Efficacy and reliability of active robotic-assisted total knee arthroplasty compared with conventional total knee arthroplasty: a systematic review and meta-analysis

Yi Ren, Shiliang Cao, Jinxuan Wu, Xisheng Weng, Bin Feng

ABSTRACT

Background In the field of prosthetics, the ultimate goal is to improve the clinical outcome by using a technique that prolongs the longevity of prosthesis. Active robotic-assisted total knee arthroplasty (TKA) is one such technique that is capable of providing accurate implant position and restoring mechanical alignment. Although relevant studies have been carried out, the differences in the efficacy and reliability between active robotic-assisted TKA and conventional arthroplasty have not yet been adequately discussed.

Methods We referenced articles, including randomised controlled trials and comparative retrospective research, from PubMed, Embase, Cochrane Library and Web of Science, in order to compare active robotic-assisted TKA with the conventional technique. Data extraction and quality assessment were conducted for each study. Statistical analysis was performed using Revman V.5.3.

Results Seven studies with a total of 517 knees undergoing TKA were included. Compared with conventional surgery, active robotic TKA showed better outcomes in precise mechanical alignment (mean difference, MD: −0.82, 95% CI: −1.15 to −0.49, p < 0.05) and implant position, with lower outliers (p < 0.05), better functional score (Western Ontario and McMaster University, Knee Society Score functional score) and less drainage (MD: −293.28, 95% CI: −417.77 to −168.79, p < 0.05). No significant differences were observed when comparing the operation time, range of motion and complication rates.

Conclusion The current research demonstrates that active robotic-assisted TKA surgeries are more capable of improving mechanical alignment and prosthetic longevity.3 4

INTRODUCTION

Total knee arthroplasty (TKA) is a common and reproducible treatment for refractory knee pain induced by degenerative knee arthritis. According to the database of Healthcare Cost and Utilization Project (HCUP) and Journal of the American Medical Association, over 600 000 TKA procedures were performed by 2010, and the number is continuously increasing.5 6 This growing tendency requires a high attention to patient satisfaction and prosthetic longevity.3 4

Perioperative factors such as surgical techniques, patient symptoms and implant selection were considered to influence postoperative survival and the patients’ quality of life.5 6 Despite the advances in etiological research, prosthetic design and surgical techniques, a proportion of the patients undergoing TKA remain dissatisfied and frequently in discomfort, due to instability of the implant.7–9

Robotic-assisted surgery was designed in an attempt to prevent this issue. Robotic systems, allowing accurate handling in a limited space, have been developed across many surgical areas.10–13 There are three types of robotic system, namely autonomous (active), hands-on (semi-active) and passive. The main difference among the three systems is the level of involvement of the surgeons during the operation. This technology was developed in knee arthroplasty surgery to better assist surgeons in the precision of bone cutting, mechanical alignment restoration and implant positioning, all of which assist in prolonging the survival of the implant.5 11–16

The active orthopaedic robot, named ‘Arthrobot’, was designed for operation in 1983. In the 1990s, the first robotic total hip arthroplasty (THA) was successfully performed under the assistance of a robotic system named ‘ROBODOC’.10 17

Compared with conventional TKA, robotic-assisted surgery involves the creation of a preoperative patient-specific model and corresponding surgical plan.10 During the operation, accurate bone cutting is performed by the robotic system based on the preoperative plan. Recent evidence showed a better clinical outcome, a lower rate of complications and improved postoperative limb alignment in patients undergoing robotic surgeries.18–20 As a result, robotic-assisted surgery became the preferred surgical technique and from 2008 to 2015, the proportion of robotic procedures had increased from 16.2% to 29.2%.21

However, the efficacy and reliability of robotic-assisted TKA surgery have not yet been thoroughly studied; this has led to some concerns regarding the cost, operation time and the potential for unexpected tissue injuries.5 15 16 19 22 To date, there is only one meta-analysis in the literature regarding robotic-assisted TKA; this study demonstrated a higher accuracy in mechanical alignment restoration and lower outliers.23 However, there were no collected data for coronal or sagittal inclination, nor any documented clinical complications. Therefore, the
aim of this systematic review is to discuss and compare active robotic-assisted TKA and conventional techniques.

MATERIALS AND METHODS
The current research was conducted in reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.24

Search strategy
Existing articles from databases including PubMed, Embase, Cochrane Library and Web of Science were referenced. The research strategy included but was not limited to the following terms: ‘Arthroplasty, Replacement, Knee’ with all entry terms; ‘Robotic Surgical Procedures’ with all entry terms; and robot* and convention*. This component of the research was carried out by two different researchers. After screening titles and abstracts, unrelated articles were excluded. Final decisions regarding the inclusion of articles were determined by carefully screening the full texts of the remaining studies. If a controversy occurred, a third researcher was consulted.

Inclusion and exclusion criteria
The inclusion criteria for this review were as follows: (1) a randomised controlled trial (RCT) or non-RCT comparative study published after the year 2000; (2) the purpose of the research was to compare the efficacy and reliability of primary robotic-assisted TKA with conventional TKA and (3) the available data must include demographics and qualitative and quantitative results. Case reports, editorials and non-comparative observational studies were excluded from this meta-analysis.

Data extraction and quality assessment
Data including basic information and clinical outcomes were extracted into statistical tables by two independent researchers. Primary outcome variables included mechanical alignment, accuracy of implant position and outliers. Secondary outcome variables included functional assessment through scoring scales (Hospital for Special Surgery [HSS], Knee Society Score [KSS], Western Ontario and McMaster University [WOMAC], etc), operation time, drainage, gap balance, range of motion (ROM) and complications. (online supplementary table 1)

The levels of evidence of all collected studies were confirmed by the Oxford Centre for Evidence-Based Medicine—levels of evidence.25 Risks of bias were evaluated according to the Cochrane Collaboration and by the following criteria: random sequence generation, allocation concealment, blinding of participants, blinding of outcome assessment, incomplete outcome data, selective reporting and other biases. Each item with an evaluation of ‘Yes’, ‘No’ or ‘Unclear’ indicated a low risk of bias, high risk of bias and lack of information or unknown risk of bias, respectively. For cohort studies, the Newcastle-Ottawa Scale was applied for quality evaluation through three perspectives scaled from 1 to 9: selection, comparability and outcomes. Each article included studies was assessed by a modified Jadad scale for quality assessment, with the maximum score being 9 and the lowest being 1. Sensitivity analysis was conducted to test the robustness of the outcome by removing one cohort and then calculating the results from the remainder.

Statistical analysis
Continuous outcomes and dichotomous outcomes were calculated using the mean difference (MD) and the OR, respectively. Statistical methods for each meta-analysis item are shown in table 1.

RESULTS
After a comprehensive search process (figure 1), 384 studies were collected from the database. Through discrete screenings, seven articles, with a total of 486 patients and 517 knees, including six RCTs and one retrospective study, were included in this research.26–32 Among them, two articles27 28 were based on the same cohort with different follow-up times; this was confirmed by the original authors via email. Therefore, for the same follow-ups during the same time periods, we selected data from the latest research after discussion with the authors. Although the RCT by Song et al29 recruited a total of 100 subjects, 26 from the conventional group and 21 from the robotic-assisted group failed to follow-up. For this reason, we analysed data with the remaining 24 subjects from the conventional group and 29 from the robotic group. The demographic data and quality assessments are shown in table 2 and figure 2, respectively.

Functional assessment
In the included studies, several scores were collected including the KSS, the HSS, the WOMAC, the Oxford Knee Score (OKS) and the Short Form-36 (SF-36) Health Survey. Song et al30 31 reported a gradual improvement in both the HSS and WOMAC scores from 3 months postoperative to the final follow-up; however, none of the comparisons between the robotic and conventional approaches were shown to be significant. Hong et al36 also showed no difference in the HSS and WOMAC scores at the final follow-up. Ming et al37 provided comparisons on the KSS, OKS and SF-36; although there was no significant difference in the OKS and KSS at the
Figure 1  The flow chart of literature screening.

2-year follow-up, the outcomes of the SF-36 general health at 6 months, the SF-36 vitality and SF-36 role emotional at 2 years were better in the robotic-assisted group. The HSS, WOMAC, and KSS functional scores were included in the meta-analysis. Differences in the data were inconspicuous with regards to HSS, but significant in both the WOMAC and KSS functional scores 6 months after surgery. The results are shown in Table 3.

Radiological assessment
Mechanical alignment and outliers
In the current review, six of the included studies compared the mechanical alignment, namely the hip–knee-ankle angle, between the robotic-assisted and conventional groups. The result of the collated data favoured the robotic group with a lower mechanical angle, and a significant difference existed in the pooled analysis (Figure 3).

Table 2  Basic information of the included researches

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Study type</th>
<th>Level of evidence</th>
<th>Cases</th>
<th>Age Mean (SD)</th>
<th>Robot type</th>
<th>Follow-up (months)</th>
<th>Quality assessment score (actual/total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong et al</td>
<td>2017</td>
<td>Cohort study</td>
<td>2b</td>
<td>RA 71</td>
<td>RA 66.3 (7.5)</td>
<td>ROBODOC</td>
<td>120</td>
<td>7/9</td>
</tr>
<tr>
<td>Ming et al</td>
<td>2017</td>
<td>RCT</td>
<td>1b</td>
<td>RA 31</td>
<td>RA 67.5 (8.6)</td>
<td>ROBODOC</td>
<td>24</td>
<td>8/8</td>
</tr>
<tr>
<td>Ming et al</td>
<td>2013</td>
<td>RCT</td>
<td>1b</td>
<td>RA 31</td>
<td>RA 67.5 (8.6)</td>
<td>ROBODOC</td>
<td>6</td>
<td>7/8</td>
</tr>
<tr>
<td>Song et al</td>
<td>2013</td>
<td>RCT</td>
<td>2b</td>
<td>RA 50</td>
<td>RA 66.1 (7.1)</td>
<td>ROBODOC</td>
<td>65</td>
<td>8/8</td>
</tr>
<tr>
<td>Song et al</td>
<td>2011</td>
<td>RCT</td>
<td>1b</td>
<td>RA 30</td>
<td>RA 67.0 (6.3)</td>
<td>ROBODOC</td>
<td>16</td>
<td>8/8</td>
</tr>
<tr>
<td>Sang et al</td>
<td>2007</td>
<td>RCT</td>
<td>1b</td>
<td>RA 32</td>
<td>RA 62.7 (6.5)</td>
<td>ROBODOC</td>
<td>Not mentioned</td>
<td>6/8</td>
</tr>
<tr>
<td>Werner et al</td>
<td>2002</td>
<td>RCT</td>
<td>2b</td>
<td>RA 70</td>
<td>RA 66.0</td>
<td>CASPAR</td>
<td>Not mentioned</td>
<td>6/8</td>
</tr>
</tbody>
</table>

CA, conventional arthroplasty; CASPAR, computer-assisted surgical planning and robotics; RA, robotic-assisted arthroplasty; RCT, randomised controlled trial.
original article

Figure 2 Risk of bias summary: review authors’ judgements about each risk of bias item for each included study.

In the collated studies, a mechanical outlier was defined as a malalignment >3°; among these studies, five reported an outlier rate in both groups receiving robotic-assisted and conventional surgeries. The data were pooled and the two groups were compared; results demonstrated a significantly lower outlier rate in the robotic-assisted group (figure 4 and table 4).

Accuracy of implant position
According to the Knee Society roentgenographic evaluation system, the femoral component alignment and tibial component alignment were evaluated through four different angles measured on anteroposterior (AP) and lateral radiographs of the studied knees; these included α (on the femoral coronal plane, the angle between the femoral anatomical axis and the joint line), β (tibial coronal inclination and the optimum 90°), γ (the femoral sagittal inclination and the optimum 0°), δ (tibial sagittal inclination and the optimum 83°) according to research performed by Hong et al.26 and Song et al.30 A concise figure is shown to clearly illustrate the four angles described above (figure 5). Five of the reviewed articles contained data relating to these angles.29 28 31 However, with respect to the α angle from the coronal plane, only two studies recorded this angle in AP view. The study by Sang et al.31 demonstrated a higher α angle in the robotic-assisted group (p<0.0001), whereas in the study by Ming et al.28 the α angle in the conventional group was higher (p=0.0004). The remaining three studies evaluated the femoral coronal alignment using an angle between the joint line and the femoral mechanical axis, known as the femoral coronal inclination angle, with an optimum of 90°. Data from these three studies were eligible for pooling. In order to directly reflect the accuracy of the implant position, we subtracted the inclination angle by its optimal value to calculate the deviation from the optimum. The results showed less deviation in the robotic-assisted group, although there were no significant differences. Similarly, the values of β, γ and δ were also evaluated by the aforementioned process. To conclude, patients in the robotic-assisted group demonstrated a lower deviation value concerning all three angles, with a statistically significant difference observed in β and γ, and no significant divergence in δ.

The outliers of the femoral and tibial inclination in both the coronal and sagittal plane (a value more than 3° from the optimum) were also examined in the three previously discussed studies. Data indicated a significantly lower outlier rate in the robotic-assisted group compared with the conventional group. No heterogeneity existed in the pooled analysis. The results are shown in table 4.

Surgical aspects
Operation time
Three RCTs recorded the operation duration and were therefore analysed in the pooled result.28–30 The assessment favoured conventional TKA for a shorter duration (table 5); however, the difference between robotic-assisted and conventional surgeries was marginally significant (p=0.08). With regards to the learning curve, Siebert et al.32 reported that, over the course of a total of 70 surgeries, the time required per operation declined from nearly 220 to 90 min.

Flexion-extension gap and gap asymmetry
The flexion-extension gap was evaluated in two studies. Although the gap balance was defined differently in both studies conducted by Song et al.,29 30 the rate of the gap balance was higher in patients from the robotic-assisted group than those from the conventional group. Meanwhile, a lower mean medial-lateral gap asymmetry was also shown in the robotic-assisted group.

Table 3 Functional assessment

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Studies</th>
<th>Participants</th>
<th>RA</th>
<th>CA</th>
<th>MD (95% CI)</th>
<th>p Value</th>
<th>Heterogeneity I² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSS</td>
<td>3 (26 29 30)</td>
<td>130</td>
<td>96</td>
<td></td>
<td>0.82 (−0.85 to 2.49)</td>
<td>0.34</td>
<td>0</td>
</tr>
<tr>
<td>WOMAC</td>
<td>3 (26 29 30)</td>
<td>130</td>
<td>96</td>
<td></td>
<td>−2.01 (−4.00 to −0.01)</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>KSS functional score</td>
<td>2 (28 31)</td>
<td>63</td>
<td>59</td>
<td></td>
<td>2.30 (0.18 to 4.42)</td>
<td>0.03</td>
<td>0</td>
</tr>
</tbody>
</table>

CA, conventional arthroplasty; HSS, Hospital for Special Surgery; KSS, Knee Society Score; RA, robotic-assisted arthroplasty; WOMAC, Western Ontario and McMaster University.
Drainage

The postoperative drainage, reflecting blood loss, was presented in two articles. Results from pooled data demonstrated a lower volume of blood loss among patients receiving robotic-assisted surgery than those who underwent the conventional procedure; the difference between the two groups was statistically significant and exhibited no heterogeneity (table 5).

Range of motion

All seven studies reported the ROM, both preoperatively and postoperatively. Siebert et al demonstrated an accelerated rehabilitation of the ROM in the robotic group despite no specific quantification. The two studies by Ming et al were excluded from the data pooling because the ROM at extension and flexion was recorded independently. In this study, there was no significant difference in the ROM at flexion between the two groups in preoperative time and 6-month and 2-year follow-ups. As for the pooled data of the remaining four studies, although a lower ROM was found in the robotic-assisted group, the difference was not statistically significant (figure 6 & table 5).

Complications and revisions

The studies involved in our meta-analysis all reported relevant complications following surgery. Sang et al and Siebert et al observed complications only in the robotic-assisted group, with a rate of 18.8% and 7.7%, respectively. Song et al found no adverse events in patients undergoing either the robotic-assisted surgery or the conventional procedure. The remaining three studies were used for data pooling in three subgroups to compare the complication rates of the two experimental groups. Such complications included whole complications, surgery-related complications and infection. Among them, surgery-related complications were determined based on the Knee Society complication list associated with TKA published in 2014. However, the findings from the pooled data analysis failed to show any significant difference in the three subgroups (table 6).

We included infection for meta-analysis due to its clinical importance for surgeons. Other complications, such as deep vein thrombosis (DVT) and prosthetic instability, were excluded from the data collection because they either lacked sufficient support or were not considered as major relevant adversities. DVT was reported in the study by Ming et al with two cases in the robotic group and one case in the conventional group. Only one patient who received conventional surgery in the study by Hong et al demonstrated prosthetic instability.

Revision surgery is often required following postoperative complications such as periprosthetic joint infection or implant instability. In the study by Ming et al, one patient in the robotic-assisted group received revision surgery due to persistent lateral knee pain. Hong et al reported revision surgery in five patients, two in the robotic-assisted group and three in the conventional group. Furthermore, Kaplan-Meier survival analysis of the data generated by Hong et al concluded that there was a higher 10 year survival rate among the patients who received robotic-assisted surgeries.

Sensitivity analysis and publication bias

Sensitivity analysis was performed by sequentially removing the data array in each study. As a result, the pooled data showed no significant changes; this may suggest that the involved outcomes are relatively stable and reliable. In terms of publication bias,
To date, our research is the one of the first meta-analysis to compare the efficacy and reliability of active robotic-assisted TKA with conventional TKA. All the studies included in the meta-analysis used the autonomous system, ROBODOC, with an image-based technique as previously stated. One of the included studies was a retrospectives study, while the other six articles were RCB. In our study, only articles published after the year 2000 were included; this was due to the rapid evolution of robotic systems in the 2000s, whereby considerable improvements were made in computer-aided work patterns, preoperative planning and precise bone management with less errors. The positive findings of our research were compared with conventional TKA. Results demonstrated that robotic-assisted surgeries offer benefits in alignment correction, implant accuracy with lower outliers, less drainage after surgery and a plausibly better score in the evaluation scales. No significant differences were found regarding the operation time, ROM and the complication rate between the two methods.

One limitation of our analysis is that since various evaluation systems were adopted to measure patients’ clinical outcomes, there was insufficient data in each system, which made it difficult to organise and evaluate. The functional assessment of the WOMAC and KSS scoring system showed significantly higher scores in the robotic-assisted TKA group. The outcome of HSS also favoured the robotic group, although there was no significant difference. Further evidence is required to assess whether the patients’ quality of life can be affected by this score distinction.

One of the most important outcomes of the current research is the accurate coronal alignment restoration of the afflicted legs. To improve the clinical and functional outcomes, and therefore extend the longevity of the implant while also reducing the likelihood of prosthetic loosening, an adequate alignment technique has been explored. Mechanical alignment is recognised as the gold standard in TKA; it is achieved through perpendicular cuts with respect to the femoral and tibial mechanical axis. Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45 Yet, the definition of a safe zone of hip–knee–ankle angle has been a challenge to orthopaedists. A neutral mechanical axis.45

### Table 4 Radiological assessment

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Studies</th>
<th>Participants</th>
<th>RA</th>
<th>CA</th>
<th>MD (95% CI)</th>
<th>OR (95% CI)</th>
<th>p Value</th>
<th>Heterogeneity I² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA</td>
<td>6 (26,729-32)</td>
<td>263</td>
<td>207</td>
<td>−0.71 (−1.38 to −0.04)</td>
<td>−0.04</td>
<td>0.04</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>FCI</td>
<td>3 (26, 29, 30)</td>
<td>130</td>
<td>96</td>
<td>−0.75 (−1.17 to −0.32)</td>
<td>−0.001</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCI</td>
<td>5 (26, 28-31)</td>
<td>193</td>
<td>155</td>
<td>−0.50 (−0.83 to −0.16)</td>
<td>0.003</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FSI</td>
<td>5 (26, 28-31)</td>
<td>193</td>
<td>155</td>
<td>−1.06 (−2.10 to −0.03)</td>
<td>0.04</td>
<td>91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSI</td>
<td>5 (26, 28-31)</td>
<td>193</td>
<td>155</td>
<td>−1.32 (−3.26 to 0.61)</td>
<td>0.18</td>
<td>93</td>
<td></td>
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<tr>
<td>MA outliers</td>
<td>5 (26, 28-30, 32)</td>
<td>231</td>
<td>177</td>
<td>0.11 (0.06 to 0.19)</td>
<td>&lt;0.001</td>
<td>0</td>
<td></td>
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</tr>
<tr>
<td>FCI outliers</td>
<td>3 (26, 29, 30)</td>
<td>130</td>
<td>96</td>
<td>0.13 (0.06 to 0.30)</td>
<td>&lt;0.001</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCI outliers</td>
<td>3 (26, 29, 30)</td>
<td>130</td>
<td>96</td>
<td>0.13 (0.03 to 0.54)</td>
<td>0.005</td>
<td>0</td>
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<tr>
<td>FSI outliers</td>
<td>3 (26, 29, 30)</td>
<td>130</td>
<td>96</td>
<td>0.14 (0.06 to 0.29)</td>
<td>&lt;0.001</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSI outliers</td>
<td>3 (26, 29, 30)</td>
<td>130</td>
<td>96</td>
<td>0.14 (0.07 to 0.29)</td>
<td>&lt;0.001</td>
<td>0</td>
<td></td>
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</tr>
</tbody>
</table>

FCl, femorocoronal inclination; FSI, femor sagittal inclination; TCI, tibial coronal inclination; TSI, tibial sagittal inclination.
detected but could be reduced by eliminating the study by Siebert et al.22 and re-evaluating the remaining studies. It is important to note that the outcome with a statistical difference was unchanged by this exclusion. The factors contributing to this heterogeneity included unclear random sequence generation, allocation concealment at the beginning of the study and the application of a different robotic system (computer-assisted surgical planning and robotics) to the other studies (ROBODOC).22 The pooled data indicated a relatively higher accuracy in the robotic system compared with the manual procedure.

Precise implantation of the prosthesis is recognised as another important factor contributing to implant survival.36 42 Additionally, Kim et al confirmed the significance of prosthetic implantation alignment.36 Previous studies also suggested that posterior inclination of the tibial component influences the postoperative ROM and prosthetic stability.36 42 44 It is evident that the robotic-assisted procedure can increase the accuracy and precision of the component placement. In this meta-analysis, we found that apart from sagittal tibial inclination, the remaining three measured angles were significantly lower in the robotic-assisted group than those in the conventional group. When considering the high heterogeneity of the included studies, caution is advised when interpreting the outcomes. Through sensitivity analysis, we found that the operation time to be related to no reaming of the intramedullary canal; therefore, robotic-assisted surgery is potentially condu.
either robotic-assisted or manual surgeries. In two of the three studies, we screened surgery-related complications in order to evaluate whether the robotic system resulted in an increase in safety issues; again, neither the TKA complication rate nor the infection rate exhibited a difference in outcome. Several complications, such as instability and anterior knee pain, which may lead to a decline in patients’ quality of life, resulted in the patients receiving revision surgeries. However, relevant data are sparse in our studies with larger sample groups are necessary.

Our study has several limitations. One such limitation was the relatively small sample size of seven studies, with a total of 486 patients. With multiple statistical testing performed, the incidence of type I errors was potentially enhanced, which could influence the reliability of positive findings. Furthermore, as the robotic systems evolve with time, this can result in heterogeneity among the included studies. Among these studies, one performed bilateral TKA simultaneously with one side using the robotic technique and the other by the conventional procedure. Additionally, one non-RCT study was included in our analysis, which may have led to bias. In addition to introducing bias, the included studies may also contain statistical errors. Four of the included studies were found with allocation bias, and two with reporting bias, which may have contributed to heterogeneity. Moreover, a high heterogeneity could be detected in several of the comparisons, which, in turn, lead to a reduction in the confidence level; to avoid this influence, we conducted a sensitivity analysis. It is also important to note that several of the clinically significant events, such as blood loss and gap balance, were not thoroughly discussed due to inadequate reporting. Additional data are therefore required in order for us to discuss the two surgical methods in greater detail.

CONCLUSIONS

Active robotic-assisted TKA provides a more accurate mechanical alignment and implant position, better functional scores and lower blood loss compared with the conventional technique. There were no significant differences regarding the operation time, ROM or complication rates. Further studies are required to evaluate the long-term clinical outcomes of active robotic-assisted TKA surgeries.

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Contributors YR planned the study and wrote the manuscript. SC and YR gathered data from literatures and designed statistical analyses. JW and BF revised the manuscript. XW and BF supervised the study.

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REFERENCES


Table 6 Complication rate

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Studies</th>
<th>Participants</th>
<th>OR (95% CI)</th>
<th>p Value</th>
<th>Heterogeneity I² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole complication rate</td>
<td>3 (26, 28, 29)</td>
<td>RA: 152</td>
<td>CA: 121</td>
<td>0.83 (0.38 to 1.80)</td>
<td>0.63</td>
</tr>
<tr>
<td>Surgery-related complication rate</td>
<td>3 (26, 28, 29)</td>
<td>RA: 152</td>
<td>CA: 121</td>
<td>0.95 (0.33 to 2.70)</td>
<td>0.92</td>
</tr>
<tr>
<td>Infection rate</td>
<td>3 (26, 28, 29)</td>
<td>RA: 152</td>
<td>CA: 121</td>
<td>0.99 (0.26 to 3.78)</td>
<td>0.98</td>
</tr>
</tbody>
</table>

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