 for RATKA and conventional TKA groups respectively postoperatively ($P = .160$)<br>Role physical was 21.8 ± 36.4 and 10.3 ± 24.6 for RATKA and conventional TKA groups respectively preoperatively ($P = .157$).<br>Role physical was 80.2 ± 37.6 and 68.1 ± 39.5 for RATKA and conventional TKA groups respectively postoperatively ($P = .261$)<br>Bodily pain was 33.4 ± 16.6 and 28.0 ± 15.4 for RATKA and conventional TKA groups respectively preoperatively ($P = .192$).<br>Bodily pain was 65.0 ± 27.1 and 64.8 ± 25.4 for RATKA and conventional TKA groups respectively postoperatively ($P = .986$)<br>General health was 75.7 ± 16.1 and 67.9 ± 25.1 for RATKA and conventional TKA groups respectively preoperatively ($P = .163$).<br>General health was 76.9 ± 17.2 and 66.5 ± 21.6 for RATKA and conventional TKA groups respectively postoperatively ($P = .062$)<br>Vitality was 71.5 ± 20.3 and 66.0 ± 22.1 for RATKA and conventional TKA groups respectively preoperatively ($P = .326$). Vitality was 80.6 ± 16.1 and 67.6 ± 18.6 for RATKA and conventional TKA groups respectively postoperatively ($P = .010$)<br>Social function was 55.2 ± 36.5 and 48.7 ± 35.6 for RATKA and conventional TKA groups respectively preoperatively ($P = .486$).<br>Social function was 87.0 ± 26.2 and 87.1 ± 22.5 for RATKA and conventional TKA groups respectively postoperatively ($P = .989$)<br>Role emotional was 88.2 ± 31.7 and 77.0 ± 41.9 for RATKA and conventional TKA groups respectively preoperatively ($P = .252$).<br>Role emotional was 100 ± 0.0 and 92.0 ± 26.2 for RATKA and conventional TKA groups respectively postoperatively ($P = .109$)<br>Mental health was 81.3 ± 14.9 and 74.5 ± 21.3 for RATKA and conventional TKA groups respectively preoperatively ($P = .155$).<br>Mental health was 89.5 ± 10.7 and 81.9 ± 16.1 for RATKA and conventional TKA groups respectively postoperatively ($P = .054$)<br>There was no statistical difference in any of the clinical outcome except postoperative SF-36 vitality scores which were higher in RATKA |

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| Jeon et al [32] (2019, South Korea) | Knee Society Knee and Function Scores, SF-36, ROM | The preoperative Knee Society Knee Score was 42.1 ± 15.7 and 44.7 ± 15.4 for RATKA and conventional TKA cohorts, respectively ($P = .725$). The postoperative Knee Society Knee Score was 89.7 ± 12.9 and 91.9 ± 15.8 for RATKA and conventional TKA cohorts, respectively ($P = .586$)<br>The preoperative Knee Society Functional Score was 46.9 ± 10.4 and 48.7 ± 10.8 for RATKA and conventional TKA cohorts, respectively ($P = .614$). The postoperative Knee Society functional score was 85.4 ± 13.1 and 89.5 ± 13.6 for RATKA and conventional TKA cohorts, respectively ($P = .327$)<br>The preoperative SF-36 physical function score was 30.9 ± 9.7 and 37.2 ± 8.8 for RATKA and conventional TKA cohorts, respectively ($P = .436$). The postoperative SF-36 physical function score was 47.5 ± 8.5 and 47.2 ± 8.5 for RATKA and conventional TKA cohorts, respectively ($P = .539$)<br>The preoperative SF-36 mental health score was 48.2 ± 4.6 and 52.7 ± 5.3 for RATKA and conventional TKA cohorts, respectively ($P = .284$). The postoperative SF-36 mental health score was 56.5 ± 10.1 and 65.8 ± 11.9 for RATKA and conventional TKA cohorts, respectively ($P = .731$)<br>The preoperative ROM was 116.5 ± 6.9 and 117.2 ± 9.1 for RATKA and conventional TKA cohorts, respectively ($P = .354$). The postoperative ROM was 137.2 ± 11.2 and 134.5 ± 9.6 for RATKA and conventional TKA cohorts, respectively ($P = .637$)<br>Tourniquet time was 124 ± 9.3 and 79 ± 12.7 for RATKA and conventional TKA cohorts, respectively ($P < .001$)<br>Tourniquet time was statistically significantly longer in the RATKA cohort. There was no difference in any of the other clinical outcomes |
| Kim et al [33] (2016, South Korea) | American Knee Society Score, SF-36, ROM, tourniquet time, postoperative blood loss, complications | American Knee Society Knee Score was 27.13 ± 5.21 and 82.84 ± 2.97 for patients undergoing RATKA preoperatively and postoperatively, respectively ($P < .001$)<br>American Knee Society Functional Score was 34.22 ± 5.73 and 80.16 ± 3.62 for patients undergoing RATKA preoperatively and postoperatively, respectively ($P < .001$)<br>SF-36 physical score was 25.71 ± 5.94 and 59.89 ± 2.63 for patients undergoing RATKA preoperatively and postoperatively, respectively ($P < .001$)<br>SF-36 mental score was 18.09 ± 4.26 and 67.17 ± 2.41 for patients undergoing RATKA preoperatively and postoperatively, respectively ($P < .001$)<br>ROM total arc of flexion was 70.78° ± 6.32° (5°-135°) and 84.69° ± 4.47° (0°-120°) for patients undergoing RATKA preoperatively and postoperatively, respectively ($P = .006$)<br>ROM flexion contracture was 17.19° ± 2.39° (0°-55°) and 3.28° ± 1.16° (0°-30°) for patients undergoing RATKA preoperatively and postoperatively, respectively ($P < .001$)<br>There was significant improvement in the Knee Society Score and SF-36 scores postop. Mean arc of flexion increased and the mean flexion contracture decreased |
| Yang et al [34] (2017, South Korea) | HSS, WOMAC, Visual analogue scale pain score, ROM | The HHS was 88.7 ± 10.1 and 87.2 ± 11.0 for RATKA and conventional TKA patient groups, respectively ($P = .79$)<br>The WOMAC was 7.6 ± 9.4 and 11.5 ± 14.5 for RATKA and conventional TKA patient groups, respectively ($P = .12$)<br>The visual analogue pain scale was 1.1 ± 1.0 and 1.2 ± 1.1 for RATKA and conventional TKA patient groups, respectively ($P = .51$)<br>The ROM was 132.6° ± 10.5° and 131.0° ± 20.4° for RATKA and conventional TKA patient groups, respectively ($P = .92$)<br>There was no statistical difference in the clinical outcomes between RATKA and conventional TKA |
| Decking et al [35] (2004, Germany) | HSS | The mean HSS after 6 mo post operation was 84 (64-96) points |
| Cho et al [36] (2019, South Korea) | ROM, HSS, WOMAC, SF-12, KSS | The postoperative ROM was 130.7 and 130.0 for RATKA and conventional TKA groups, respectively ($P = .701$)<br>The postoperative HSS was 88.5 and 86.7 for RATKA and conventional TKA groups, respectively ($P = .245$)<br>The postoperative KSS pain score was 45.3 and 45.8 for RATKA and conventional TKA groups, respectively ($P = .453$)<br>The postoperative KSS function score was 87.8 and 88.4 for RATKA and conventional TKA groups, respectively ($P = .726$)<br>The postoperative WOMAC score was 10.1 and 13.0 for RATKA and conventional TKA groups, respectively ($P = .080$)<br>The postoperative SF-12 physical score was 48.3 and 47.6 for RATKA and conventional TKA groups, respectively ($P = .381$)<br>The postoperative SF-12 mental score was 44.8 and 44.1 for RATKA and conventional TKA groups, respectively ($P = .486$)<br>There was no difference in clinical outcomes between RATKA and conventional TKA; however, there was a significant improvement in functional outcomes in both groups |
| Kayani et al [37] (2019, UK) | Operative times, surgical time anxiety levels using STAI questionnaire and complications | The operative time was 62.1 ± 5.7 and 69.4 ± 8.1 for conventional and RATKA groups, respectively ($P > .05$). The operative time was 89.2 ± 4.2 and 66.8 ± 3.5 for the first 7 cases and the second 53 cases, respectively ($P = .01$)<br>The preoperative stress levels for the operating surgeon was 12.1 ± 3.4 and 13.0 ± 4.1 for conventional and RATKA groups, respectively ($P > .05$)<br>The preoperative stress levels for the anesthetist was 9.1 ± 2.5 and 9.7 ± 2.5 for conventional and RATKA groups, respectively ($P > .05$)<br>The preoperative stress levels for the scrub nurse was 12.8 ± 3.1 and 13.3 ± 2.6 for conventional and RATKA groups, respectively ($P > .05$)<br>The preoperative stress levels for the circulating nurse was 11.1 ± 2.1 and 10.2 ± 2.9 for conventional and RATKA groups, respectively ($P > .05$)<br>The preoperative stress levels for the operating department manager was 8.6 ± 3.1 and 7.6 ± 2.4 for conventional and RATKA groups, respectively ($P > .05$) |

(*continued on next page*)

**Table 3** (*continued* )

| Author (Year, Country) | Clinical Outcomes Measured | Clinical Outcome Conclusion |
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| | | There is an initial increase in surgical team anxiety and operating time with use of RATKA; however, this quickly decreases after 7 cases |
| Kayani et al [14] (2018, UK) | Operating time, postoperative pain score (using the numerical rating scale), postoperative analgesia use, ROM, number of physiotherapy sessions and time to discharge | The mean operating time was 61.2 (54.6-83.1) and 70.4 (59.2-91.7) for conventional TKA and RATKA patient groups, respectively ($P = .34$)<br>The mean fall in hemoglobin was 26.1 (5.1-49.6) and 18.7 (8.0-37.2) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The mean postoperative pain score at day 0 was 5.4 (3.0-7.0) to 3.1 (2.0-5.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The mean postoperative pain score at day 1 was 6.3 (4.0-8.0) to 3.6 (2.0-6.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The mean postoperative pain score at day 2 was 6.1 (3.0-8.0) to 3.3 (1.0-5.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The mean postoperative pain score at day 3 was 4.5 (2.0-7.0) to 2.6 (1.0-5.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The median postoperative median analgesia use at day 0 was 36.0 mg (IQR 16.0-51.3) to 20.0 mg (IQR 16.0-28.5) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The median postoperative median analgesia use at day 1 was 10.0 mg (IQR 10.0-20.0) to 10.0 mg (0.0-10.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The median postoperative median analgesia use at day 2 was 10.0 mg (10.0-20.0) to 10.0 mg (0.0-10.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>The median postoperative median analgesia use at day 3 was 10.0 mg (0.0-10.0) to 0.0 mg (0.0-5.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>Mean knee flexion was 93.3° (90.0-110.0) and 104.1° (90.0-120.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>Median physiotherapy sessions were 11.0 (IQR 9.0-11.0) and 5.0 (IQR 5.0-6.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>Median time to discharge was 105.0 h (IQR 98.0-126.0) and 77.0 h (IQR 74.0-81.0) for conventional TKA and RATKA patient groups, respectively ($P < .001$)<br>There was a statistically significant reduction in pain, improved early functional recovery, and earlier discharge with patients undergoing RATKA |
| Song et al [38] (2013, South Korea) | ROM, HSS, WOMAC, postoperative drainage, operative time | The preoperative ROM was 125° ± 7.6° and 123° ± 12.3° for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The postoperative ROM was 128 ± 5.1 and 129 ± 12.4 for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative HSS was 70.6 ± 11.2 and 63.8 ± 9.0 for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The postoperative HSS was 95.7 ± 4.0 and 94.7 ± 6.7 for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative WOMAC score was 65.6 ± 10.2 and 75.2 ± 11.1 for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The postoperative WOMAC score was 28.9 ± 4.4 and 30 ± 7.5 for RATKA and conventional TKA groups, respectively ($P > .05$)<br>The postoperative drainage was 613 ± 318 and 933 ± 467 for RATKA and conventional TKA groups, respectively ($P < .001$)<br>The operating time was 99 ± 11 and 74 ± 10 for RATKA and conventional TKA groups, respectively ($P < .001$)<br>There was no statistical difference in any of the clinical outcomes between RATKA and conventional TKA except with drainage and operating time. Drainage was lower for the RATKA cohort. Operating time was longer for the RATKA cohort |
| Liow et al [39] (2017, Singapore) | ROM, Oxford Knee Scores, Knee Society Knee and Functional Scores, SF-36, patient satisfaction | The preoperative ROM extension was 6.8° ± 6.4° and 7.9° ± 7.1° for the RATKA and conventional TKA groups, respectively ($P > .05$). The 6-mo ROM extension was 5.2° ± 5.2° and 4.5° ± 4.0° for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y ROM extension was 1.5° ± 3.5° and 1.7° ± 4.0° for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative ROM flexion was 121.0° ± 17.4° and 119.8° ± 17.9° for the RATKA and conventional TKA groups, respectively ($P > .05$). The 6-mo ROM flexion was 114.1° ± 20.1° and 122.4° ± 10.7° for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y ROM flexion was 118.3° ± 15.6° and 125.2° ± 10.3° for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative Oxford Knee Score was 33.6 ± 7.8 and 38.2 ± 9.5 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 6-mo Oxford Knee Score was 19.9 ± 7.9 and 19.6 ± 6.8 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y Oxford Knee Score was 18.3 ± 7.0 and 17.7 ± 4.2 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative Knee Society Function Score was 55.4 ± 16.9 and 51.0 ± 20.4 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 6-mo Knee Society Function Score was 70.5 ± 20.3 and 70.0 ± 15.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y Knee Society Function Score was 77.0 ± 17.1 and 73.9 ± 19.6 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative Knee Society Knee Score was 34.3 ± 14.6 and 34.0 ± 17.1 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 6-mo Knee Society Knee Score was 78.3 ± 18.0 and 82.6 ± 14.7 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y Knee Society Knee Score was 81.6 ± 14.9 and 87.9 ± 10.6 for the RATKA and conventional |

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| | | TKA groups, respectively ($P > .05$)<br>Ten aspects of the SF-36 were investigated: physical function, role physical, bodily pain, general health, vitality, social function, role emotional, mental health, PCS, and MCS<br>The preoperative SF-36 physical function score was 41.8 ± 21.6 and 33.1 ± 23.7 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 physical function score was 66.0 ± 23.8 and 60.0 ± 23.8 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 physical function score was 79.5 ± 20.7 and 66.9 ± 28.5 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 role physical score was 21.8 ± 36.4 and 10.3 ± 24.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 role physical score was 71.0 ± 41.4 and 68.1 ± 39.5 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 role physical score was 80.8 ± 35.2 and 68.5 ± 43.1 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 bodily pain score was 33.4 ± 16.6 and 28.0 ± 15.4 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 bodily pain score was 60.0 ± 28.5 and 64.8 ± 25.4 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 bodily pain score was 72.5 ± 24.3 and 68.6 ± 27.3 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 general health score was 75.7 ± 16.1 and 67.9 ± 25.1 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 general health score was 76.8 ± 16.2 and 66.5 ± 21.6 for the RATKA and conventional TKA groups, respectively ($P = .04$). The 2-y SF-36 general health score was 75.9 ± 18.8 and 69.0 ± 22.8 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 vitality score was 71.5 ± 20.3 and 66.0 ± 22.1 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 vitality score was 77.3 ± 19.5 and 67.6 ± 18.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 vitality score was 84.0 ± 18.8 and 72.2 ± 20.1 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 social function score was 55.2 ± 36.5 and 48.7 ± 35.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 social function score was 82.7 ± 27.3 and 87.1 ± 22.5 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 social function score was 95.4 ± 14.9 and 89.4 ± 27.0 for the RATKA and conventional TKA groups respectively ($P > .05$)<br>The preoperative SF-36 role emotional score was 88.2 ± 31.7 and 77.0 ± 41.9 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 role emotional score was 100 ± 0.0 and 92.0 ± 26.2 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 role emotional score was 98.9 ± 6.1 and 81.5 ± 39.6 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 mental health score was 81.3 ± 14.9 and 74.5 ± 21.3 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 mental health score was 88.4 ± 11.8 and 81.9 ± 16.1 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 mental health score was 88.8 ± 13.6 and 82.2 ± 20.0 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 PCS score was 32.4 ± 9.6 and 29.1 ± 9.2 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 PCS score was 46.2 ± 9.1 and 46.7 ± 11.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 PCS score was 50.3 ± 7.0 and 46.2 ± 13.9 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>The preoperative SF-36 MCS score was 53.9 ± 8.2 and 50.0 ± 12.6 for the RATKA and conventional TKA groups, respectively ($P > .05$). The SF-36 MCS score was 57.0 ± 8.8 and 52.6 ± 9.7 for the RATKA and conventional TKA groups, respectively ($P > .05$). The 2-y SF-36 MCS score was 59.3 ± 9.8 and 54.7 ± 10.3 for the RATKA and conventional TKA groups, respectively ($P > .05$)<br>There was a statistical difference in the SF-36 vitality score at 6 mo postoperatively and role emotional scores at 2 y postoperatively |
| Song et al [40] (2011, South Korea) | ROM, HSS, WOMAC | The preoperative ROM was 120° ± 16.0° and 123° ± 14.3° for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The postoperative ROM was 129° ± 13.8° and 129° ± 12.8° for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>The preoperative HSS was 65 ± 7.0 and 66 ± 7.4 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 3-mo postoperative HSS was 91.1 ± 6.7 and 90.5 ± 6.6 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 6-mo postoperative HSS was 93.4 ± 6.5 and 93.5 ± 5.9 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 1-y postoperative HSS was 95.9 ± 5.2 and 94.7 ± 5.5 for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>The preoperative WOMAC was 80 ± 16.0 and 75 ± 15.0 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 3-mo postoperative WOMAC was 36.8 ± 12.0 and 36.4 ± 12.4 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 6-mo postoperative WOMAC was 28.1 ± 11.0 and 27.9 ± 10.1 for the RATKA and conventional TKA cohorts, respectively ($P > .05$). The 1-y postoperative WOMAC was 18.5 ± 4.0 and 20.1 ± 8.5 for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>There was no statistical difference in the clinical outcomes between robotic-assisted and conventional techniques in TKA |
| Siebert et al [41] (2002, Germany) | Operating time | Operating time was 135 min (80-220) for the first 70 robotic cases.<br>There was no difference between robotic-assisted and conventional TKA groups for KSS ($P > .05$) |

HSS, Hospital for Special Surgery score; WOMAC, Western Ontario and McMaster Universities score; ROM, range of motion; SF-36, short form 36; SF-12, short form 12; LEAS, lower extremity activity scale; MASTI score, macroscopic soft tissue injury score; KSS, Knee Society Score; PROM, patient-reported outcome measures; STAI, State-Trait Anxiety Inventory; IQR, interquartile range; RATKA, robotic-assisted total knee arthroplasty; N/A, not applicable.

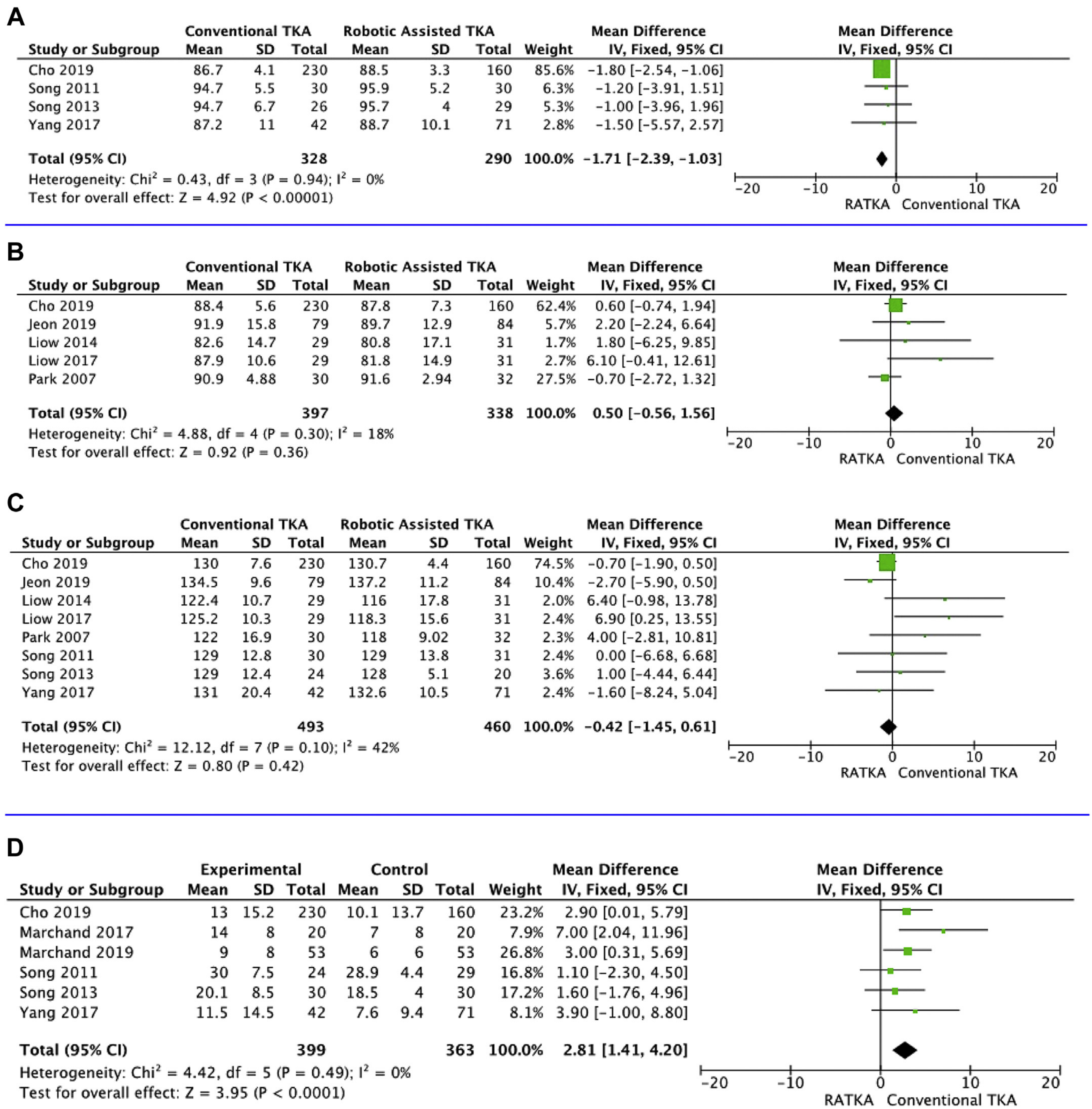


**Fig. 2.** Forest plot showing the Hospital for Special Surgery scores (A), Knee Society Scores (B), range of motion (C), and Western Ontario and McMaster Universities scores (D) between RATKA and conventional TKA groups. SD, standard deviation; IV, inverse variance method; CI, confidence interval; df, degrees of freedom; RATKA, robotic-assisted total knee arthroplasty.

from after 2015 and were conducted in either South Korea (n = 4) [22,24,32,34,36,38,40] or United States (n = 4) [23,26,28]. The prospective studies were conducted in South Korea (n = 4) [21,22,38,40], Singapore (n = 3) [24,31,39], UK (n = 3) [14,25,37], Germany (n = 2) [35,41], United States (n = 1) [29], and Belgium (n = 1) [30].

ROBODOC was the most common robotic apparatus used with Zimmer implants, with 48% (n = 11) [21,22,24,26–28,31,32,34,36,38–40] studies utilizing this hardware consistently throughout this decade. South Korea (n = 8) [21,22,24,32,34,36,38,40] and Singapore (n = 3) [24,31,39] were the only countries to use ROBODOC. Mako, used with Stryker implants, has only been used since 2017 and was the second most commonly used hardware; it was used in 4 American [23,26,28,29] and 2 British [14,25] studies. Two German [35,41] and one Belgian [30] study used CASPAR robots, and these studies were from before 2008.

One study conducted in the USA only focused on radiological outcomes [23]. Six studies only focused on clinical outcomes [14,21,23,25–29,31,41]. The mean follow-up times for all studies was 33.89 months (n = 20) [14,21,22,24,26,31,41]. Studies with the shortest follow-up time of either 1 month or 3 months were all conducted in

**Table 4**
Geographic Location, Publication Year, Types of Radiological Outcomes Measured, and Radiological Outcome Conclusions Made for Each of the Studies Included in This Review.

| Author (Year, Country) | Radiological Outcomes Measured | Radiological Outcome Conclusion |
|---|---|---|
| Yim et al [21] (2013, South Korea) | Mechanical axis, coronal plane alignment of the femoral and tibial components, sagittal inclination of the tibial component, varus and valgus laxities | There was no statistical difference in the mechanical axis between classic (0.71° ± 1.73°) and anatomical (0.39° ± 2.01°) alignment methods ($P$ = .47)<br>There was also no statistical difference in the sagittal inclination of the tibial component between classic (84.1° ± 0.66°) and anatomical (85.42° ± 1.66°) alignment methods ($P$ = .82)<br>There was a statistical difference in the coronal inclination of the tibia between classic (90.1° ± 0.37°) and anatomical (87.48° ± 1.68°) alignment methods ($P$ = .04)<br>There was a statistical difference in the coronal inclination of the femur between classic (89.5° ± 0.39°) and anatomical (91.71° ± 1.93°) alignment methods ($P$ = .03)<br>The mean varus and valgus laxities in the classical group were 6.75° ± 3.34° and 3.49° ± 2.57°, respectively and in the anatomical group were 5.89° ± 3.25° and 3.17° ± 2.54°, which were not statistically significant ($P$ = .16 and .49, respectively) |
| Park et al [22] (2007, South Korea) | Postoperative tibiofemoral angle, femoral flexion angle, tibial angle | The postoperative tibiofemoral angles were 5.3° ± 2.6° and 6.0° ± 1.8° for conventional and robotic-assisted TKA groups, respectively ($P$ = .19)<br>The femoral flexion angle and tibial angle in the AP X-ray of the conventional TKA group were 95.6° ± 2.65° and 88.6° ± 2.58°, respectively and for the RATKA group were 97.7° ± 0.97° and 88.8° ± 1.59°, respectively. There was a statistical difference in femoral flexion angle in the RATKA group ($P$ < .01) but not for tibial angle ($P$ = .74)<br>The femoral flexion angle and tibial angle in the lateral X-ray of the conventional TKA group were 4.19° ± 3.28° and 89.7° ± 1.7°, respectively and for the RATKA group were 0.17° ± 0.65° and 85.5° ± 0.92°, respectively. There was a statistical difference in these angles ($P$ < .01) |
| Marchand et al [23] (2018 USA) | Correction of varus and valgus deformity | All 132 knees with less than 7° varus (mean 4°, range 1°-6°) were corrected to neutral (mean 1°, range −1° to 3°). Of the 129 knees with 7° varus or greater, only 82 (64%) of the cases were corrected to neutral (mean 2°, range 0°-3°). Forty-seven cases (36%) were not (mean 5°, range 4°-7°)<br>All cases with valgus deformity were corrected to neutral (mean 2°, range 0°-3°). These were all with 7° valgus or greater |
| Liow et al [24] (2014, Singapore) | Coronal plane mechanical axis | The preoperative mean lower limb mechanical axis was 9.8° ± 4.1° and the postoperative mean lower limb mechanical axis was −0.4° ± 1.7°. There is more consistent and accurate postoperative mechanical alignment which might lead to longer implant survival |
| Kayani et al [25] (2018, UK) | N/A | N/A |
| Naziri et al [26] (2019, USA) | Coronal plane mechanical axis alignment | There was no significance in postoperative alignment where it was within +3.0° of the mechanical axis for all patients in both RATKA and conventional TKA groups |
| Marchand et al [27] (2019, USA) | N/A | N/A |
| Marchand et al [28] (2017, USA) | N/A | N/A |
| Khlopas et al [29] (2019, USA) | N/A | N/A |
| Bellemans et al [30] (2007, Belgium) | Coronal plane alignment, coronal and sagittal femoral and tibial component alignment | Preoperative overall leg alignment was varus in 21 cases (range 1°-13°) and valgus in 4 cases (range 1°-8°)<br>Postoperative coronal plane alignment was within 1° of neutral alignment in all cases. Femoral component rotation was within 1° of neutral. Frontal and sagittal tibial and femoral component alignment was within 1°, as measured on long lateral films. No outliers beyond the ±1° error range were seen for any of these reported measurements |
| Liow et al [31] (2014, Singapore) | Coronal plane mechanical axis, femoral flexion and tibial slope with AP X-rays, femoral flexion and tibial slope with lateral X-rays, joint line measurements | There was no statistical difference in preoperative and postoperative coronal plane mechanical axis. Preoperatively, they were 8.8° ± 4.6° and 8.6° ± 6.3° for the RATKA and conventional TKA groups, respectively ($P$ = .892). Postoperatively, they were 1.3° ± 0.9° and 1.8° ± 1.2° for the RATKA and conventional TKA groups, respectively ($P$ = .095)<br>Femoral flexion in AP X-rays was 95.5° ± 1.3° and 97.0° ± 1.9° for the RATKA and conventional TKA groups, respectively ($P$ = .001). Femoral flexion in lateral X-rays was 2.2° ± 1.9° and 2.3° ± 2.4° for the RATKA and conventional TKA groups, respectively ($P$ = .841)<br>Tibial angle in AP X-rays were 89.7° ± 1.1° and 89.1° ± 1.8° for the RATKA and conventional TKA groups, respectively ($P$ = .179). Tibial angle in lateral X-rays were 84.9° ± 2.0° and 85.0° ± 3.5° for the RATKA and conventional TKA groups, respectively ($P$ = .893)<br>The difference in preoperative and postoperative joint line measurements were 1.9 ± 1.1 and 3.5 ± 2.8 for the RATKA and conventional TKA groups, respectively ($P$ = .010)<br>In the RATKA cohort, there were 0/31 patients where there were coronal plane MA outliers (malalignment >3°) and in the conventional TKA cohort there were 4/29 (19.4%) patients ($P$ = .049)<br>In the RATKA cohort, there were 1/31 (3.2%) patients where there were joint line shift outliers (>5 mm |

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**Table 4** (*continued* )

| Author (Year, Country) | Radiological Outcomes Measured | Radiological Outcome Conclusion |
|---|---|---|
| | | deviation) and in the conventional TKA cohort there were 6/29 (20.6%) patients ($P = .049$)<br>In the RATKA cohort, there were 0/31 patients with anterior femoral notching and in the conventional TKA cohort there were 3/29 (10.3%) patients ($P = .238$)<br>There was a difference in AP femoral flexion angle and RATKA managed to restore the joint line more accurately than conventional TKA |
| Jeon et al [32] (2019, South Korea) | Hip-knee-ankle angle, coronal and sagittal alignments of the femoral and tibial components, radiological abnormalities | Hip-knee-ankle angle was 177.5 (175-181) and 178.8 (176-182) for the RATKA and conventional TKA groups, respectively ($P = .228$). There was no statistical significance for the outliers (>3°) ($P = .172$)<br>Coronal alignment of the femoral component was 95.8 (92-100) and 94.3 (91-99) for the RATKA and conventional TKA groups, respectively ($P = .231$). There was no statistical significance for the outliers (>3°) ($P = .582$)<br>Sagittal alignment of the femoral component was 2.4 (0.2-8.9) and 3.7 (−1 to 9.7) for the RATKA and conventional TKA groups, respectively ($P = .411$). There was no statistical significance for the outliers (>3°) ($P = .179$)<br>Coronal alignment of the tibial component was 89.4 (86-92) and 88.5 (85-93) for the RATKA and conventional TKA groups, respectively ($P = .389$). There was no statistical significance for the outliers (>3°) ($P = .227$)<br>Sagittal alignment of the tibial component was 84.9 (76-90) and 85.2 (77-90) for the RATKA and conventional TKA groups, respectively ($P = .327$). There was no statistical significance for the outliers (>3°) ($P = .183$)<br>There was no difference in Hip-knee-ankle angle between the 2 groups, coronal and sagittal alignments of femoral and tibial components |
| Kim et al [33] (2016, South Korea) | Hip-knee-ankle angle, femorotibial angle, coronal and sagittal alignments of the femoral and tibial components | The hip-knee-ankle angle for varus cases was $-6.25° \pm 0.91°$ and $+0.09° \pm 0.34°$ for patients with hemophilia undergoing RATKA preoperatively and postoperatively, respectively ($P = .001$). The hip-knee-ankle angle for valgus cases was $+8.24° \pm 2.16°$ and $+0.47° \pm 0.61°$ for patients with hemophilia undergoing RATKA preoperatively and postoperatively, respectively ($P = .003$)<br>The femorotibial angle for varus cases was $-0.57° \pm 0.98°$ and $+5.28° \pm 0.29°$ for patients with hemophilia undergoing RATKA preoperatively and postoperatively, respectively ($P = .004$). The femorotibial angle for valgus cases was $+13.35° \pm 2.19°$ and $+5.69° \pm 0.73°$ for patients with hemophilia undergoing RATKA preoperatively and postoperatively, respectively ($P = .0043$)<br>There was no statistical difference in the postoperative coronal femoral angle which was 95.13 ± 1.47 ($P = .072$)<br>There was no statistical difference in the postoperative sagittal femoral angle which was 90.04 ± 1.47 ($P = .443$)<br>There was no statistical difference in the postoperative coronal tibial angle which was 1.77 ± 1.51 ($P = .868$)<br>There was no statistical difference in the postoperative sagittal tibial angle which was 87.29 ± 1.97 ($P = .130$)<br>Postoperative hip-knee-ankle angle in varus and valgus groups were corrected, and coronal and sagittal alignment of the components was satisfactory |
| Yang et al [34] (2017, South Korea) | Coronal plane mechanical axis, coronal and sagittal femoral and tibial component alignments, radiological outliers | The mechanical axis was 1.8 ± 1.5 and 2.4 ± 3.7 for the RATKA and conventional TKA groups, respectively ($P = .31$)<br>The coronal femoral inclination was 89.4 ± 2.1 and 88.4 ± 3.1 for the RATKA and conventional TKA groups, respectively ($P = .14$)<br>The coronal tibial inclination was 90.0 ± 1.3 and 90.2 ± 2.0 for the RATKA and conventional TKA groups, respectively ($P = .06$)<br>The sagittal femoral inclination was 2.0 ± 1.6 and 3.5 ± 3.1 for the RATKA and conventional TKA groups, respectively ($P = .51$)<br>The sagittal tibial inclination was 83.5 ± 1.2 and 84.5 ± 3.4 for the RATKA and conventional TKA groups, respectively ($P = .21$)<br>Mechanical axis outliers for the RATKA group was 6/69 and for the conventional TKA group was 13/39 ($P < .001$)<br>Coronal femoral inclination outliers for the RATKA group was 4/69 and for the conventional TKA group was 12/39 ($P < .001$)<br>Coronal tibia inclination outliers for the RATKA group was 1/69 and for the conventional TKA group was 4/39 ($P = .03$)<br>Sagittal femoral inclination outliers for the RATKA group was 10/69 and for the conventional TKA group was 23/39 ($P < .001$) |

| | | |
|---|---|---|
| | | Sagittal tibial inclination outliers for the RATKA group was 6/69 and for the conventional TKA group was 17/39 ($P < .001$)<br>There were fewer radiolucent lines and a reduced number of outliers in the patient group undergoing RATKA |
| Decking et al [35] (2004, Germany) | Mechanical axis, femoral and tibial plateau angle, slope and rotation of femoral and tibial components | The mean differences in preoperative and postoperative mechanical axis parameters for patients undergoing RATKA was 0.2° (−0.1° to 0.5°)<br>The mean differences in preoperative and postoperative femoral plateau angle parameters for patients undergoing RATKA was −0.2° (−0.5° to 0.2°)<br>The mean differences in preoperative and postoperative tibial plateau angle parameters for patients undergoing RATKA was 0.2° (−0.1° to 0.5°)<br>The mean differences in preoperative and postoperative slope of the femoral component parameters for patients undergoing RATKA was −0.8° (−1.2° to −0.3°)<br>The mean differences in preoperative and postoperative slope of the femoral component parameters for patients undergoing RATKA was −0.8° (−1.2° to −0.3°)<br>The mean differences in preoperative and postoperative slope of the tibial component parameters for patients undergoing RATKA was 0.0° (−0.5° to 0.5°)<br>The mean differences in preoperative and postoperative rotation of the femoral component parameters for patients undergoing RATKA was −0.3° (−0.8° to 0.2°)<br>The mean differences in preoperative and postoperative rotation of the tibial component parameters for patients undergoing RATKA was 0.3° (−0.2° to 0.7°)<br>During the postoperative period, the mechanical axis was neutral in 9 cases, 1° varus in 1 case and 1° valgus in 3 cases |
| Cho et al [36] (2019, South Korea) | Hip-knee-ankle angle, coronal and sagittal femoral and tibial component alignments, radiological outliers | The postoperative hip-knee-ankle angle was 2.1 and 2.5 for the RATKA and conventional TKA cohorts, respectively ($P = .838$)<br>The postoperative coronal inclination of the femoral component was 95.2 and 95.5 for the RATKA and conventional TKA cohorts, respectively ($P = .406$)<br>The postoperative coronal inclination of the tibial component was 89.5 and 90.1 for the RATKA and conventional TKA cohorts, respectively ($P = .475$)<br>The postoperative sagittal inclination of the femoral component was 2.1 and 5.0 for the RATKA and conventional TKA cohorts, respectively ($P < .001$)<br>The postoperative sagittal inclination of the tibial component was 84.9 and 85.5 for the RATKA and conventional TKA cohorts, respectively ($P = .11$)<br>The mechanical axis outliers were 12/113 and 37/140 for the RATKA and conventional TKA cohorts, respectively ($P = .002$)<br>The coronal femoral inclination outliers were 9/113 and 21/140 for the RATKA and conventional TKA cohorts, respectively ($P = .085$)<br>The coronal tibial inclination outliers were 8/113 and 11/140 for the RATKA and conventional TKA cohorts, respectively ($P = .816$)<br>The sagittal femoral inclination outliers were 4/113 and 46/140 for the RATKA and conventional TKA cohorts, respectively ($P < .001$)<br>The sagittal tibial inclination outliers were 6/113 and 45/140 for the RATKA and conventional TKA cohorts, respectively ($P < .001$)<br>There was a significant difference in sagittal inclination of the femur and there was statistically significantly less outliers in the RATKA |
| Kayani et al [37] (2019, UK) | Coronal plane mechanical axis, coronal and sagittal femoral and tibial component alignments, joint line measurements, posterior slope of tibial component, posterior condylar offset ratio | The postoperative mechanical alignment was 3.2° ± 1.2° and 1.5° ± 0.9° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative posterior condylar offset ratio was 0.3 ± 0.1 and 0.2 ± 0.1 for the conventional TKA and RATKA cohorts, respectively ($P > .05$)<br>The postoperative posterior tibial slope was 3.4° ± 1.1° and 1.4° ± 0.6° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative joint line measurements were 2.9° ± 1.4° and 1.0° ± 0.6° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative femoral component coronal alignment was 4.1° ± 1.1° and 1.0° ± 0.4° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative femoral component sagittal alignment was 4.2° ± 0.8° and 2.1° ± 0.7° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative tibial component coronal alignment was 3.6° ± 0.8° and 1.0° ± 0.5° for the conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>The postoperative tibial component sagittal alignment was 3.9° ± 1.0° and 2.0° ± 0.6° for the |

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**Table 4** (*continued* )

| Author (Year, Country) | Radiological Outcomes Measured | Radiological Outcome Conclusion |
|---|---|---|
| | | conventional TKA and RATKA cohorts, respectively ($P < .001$)<br>There was an improved accuracy in all radiological outcomes with RATKA compared to conventional TKA except posterior condylar offset ratio |
| Kayani et al [14] (2018, UK) | N/A | N/A |
| Song et al [38] (2013, South Korea) | Coronal plane mechanical axis alignment, flexion and extension gap balance | The postoperative mechanical axis was 0.5° ± 1.4° and 1.2° ± 2.9° for the RATKA and conventional TKA cohorts, respectively ($P = .06$)<br>The coronal inclination for the femoral component was 89.5° ± 0.7° and 88° ± 1.3° for the RATKA and conventional TKA cohorts, respectively ($P < .001$)<br>The coronal inclination for the tibial component was 90.1° ± 0.9° and 90.7° ± 1.8° for the RATKA and conventional TKA cohorts, respectively ($P = .04$)<br>The sagittal inclination for the femoral component was 1.1° ± 0.7° and 1.1° ± 1.1° for the RATKA and conventional TKA cohorts, respectively ($P = .85$)<br>The sagittal inclination for the tibial component was 85.6° ± 3.4° and 86.1° ± 4.6° for the RATKA and conventional TKA cohorts, respectively ($P = .51$)<br>The mechanical axis outliers were 0 for the RATKA group and 12 for the conventional TKA group ($P < .001$)<br>The femoral coronal inclination outliers were 0 for the RATKA group and 2 for the conventional TKA group ($P = .15$)<br>The femoral sagittal inclination outliers were 0 for the RATKA group and 2 for the conventional TKA group ($P = .15$)<br>The tibial coronal inclination outliers were 0 for the RATKA group and 3 for the conventional TKA group ($P = .08$)<br>The tibial sagittal inclination outliers were 1 for the RATKA group and 3 for the conventional TKA group ($P = .31$)<br>The extension gap was 21.4 ± 1.7 mm and 21.8 ± 1.5 mm for the RATKA and conventional TKA groups, respectively. The flexion gap was 23.5 ± 1.8 mm and 22.9 ± 2.0 mm for the RATKA and conventional TKA groups, respectively. More patients were able to achieve the flexion extension gap balance in the RATKA than the TKA ($P = .037$) |
| Liow et al [39] (2017, Singapore) | N/A | N/A |
| Song et al [40] (2011, South Korea) | Coronal plane mechanical axis, coronal and sagittal femoral and tibial component inclinations | The postoperative mechanical axis was 0.2° ± 1.6° and 1.2° ± 2.1° for the RATKA and conventional TKA cohorts, respectively ($P = .035$)<br>The coronal inclination of the femoral component was 89.2° ± 1.3° and 90.1° ± 1.7° for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>The coronal inclination of the tibial component was 90.0° ± 1.3° and 90.7° ± 1.1° for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>The sagittal inclination of the femoral component was 0.8° ± 0.8° and 1.0° ± 0.6° for the RATKA and conventional TKA cohorts, respectively ($P = .004$)<br>The sagittal inclination of the tibial component was 85.2° ± 1.4° and 85.7° ± 2.7° for the RATKA and conventional TKA cohorts, respectively ($P > .05$)<br>There is better lower limb alignment with no radiological outliers for RATKA |
| Siebert et al [41] (2002, Germany) | Mechanical axis, coronal and sagittal femoral and tibial component alignment | The mean difference between the preoperative and postoperative tibiofemoral alignment was 0.8° (0°-4.1°) in the RATKA cohort and 2.6° (0°-7°) in the conventional TKA cohort ($P < .0001$). There was less than 1° alignment to neutral in the patients who underwent RATKA |

AP, anterior posterior; RATKA, robotic-assisted total knee arthroplasty; N/A, not applicable.

| Study or Subgroup | Conventional TKA Events | Conventional TKA Total | Robotic Assisted TKA Events | Robotic Assisted TKA Total | Weight | Odds Ratio M-H, Fixed, 95% CI |
|---|---|---|---|---|---|---|
| Cho 2019 | 37 | 196 | 12 | 155 | 49.4% | 2.77 [1.39, 5.52] |
| Jeon 2019 | 10 | 79 | 8 | 84 | 30.8% | 1.38 [0.51, 3.69] |
| Liow 2014 | 4 | 29 | 0 | 31 | 1.9% | 11.12 [0.57, 216.28] |
| Naziri 2019 | 0 | 40 | 0 | 40 | | Not estimable |
| Siebert 2002 | 18 | 50 | 1 | 70 | 2.4% | 38.81 [4.96, 303.56] |
| Song 2011 | 24 | 30 | 0 | 31 | 0.5% | 237.46 [12.75, 4422.67] |
| Song 2013 | 12 | 24 | 0 | 29 | 1.0% | 59.00 [3.24, 1075.56] |
| Yang 2017 | 13 | 42 | 6 | 71 | 14.0% | 4.86 [1.68, 14.04] |
| **Total (95% CI)** | | **490** | | **511** | **100.0%** | **5.35 [3.52, 8.11]** |
| Total events | 118 | | 27 | | | |

Heterogeneity: $Chi^2 = 23.69$, df = 6 (P = 0.0006); $I^2 = 75\%$
Test for overall effect: Z = 7.88 (P < 0.00001)

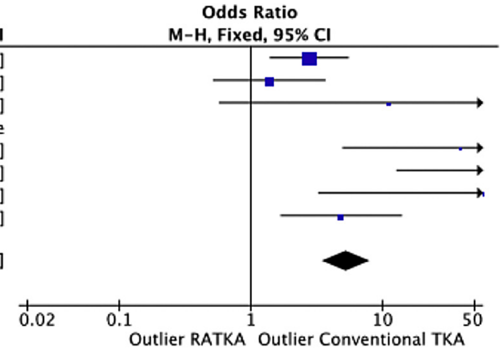


**Fig. 3.** Forest plot showing the number of patients who deviated more than 3° in the coronal mechanical axis alignment, and so were deemed as outliers.

2018 or 2019 either in USA (n = 2) [26,29] or in the UK (n = 2) [14,37]. On the other hand, 80% (n = 4) [32,34,36,38] of the studies which had follow-up times of 5 year or more were South Korean.

From the study characteristics, some trends were elucidated. The number of studies using RATKA has seen a significant increase since 2017. Most studies were from South Korea using the ROBODOC apparatus with Zimmer prostheses, and tended to have greater follow-up times. On the other hand, studies conducted in the UK or USA, using the Mako robotic system with Stryker implants, had the shortest follow-up times.

## Discussion

The use of robotics in orthopedic surgery is gaining traction. The appeal of this technology, specifically for TKA, is the potential to reduce soft tissue damage and to improve tibial and femoral bone cutting. This review has focused on the clinical and radiological outcomes which follow RATKA.

The most common clinical outcomes measured in the studies included in our review were the HSS score, KSS score, ROM, and WOMAC score. Other clinical outcome measures studied include assessments of pain and function, short form 36 (SF-36) scores, postoperative complications, and gait analysis. All studies included in our review found that knee arthroplasty improved the clinical outcomes significantly, and 12 studies found significant differences in the clinical outcomes of RATKA and conventional TKA [14,24–28,31,33,35,37,39]. Four studies showed that there was greater reduction in pain in the RATKA cohort compared to the conventional TKA cohort [14,24,27,28]. Three studies found that there was better function including ROM and walking scores in patients who underwent RATKA as well as better outcome scores [29,30,33]. Liow et al [24] and Marchand et al [28] found improved pain and function after RATKA surgery. Two studies showed that the RATKA patient cohort had better SF-36 scores [31,39]. Kayani et al [25] in 2018 and 2019 showed that patients undergoing RATKA are far less likely to have bone and soft issue injury, with significantly reduced operating times [37], pain, and length of stay [14] compared with conventional TKA. Kayani et al [37] also investigated the learning curve associated with RATKA, and determined 7 cases as the minimum threshold after which operating time and stress levels decrease. Most of these studies found that there were improvements in pain reduction and functional mobility. These are clinically significant outcomes which may improve the patient's satisfaction levels and quality of life following knee arthroplasty. Several studies determined that functional scores such as HSS, KSS, WOMAC, and SF-36 were significantly better after any TKA, but more so after RATKA [27,30,31,33,35,39]; our combined analyses show statistically significant differences in HSS and WOMAC scores with better scores in RATKA compared with conventional TKA.

Although Khlopas et al noted that pain after walking was significantly reduced in RATKA patients compared with conventional TKA, this was only at 4-6 weeks postoperatively and not at later follow-ups [29]. Nine studies found no difference in the clinical outcomes between RATKA and conventional TKA studies [21,22,26,32,34,36,38,40,41]. One of these studies did find that the length of stay was shorter for RATKA patients compared to conventional TKA [26]. Yim et al [21] compared the use of anatomical and classical alignment methods in RATKA, and found no statistical difference in ROM, HSS score, and WOMAC score between the 2 groups. The combined analyses revealed that there was no statistical significance in ROM and KSS between conventional TKA and RATKA techniques. Thus it is unclear whether the significant differences in HSS and WOMAC scores result in the clinically significant differences such as pain reduction and improved function between the 2 arthroplasty techniques.

Neutral limb alignment following knee arthroplasty theoretically result in improved function and reduced revision rates [42]. In our systematic review, we also investigated the effect RATKA has on radiological outcomes. The most common measures used were coronal plane alignment, coronal and sagittal plane alignment of femoral and tibial components, and hip-knee-ankle angles. Although 2 studies found no statistical significance in any of the radiological outcomes [26,32], the remaining studies did elucidate a statistically significant difference. The consensus of these studies was that RATKA resulted in more consistent and accurate postoperative mechanical alignment. Six studies showed that there was better postoperative mechanical alignment after RATKA, with much fewer radiological outliers [24,34,36,38,40]. Five studies found that RATKA resulted in correction of varus and valgus deformities to neutral, with some corrected within 1° of neutral [23,30,33,35,41]. Yim et al [21] found that there was better coronal inclination of the femur and tibia with RATKA. Park et al [22] found a difference between the femoral flexion and tibial angle in the lateral X-ray between RATKA and conventional TKA. Liow et al [31] found a difference between anterior-posterior femoral flexion angles and concluded that RATKA was able to restore the joint line more accurately than conventional TKA. Only 2 papers, Liow et al [31] and Yang et al [34], compared the prosthesis alignment between the RATKA and conventional TKA cohorts. Due to the small number it was deemed pooled analyses should not be conducted. Eight papers investigated the number of patients who were coronal mechanical axis alignment outliers, and combined analyses were conducted for these [26,31,32,34,36,38,40,41]. The analyses showed that in all papers there was a significantly lower outlier number in RATKA, compared to conventional TKA. This suggests that RATKA is more accurate than conventional TKA at aligning prostheses in TKA.

A study conducted by Ren et al [43] was recently published which compared clinical and radiological outcomes between

**Table 5**
Characteristics of the Studies Included in the Review (n = 22).

| Study Characteristic | Number (%) |
|---|---|
| Study design | |
| Prospective cohort study | 14 (64) |
| Retrospective cohort study | 8 (36) |
| Country of origin | |
| South Korea | 8 (36) |
| USA | 5 (23) |
| Singapore | 3 (14) |
| UK | 3 (14) |
| Germany | 2 (9) |
| Belgium | 1 (5) |
| Year published | |
| 2002 | 1 (5) |
| 2004 | 1 (5) |
| 2007 | 2 (9) |
| 2011 | 1 (5) |
| 2013 | 2 (9) |
| 2014 | 2 (9) |
| 2016 | 1 (5) |
| 2017 | 3 (14) |
| 2018 | 3 (14) |
| 2019 | 6 (27) |
| Number of patients | |
| <50 | 6 (27) |
| 50-100 | 7 (32) |
| 100-150 | 5 (23) |
| >150 | 4 (18) |
| Mean follow-up time | |
| 1 mo | 2 (9) |
| 3 mo | 2 (9) |
| 6 mo | 5 (23) |
| 1 y | 2 (9) |
| 2 y | 2 (9) |
| 3 y | 1 (5) |
| 3.9 y | 1 (5) |
| ≥5 y | 5 (23) |
| None | 2 (9) |
| Type of implant | |
| Triathlon CR system Stryker prosthesis | 5 (23) |
| Triathlon cruciate substituting knee system and asymmetrical patella resurfacing | 1 (5) |
| Triathlon posterior stabilized knee system and asymmetrical patella resurfacing | 1 (5) |
| Triathlon PS Stryker prosthesis | 1 (5) |
| NexGen LPS flex Zimmer prosthesis | 5 (23) |
| NexGen posterior CR Zimmer prosthesis | 4 (18) |
| NexGen Zimmer prosthesis | 2 (9) |
| P.F.C. Sigma DePuy prosthesis | 1 (5) |
| LC search evolution knee system | 1 (5) |
| Cemented prosthesis | 1 (5) |
| Not mentioned | 2 (9) |
| Type of robot used | |
| ROBODOC | 11 (50) |
| Mako | 6 (27) |
| CASPAR | 3 (14) |
| Not mentioned | 2 (9) |
| Outcomes measured | |
| Clinical outcomes only | 6 (27) |
| Radiological outcomes only | 1 (5) |
| Both clinical and radiological outcomes | 15 (68) |

CR, cruciate retaining; PS, posterior stabilized; LPS, legacy posterior stabilized.

conventional TKA and RATKA. This paper has added value to the literature surrounding this topic. Their paper had a narrow remit only focusing on comparative studies and RCTs, and only included 7 studies. Due to the nature of their search criteria no studies conducted after 2017 were included and hence no studies which used a mainstream robotic system, Mako. Since our study broadened the search criteria to include other studies, 22 studies were analyzed [14,21–41], and our study also included 9 studies from 2018 and 2019 comprising 41% of our studies [14,23,25–27,29,32,36,37], and included studies analyzing the Mako robotic system. Our study includes all studies analyzed in Ren et al (2019) [22,34,38–41]; however, the inclusion of the 15 other studies provides further insight into the clinical and radiological outcomes when comparing conventional TKA and RATKA.

Our review was limited by the quality of the included studies. Despite inclusion of RCTs, most studies were cohort studies which are considered level 2 evidence. Although several RCTs are currently ongoing on this topic, none provided access to data sets, and thus could not be utilized in this review. Although the gold standard would be to look at RCTs only, there were an insufficient number of completed RCTs to analyze. This may be because of the costs of robots and recruitment of patients. Thus, a compromise of inclusion of studies of various levels was included. Analyses of the quality of these studies were conducted before inclusion, however. This allowed broader view of outcomes. Another limitation was the follow-up duration that varied between studies and is a caveat that needs to be considered when interpreting Figure 2. Furthermore, there may be commercial bias in many of the studies. Ten of the studies declared a conflict of interest regarding funding or royalties. Two studies received noncommercial grants [21,34]. Yang et al [34] received a research grant from the Research Institute of Medical Sciences, Chonnam National University. Yim et al [21] received research support from the National Research Foundation. The other 8 studies received commercial funding or royalties. Song et al [38] received funding from Curexo Technology Corporation, while the other 7 studies [14,23,25–27,29,37] received money from Stryker. As a result, the results from these studies may have been influenced to favor RATKA.

## Conclusion

TKA is one of the most commonly performed operations in orthopedics. With a high demand for this surgery, which is only set to rise in the future, patient satisfaction rates must also increase. The evidence in the literature shows that RATKA results in greater improvements in WOMAC and HSS scores postoperatively compared to conventional TKA. Furthermore, RATKA results in more consistent postoperative alignment. However, despite its merits in improving alignment and clinical scores, it is unclear whether these conclusions directly result in the reduction in pain and improved functional mobility reported by several studies. Thus, it is not clear to say that RATKA is convincingly superior to conventional TKA. In addition, implications of the cost effectiveness of robots and additional training burdens need to be addressed. More level one studies, in the form of RCTs, must also be conducted in this topic before widespread implementation of this technique.

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## Appendix. Appendix 1

Databases searched:

*OVID MEDLINE: 1946 to Week 2 of July 2019*

Date of search: July 22, 2019
Date range searched: January 1946 to July 2019
Search strategy

1. exp Arthroplasty, Replacement, Knee/
2. exp Knee Prosthesis/
3. (tka or tkr).tw.
4. exp Knee Joint/
5. exp Knee/
6. knee.tw.
7. (arthroplas* or replace* or implant* or prosthes*).tw.
8. exp Joint Prosthesis/
9. exp "Prostheses and Implants"/
10. 7 or 8 or 9
11. (surf* or resurf*).tw.
12. leg bones/or exp femur/or exp pelvic bones/
13. 4 or 5 or 6 or 12
14. 10 and 13
15. 11 and 13
16. 1 or 2 or 3 or 14 or 15
17. robo.tw
18. exp Robotics/
19. exp Robotic Surgical Procedures/
20. 17 or 18 or 19
21. 16 and 20
22. knee.tw.
23. 21 and 22
24. **Limit** 23 to (english language and humans)

*EMBASE: 1974 to July 22, 2019*

Date of search: July 22, 2019
Date range searched: January 1974 to July 2019
Search strategy

1. exp knee arthroplasty/
2. exp knee prosthesis/
3. (tka or thr).tw.
4. exp knee/
5. knee.tw.
6. 4 or 5
7. (arthroplas* or replace* or implant* or prosthes*).tw.
8. exp joint prosthesis/
9. exp prosthesis/or exp implant/or exp "prostheses and orthoses"/
10. 7 or 8 or 9
11. 6 and 10
12. (surf* or resurf*).tw.
13. 6 and 10
14. 1 or 2 or 3 or 11 or 13
15. robo*.tw.
16. exp robotics/
17. exp robotic surgical device/
18. exp robot assisted surgery/
19. 15 or 16 or 17 or 18
20. 14 and 19
21. (tka or tkr or total knee*).tw.
22. 20 and 21
23. **Limit** 22 to (human and english language)

*Cochrane library: 1946 to July 2019*

Date of search: July 22, 2019
Date range searched: January 1946 to July 2019
Search strategy

#1 MeSH descriptor: [Arthroplasty, Replacement, Knee] explode all trees
#2 MeSH descriptor: [Knee Prosthesis] explode all trees
#3 tka and tkr
#4 MeSH descriptor: [Knee Joint] explode all trees
#5 MeSH descriptor: [Knee] explode all trees
#6 knee*
#7 #4 or #5
#8 #6 and #7
#9(arthroplast* or replace* or implant* or prosthes*)
#10 MeSH descriptor: [Joint Prosthesis] explode all trees
#11 MeSH descriptor: [Prostheses and Implants] explode all trees
#12 #9 or #10 or #11
#13#8 and #12
#14 (surf* or resurf*)
#15 #8 and #14
#16 #1 or #2 or #3 or #13 or #15
#17 MeSH descriptor: [Robotics] explode all trees
#18 MeSH descriptor: [Robotic Surgical Procedures] explode all trees
#19 robo*
#20 #17 or #18 or #19
#21 #16 and #20

*Web of Science: 1900 to 2019*

Date of search: July 22, 2019
Date range searched: 1900 to July 2019
Search strategy

#1: ((TS=(tka or tkr))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#2: ((TS=(knee* or "femoral head*" or "femur head*" or tibia*)) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#3: ((TS=(arthroplast* or implant* or replace* or prosthes*))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#4: ((TS=(surf* or resurf*))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#5: #4 OR #3 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#6: #5 AND #2 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#7: #6 OR #1 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#8: ((TS=(robo*))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#9: ((TS=(robotics))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#10: ((TS=(robotic surgical procedure))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#11: #8 OR #9 OR #10 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019
#12: #7 OR #11 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019

#13: #7 OR #11 Refined by: DOCUMENT TYPES: (ARTICLE OR PROCEEDINGS PAPER) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019

#14: ((TS=(tka or tkr or total knee*))) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019

#15: #13 AND #14 Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019

#16: #13 AND #14 Refined by: DOCUMENT TYPES: (ARTICLE OR PROCEEDINGS PAPER) Indexes=SCI-EXPANDED, CPCI-S Timespan=1900-2019