BMJ Open

Fewer complications and lower revision rates with robotic-assisted unicompartmental knee arthroplasty

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044778
Article Type:	Original research
Date Submitted by the Author:	12-Sep-2020
Complete List of Authors:	Sun, Yifeng; First Affiliated Hospital of Shandong First Medical University Liu, Wei; First Affiliated Hospital of Shandong First Medical University Hou, Jian Hu, Xiuhua; First Affiliated Hospital of Shandong First Medical University Zhang, Wenqiang; First Affiliated Hospital of Shandong First Medical University
Keywords:	Orthopaedic & trauma surgery < SURGERY, Adult surgery < SURGERY, Knee < ORTHOPAEDIC & TRAUMA SURGERY, Adult orthopaedics < ORTHOPAEDIC & TRAUMA SURGERY

Fewer complications and lower revision rates with robotic- assisted unicompartmental knee arthroplasty

A Systematic Review and Meta-Analysis

Yifeng Sun[1], Wei Liu[1], Jian Hou[2], Xiuhua Hu[1], Wenqiang Zhang[1*]

[1]Orthopaedics Department of The First Affiliated Hospital of Shandong First Medical University, Jingshi Road 16766, Jinan, Shandong 250014, PR China

[2]Jimo Traditional Chinese Hospital, Qingdao, Shandong 266200, PR China

*Correspondence and requests for materials should be addressed to Wenqiang Zhang (qfszwq@sina.com).

Abstract

Objective: We conducted a systematic review and meta-analysis of patients who had undergone UKA in order to compare complications, revision rate and non-device specific complications between robotic-assisted and conventional UKA.

Design: Systematic review and meta-analysis.

Data sources: PubMed, Embase, Web of Science, and Cochrane databases were searched up to 30 June 2020

Eligibility criteria: Case-control studies between robotic-assisted and conventional UKA

Data extraction and synthesis: Data from all eligible articles were independently extracted by two authors. We analysed the differences in outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence interval (CI) and pooled relative risk (RR]). Heterogeneity was assessed using chi-square and I-square tests. All the analyses were performed using the 'metafor' packages of the R 3.6.2 software

Results: We found that robotic-assisted UKA had less complications (RR: 0.51, 95% CI: 0.27-0.95, P=0.03) and lower revision rates (RR: 0.39, 95% CI: 0.19-0.81, P=0.01) than conventional UKA. We observed no significant differences in the non-device specific complications between two surgical techniques (RR: 0.83, 95% CI: 0.40-1.70, P=0.61). No publication bias was found in this meta-analysis.

Conclusions: We acknowledge that robotic-assisted UKA does show obviously better superiority than conventional UKA in controlling complications and revision rates.

Strengths and limitations of this study

►We conducted a meta-analysis to find the best evidence to compare the robotic-arm assisted and manual Unicompartmental Knee Arthroplasty (UKA).

►All the included research was limited to English literature, so some related published studies in other languages that might meet the inclusion criteria might have been missed.

►The comparatively modest size of the sample can unavoidably increase the risk of bias.

►Our results were unadjusted for other factors that may influence knee function outcomes such as patient age and weight, the anterior cruciate ligament, soft tissue balance, composition and thickness of the polyethylene component, and so on

Keywords: Unicompartmental knee arthroplasty; Robotic arm-assisted UKA; Conventional UKA; Meta-analysis.

Abbreviations: Unicompartmental knee arthroplasty, UKA; Robotic arm-assisted UKA, RAUKA; Conventional UKA;

Introduction

Unicompartmental knee arthroplasty (UKA) is often used for treating isolated compartmental knee osteoarthritis because of the minimally invasive approach and the bone resection needed during surgery. However, higher revision rates (10%–20%) have been reported in patients undergoing UKA than in those with total knee arthroplasty[1]. Numerous reasons may account for the higher failure rate including poor patient selection and component design, and some authors have attributed it to malpositioning[2]. The robotic systems with promising short-term radiological outcomes of the implants and precision in bone cuts during UKA has subsequently increased. Recently, approximately 15–20% of robotic-assisted UKA surgeries have been developed to improve the clinical efficacy[3]. Most scholars believed that the use of robotic-assisted UKA was associated with a significantly better component angle alignment accuracy and functional outcomes and higher satisfaction compared with conventional UKA, but the complication and revision rates in previous studies varied greatly, making it difficult to estimate safety outcomes of the two surgical techniques[4 5].

Previous meta-analyses were performed to compare the effects and safety between the robotic-assisted and conventional UKA. Fu et al. reported that the robotic-assisted system in UKA is unable to decrease adverse events[6], but Zhang et al. hold the opposite view that robotic-assisted UKA could significantly reduce complication rate[4], and the latest meta-analysis did not provide a definitive answer regarding the complications[5]. Therefore, we conducted a systematic review and meta-analysis of patients who had undergone UKA in order to compare complications, revision rate and non-device specific complications between robotic-assisted and conventional UKA.

Methods

Search strategy

We searched PubMed, Web of Science, Embase and Cochrane databases using combinations of the following keywords: ‘Unicompartmental Knee Arthroplasty’, ‘UKA’, ‘conventional UKA’, ‘traditional UKA’, ‘manual UKA’, ‘robotic-assisted UKA’, ‘complications’, ‘adverse events’ and ‘revision’ (last updated on 30 June 2020). References of identified reports were also retrieved and reviewed for other possible related studies. All studies were carefully and repeatedly evaluated. Study period, treatment information, the hospital, and any additional inclusion criteria were used to define duplicate or overlapping data.

Inclusion and exclusion criteria

Studies that met the following criteria were eligible for inclusion in this study: (1) original studies specified for unicompartmental knee arthroplasty; (2) comparison of robotic-assisted and conventional UKA; and (3) publication in English. Exclusion criteria were as follows: (1) the type of literature specified as a talk, review, digest, letter, commentary, digest or case report; (2) model-based or cadaver studies; (3) duplicate or overlapping data; and (4) not case-control studies.

Data extraction and quality assessment

Data from all the eligible articles were independently extracted by two authors, who also discussed any disagreements and arrived at a consensus. Data retrieved for each study included the first author’s name, published year, original country, methods, number of patients, Follow-up time, complications, revision rate and non-device specific complications. Two reviewers used the Modified Newcastle-Ottawa Quality Assessment Scale (NOS) to evaluate the quality of the selected studies. Studies of superior quality were assigned a score of 9 stars, high quality studies a score ⩾6 stars, moderate quality studies a score between 3 and 5 stars and low quality studies a score < 3[7].

Statistical analysis

We analysed the differences in outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence interval (CI) and pooled relative risk (RR]). Heterogeneity was assessed using chi-square and I-square tests. Fixed and random effect models were employed when there was no significant heterogeneity ($I^2 \leq 50\%$, $P>0.10$, fixed-effects model) or an obvious heterogeneity ($I^2>50\%$, $P<0.10$, random-effects model) among the included studies. Galbraith plots were used to detect the potential sources of heterogeneity[8]. Normal quantile-quantile (Q-Q) plots were used to check whether our data deviates from the confidence interval. Outlier and influence analyses were made by inspecting the plots for externally standardised residues, DFFITS values, Cook's distances, covariance ratios, estimates of τ^2 and test statistics for residual heterogeneity when each study is removed in turn, hat values and weights for each study included in the analysis[9]. Publication bias was assessed by inspection of a contour-enhanced funnel plot, with contours at the 90%, 95% and 99% confidence intervals. All the analyses were performed using the 'metafor' packages of the R 3.6.2 software[10]. A 2-tailed $p<0.05$ was considered as statistically significant.

Results

Study characteristics

We initially identified 312 studies via our search of the PubMed, Embase, Web of Science and CBM databases. Of these, 261 reports did not meet the inclusion criteria and were excluded following the review of the title and abstract. Of the 51 remaining studies that underwent a full-text review, 28 were excluded because they were not comparison trials. In addition, 8 full-text articles were excluded with the following reasons: (1) data were incomparable or incomplete and (2) have no complication results. Finally, 15 studies involving 37612 patients were included in the final meta-analysis. The study flow diagram is presented in Fig 1. Table 1 summarises the main characteristics of the 15 included studies. The quality assessment of the included studies is presented in detail in the supplementary material, and all the studies were evaluated as being of moderate-to-high quality (Table S1).

Table 1. Main characteristics of all articles included in the meta-analysis (RA-UKA: Robotic-assisted UKA; CONV-UKA: Conventional UKA)

Order	Studys	Year	Country	Design	No.keens RA-UKA	Follow-up (Month)	Complication	Revision	Function scoring system
1	Cobb *et al*[11]	2006	UK	RCT	19	4.5M	1	NULL	AKSS, WOMAC
					15		2		
2	Lonner *et al*[3]	2010	USA	PCT	31	3 M	1	NULL	NULL
					27		0		
3	Hansen *et al*[12]	2014	USA	Case control	30	24M	7	0	Recovery time First, Ambulation
					32		3	1	
4	Maccallum *et al*[13]	2016	USA	PCT	87	32.4M	3	3	NULL
					177		7	7	
5	Blyth *et al*[14]	2017	UK	RCT	64	12M	1	NULL	AKSS, AKSS
					65		1		
6	Gilmour *et al*[15]	2018	UK	RCT	58	24M	0	0	AKSS,OKS,FJS Pain VAS
					54		2	2	
7	Kayani *et al*[16]	2018	UK	PCT	60	1M	0	NULL	NULL
					60		2		
8	Batailler *et al*[17]	2018	France	Case control	80	19.7M	4	4	IKSS
					80		7	7	
9	Canetti *et al*[18]	2018	France	Retrospective cohort	11	39.3 M	0	NULL	IKSS
					17		1		
10	Banger *et al*[19]	2019	UK	RCT	74	60M	0	0	AKSS, JFS, Pain VAS, Siffness VAS,OKS
					65		6	2	
11	Wong *et al*[20]	2019	USA	Retrospective cohort	58	3M	7	7	SF-12, WOMAC, KSFS
					118		7	7	

12	**Christina *et al*[21]**	**2019**	**USA**	Retrospective comparative study	**246** **492**	**24M**	**2** **26**	**2** **26**	**NULL**
13	Kayani *et al*[22]	2019	UK	PCT	73 73	3M	0 2	NULL	Pain scores, Opiate analgesia, Straight leg raise,Knee flexion
14	Rushabh *et al*[23]	2019	USA	Retrospective comparative study	13,617 21,444	36M	125 1327	125 1327	NULL
15	Mergenthaler *et al*[24]	2020	France	Case control	200 191	24M	19 34	8 21	KSS score

Complications

All the 15 studies reported data regarding complications, which mainly included prosthetic loosening, subsidence, dislocated polyethylene bearing, periprosthetic fracture, Knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain and so on. The chi-square and I-square test results showed statistical heterogeneity among the included studies ($p<0.01$; $I^2= 73.4\%$), and Galbraith plots showed that no studies were found to cause heterogeneity (Fig. 2A). The plotted points laid close to a sloped straight line on the quantile-quantile (Q-Q) plot (Fig. 2B), which showed that there was no significant deviation from the confidence interval in our studies. Therefore, a random-effects model was used for the analysis. We found that robotic-assisted UKA had less complications than conventional UKA (RR: 0.51, 95% CI: 0.27-0.95, P=0.03; Fig. 2).

Revision rate

Nine studies reported data regarding complications that required surgery between the two groups. The chi-square and I-square test results showed statistical heterogeneity among the included studies ($p<0.01$; $I^2= 74.1\%$), and Galbraith plots were used to determine the most heterogeneous studies, but no studies were removed (Fig. 3A). As seen from the Q-Q plot, there was no significant deviation from the confidence interval in our studies (Fig. 3B). Data pooled using a random-effects model indicated that robotic-assisted UKA had lower revision rates (RR: 0.39, 95% CI: 0.19-0.81, P=0.01; Fig. 3C).

Non- device specific complications

Non-device specific complications were recorded in a total of 9 studies. The chi-square and I-square test results indicated statistical heterogeneity among the included studies ($p=0.39$; $I^2= 13.6\%$), and Galbraith plots (Fig. 4A) and quantile-quantile (Q-Q) plots (Fig. 4B) also showed that there was no statistical heterogeneity. We observed no significant differences in the Non-device specific complications between the 2 groups by using a fixed-effects model (RR: 0.83, 95% CI: 0.40-1.70, P=0.61; Fig. 4C).

Publication bias

We assessed publication bias using Begg's test[25]. The contour-enhanced funnel plot for the meta-analysis of the complications for robotic-assisted versus conventional UKA was largely symmetric ($P_{Begg}=0.94$; Fig. 5A). Similar results were observed for the revision rate ($P_{Begg}=0.98$; Fig. 5B) and non-device specific complications ($P_{Begg}=0.32$; Fig. 5C).

Outlier and influence analyses

The presence of outliers and influential cases may affect the validity and robustness of the conclusions from a meta-analysis. Figure 5 shows the standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ^2 (tau2.del) and test statistics (QE.del) for this random-effects model that was used for the analysis of the complications (Fig. 6). Study 14 (Rushabh,2019) was identified as a potential outlier, and also appeared to be an influential case. Due to the fact that the study had as advantages the large sample size (35,061 patients, Robot =13,617; CONV =21,444), which makes it suitable to study national trends, and that the hat values and weights values showed that this study occupied the largest proportion in the meta-analysis, this study was not be removed, but the outlier was included in the meta-analysis. This is also the case in the analysis of the revision rate. No outlier was included in the analysis of Non-device specific complications.

Discussion

For over fifty years, unicompartmental knee arthroplasty (UKA) has been used to treat isolated compartmental knee arthritis. Despite the many years of experience performing UKA, Some literatures still reported that UKA has higher failure rates compared to total knee arthroplasty (TKA)[26].Complications that lead to failure can occur following UKA including bearing dislocation, aseptic loosening, polyethylene wear, periprosthetic fracture, progression of the arthritis to the contralateral compartment, infection, bone-implant impingement, retaining of cement debris in the joint, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain and other adverse events [27-29]. Newly designed robotic-assisted systems are believed to increase the precision and accuracy with which unicompartmental knee arthroplasty can be performed, possibly leading to fewer complications and lower revision rates[30]. Many publications have studied the complications of robotic-assisted UKA, but few are comparative studies on the complications of robotic-assisted UKA compared to conventional UKA. However, researchers have reported conflicting results regarding the complication rate between robotic-assisted and conventional UKA. Hansen et al. [13] and Blyth et al. [4] did not find a significant difference in terms of complications between robotic-assisted UKA and conventional UKA. Wong et al.[20] found that the RAA cohort had a higher early revision rate than the CONV group, while others hold the view that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA. It is important to assess the complications of this new technology before its widespread use[21]. Therefore, we conducted a systematic review and meta-analysis to compare the complication rates, revision rate and non-device specific complications between robotic-assisted and conventional UKA. The main finding of our meta-analysis is that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA, but no significant differences in the non-device specific complications. Thus, we acknowledge that robotic-assisted UKA does show obviously better superiority than conventional UKA in controlling complications and revision rates.

Many publications have explored the relationship between the component position and its impact on implant survival and patient satisfaction[31 32]. Some authors believe that a reduction in the alignment errors of these component will ultimately have an impact on implant function or survival. Some studies confirmed that the proportion of patients with tibial and femoral component implantation within 2° of the target position was significantly greater in the group that underwent robotic-assisted UKA, resulting in better long-term clinical scores and a lower implant failure rate[13 33 34]. Therefore, it could be shown that the use of robotic-assisted system in UKA is able to reduce the implantation errors, which may be the reason why robotic-assisted UKA had fewer complications and lower revision rates than conventional UKA.

Non- device specific complications were recorded in a total of 9 studies, which mainly included infection, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain in our meta-analysis. While these adverse events are likely to be related to the procedure, fewer were considered to be directly related to the comparative study itself[11]. Mergenthaler reported that there was no complication due to the use of the robotic system[24]. Andrew believes that no further rigid fixation device is necessary, which reduces potential complications such as infection, iatrogenic fractures, or soft tissue injury, because of the robot's weight and movement[35]. However, there were no significant differences in the non- device specific complications in our meta-analysis. Therefore, no evidence suggested that the use of robotic-assisted UKA may add the non-device specific complications to this procedure.

There are several limitations to this meta-analysis. Firstly, there is a possibility of publication bias. All the included studies were limited to the English literature; therefore, some related published studies in other languages that might have met the inclusion criteria might have been missed.

Besides, we tried to identify and retrieve all additional unpublished information, but some missing data were inevitable. In addition, our results were unadjusted for other factors that may influence complication outcomes such as patient age and weight, the anterior cruciate ligament, soft tissue balance, composition and thickness of the polyethylene component and so on. Finally, given that there is no acknowledged functional scoring system for measuring postoperative function and due to the limited number of exact P-values, we did not evaluate the functional outcome in our meta-analysis (Table 1). Therefore, it is necessary to establish a universal system for assessing the postoperative function in patients with UKA.

Conclusions

In summary, data from this meta-analysis indicate that robotic-assisted UKA is associated with fewer complications and lower revision rates than conventional UKA. No evidence suggested that the use of robotic-assisted UKA may add the non-device specific complications to this procedure. Therefore, robotic-assisted UKA does have obviously better survivorship than conventional UKA. More large-scale studies aimed at establishing a universal standard for evaluating the efficacy of both treatments in this patient population are needed in the future.

Acknowledgments

We gratefully appreciate Shandong First Medical University for providing the statistical and technical assistance. Yi-Feng Sun conceived the study and wrote the manuscript, Wen-Qiang Zang analyzed the data, and Wei Liu generated data. All authors reviewed the manuscript.

Funding sources

This work was supported by the Natural Science Foundation of China (81702667) and Wu Jieping Medical Foundation (320.6750.18466), and Shandong Provincial Key Research and Development Project (GG201809250496).

Declaration of interest

The authors declare they have no conflict of interest.

References

1. outcome And Reproducibility Of Data Concerning The Oxford Medial Unicompartmental Knee Arthroplasty. Orthopaedic Proceedings; 2011. The British Editorial Society of Bone & Joint Surgery.

2. Lang J, Mannava S, Floyd A, et al. Robotic systems in orthopaedic surgery. *The Journal of bone and joint surgery British volume* 2011;93(10):1296-99.

3. Lonner JH, Moretti VM. The Evolution of Image-Free Robotic Assistance in Unicompartmental Knee Arthroplasty. *American journal of orthopedics* 2016;45(4):249-54.

4. Zhang F, Li H, Ba Z, et al. Robotic arm-assisted vs conventional unicompartmental knee arthroplasty: A meta-analysis of the effects on clinical outcomes. *Medicine* 2019;98(35)

5. Chin BZ, Tan SSH, Chua KCX, et al. Robot-Assisted versus Conventional Total and Unicompartmental Knee Arthroplasty: A Meta-analysis of Radiological and Functional Outcomes. *Journal of Knee Surgery* 2020

6. Fu J, Wang Y, Li X, et al. Robot-assisted vs. conventional unicompartmental knee arthroplasty : Systematic review and meta-analysis. *Orthopade* 2018;47(12):1009-17.

7. Zhang W, Sun J, Liu C, et al. Comparing the Intramedullary Nail and Extramedullary Fixation in Treatment of Unstable Intertrochanteric Fractures. *Scientific Reports* 2018;8(1):2321-21.

8. Galbraith RF. Some Applications of Radial Plots. *Journal of the American Statistical Association* 1994;89(428):1232-42.

9. Viechtbauer W, Cheung MWL. Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods* 2010;1(2):112-25.

10. Viechtbauer W. Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software* 2010;36(3):1-48.

11. Cobb J, Henckel J, Gomes P, et al. Hands-on robotic unicompartmental knee replacement - A prospective, randomised controlled study of the Acrobot system. *Journal of Bone and Joint Surgery-british Volume* 2006;88(2):188-97.

12. Hansen DC, Kusuma SK, Palmer RM, et al. Robotic Guidance Does Not Improve Component Position or Short-Term Outcome in Medial Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2014;29(9):1784-89.

13. Maccallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic-assisted and conventional unicompartmental knee arthroplasty. *European Journal of Orthopaedic Surgery and Traumatology* 2016;26(1):93-98.

14. Blyth M, Anthony I, Rowe P, et al. Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. *Bone and Joint Research* 2017;6(11):631-39.

15. Gilmour A, Maclean A, Rowe P, et al. Robotic-Arm Assisted Versus Conventional Unicompartmental Knee Arthroplasty. The 2 year Clinical outcomes of a Randomised Controlled Trial. *Journal of Arthroplasty* 2018:S0883540318301980.

16. Kayani, Konan, T JR, et al. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty. *Bone & Joint Journal* 2018

17. Batailler C, White N, Ranaldi FM, et al. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2019;27(4):1232-40. doi: 10.1007/s00167-018-5081-5 [published Online First: 2018/08/02]

18. Canetti R, Batailler C, Bankhead C, et al. Faster return to sport after robotic-assisted lateral unicompartmental knee arthroplasty: a comparative study. *Archives of Orthopaedic and Trauma Surgery* 2018;138(12):1765-71.

19. Banger M, Blyth M, Jones B, et al. 5 Year Results Of A Randomised Trial Of Robotic Arm Assisted Vs

Manual Unicompartmental Knee Arthoplasty.

20. Wong J, Murtaugh T, Lakra A, et al. Robotic-assisted unicompartmental knee replacement offers no early advantage over conventional unicompartmental knee replacement. *Knee Surgery, Sports Traumatology, Arthroscopy* 2019;27(7):2303-08.
21. Cool CL, Needham K, Khlopas A, et al. Revision Analysis of Robotic Arm–Assisted and Manual Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2019;34(5):926-31.
22. Kayani B, Konan S, Tahmassebi J, et al. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty. *Journal of Bone and Joint Surgery-british Volume* 2019(1):24-33.
23. Citak M, Suero EM, Citak M, et al. Unicompartmental knee arthroplasty: is robotic technology more accurate than conventional technique? *Knee* 2013;20(4):268-71.
24. Mergenthaler G, Batailler C, Lording T, et al. Is robotic-assisted unicompartmental knee arthroplasty a safe procedure? A case control study. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2020 doi: 10.1007/s00167-020-06051-z [published Online First: 2020/05/12]
25. Macaskill P, Walter SD, Irwig L. A comparison of methods to detect publication bias in meta ‐ analysis. *Statistics in medicine* 2001;20(4):641-54.
26. Sun X, Su Z. A meta-analysis of unicompartmental knee arthroplasty revised to total knee arthroplasty versus primary total knee arthroplasty. *Journal of Orthopaedic Surgery and Research* 2018;13(1):158.
27. Epinette JA, Brunschweiler B, Mertl P, et al. Unicompartmental knee arthroplasty modes of failure: Wear is not the main reason for failure: A multicentre study of 418 failed knees. *Orthopaedics & Traumatology-surgery & Research* 2012;98(6)
28. Kim KT, Lee S, Lee JI, et al. Analysis and Treatment of Complications after Unicompartmental Knee Arthroplasty. *Knee Surgery and Related Research* 2016;28(1):46-54.
29. Qidon Z. Analysis of early and mid-term complications in unicompartmental knee arthroplasty. *Chinese Journal of Joint Surgery* 2013
30. Roche MW. Robotic-assisted unicompartmental knee arthroplasty: the MAKO experience. *Clinics in Sports Medicine* 2014;33(1):123-32.
31. Gromov K, Korchi M, Thomsen MG, et al. What is the optimal alignment of the tibial and femoral components in knee arthroplasty? An overview of the literature. *Acta orthopaedica* 2014;85(5):480-87.
32. Vandekerckhove P-J, Lanting B, Bellemans J, et al. The current role of coronal plane alignment in total knee arthroplasty in a preoperative varus aligned population: an evidence based review. *Acta Orthop Belg* 2016;82(1):129-42.
33. Gromov K, Korchi M, Thomsen MG, et al. What is the optimal alignment of the tibial and femoral components in knee arthroplasty. *Acta Orthopaedica* 2014;85(5):480-87.
34. Chatellard R, Sauleau V, Colmar M, et al. Medial unicompartmental knee arthroplasty: Does tibial component position influence clinical outcomes and arthroplasty survival? *Orthopaedics & Traumatology-surgery & Research* 2013;99(4)
35. Pearle AD, Oloughlin PF, Kendoff D. Robot-Assisted Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2010;25(2):230-37.

Figure legends

Figure 1. Flow diagram depicting the study selection procedure.

Figure 2. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 3. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 4. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of non-device specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-device specific complications (C).

Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of $\tau2$ (tau2.del) and test statistics (QE.del) for this random-effects model that was used for the analysis of the complications.

Table

Table 1. Main characteristics of all articles included in the meta-analysis

Table S1. Assessment of the studies' qualities using the Newcastle-Ottawa Scale.

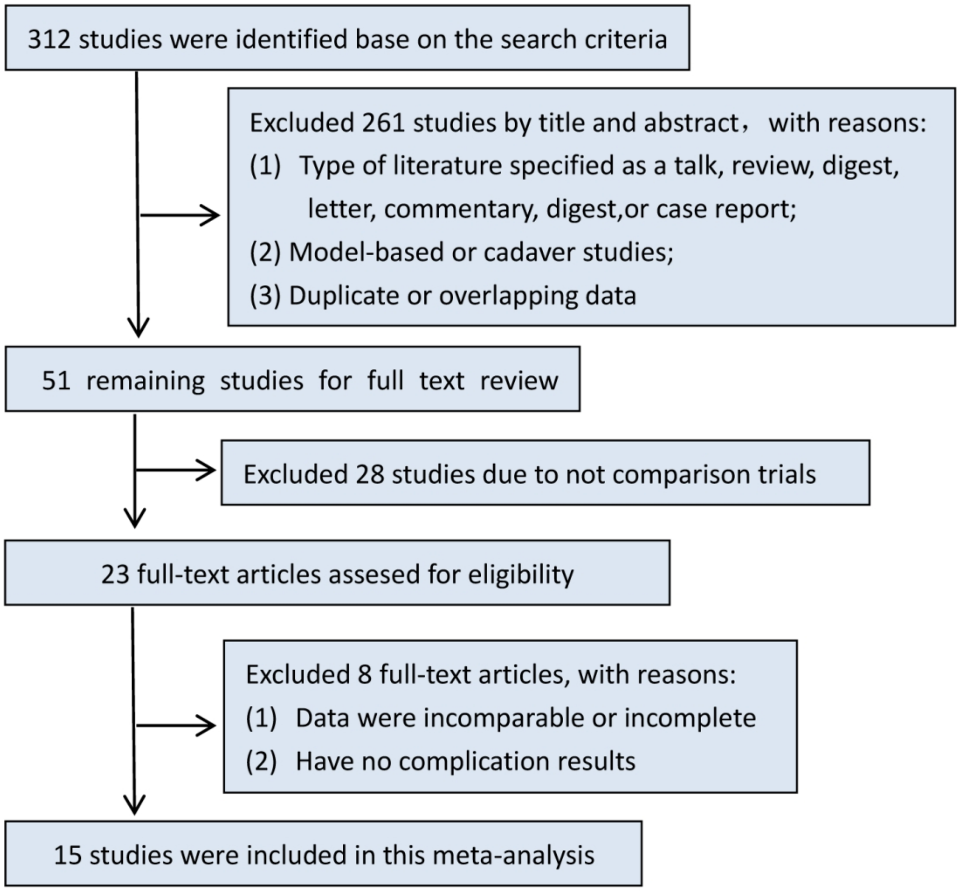


Figure 1. Flow diagram depicting the study selection procedure.

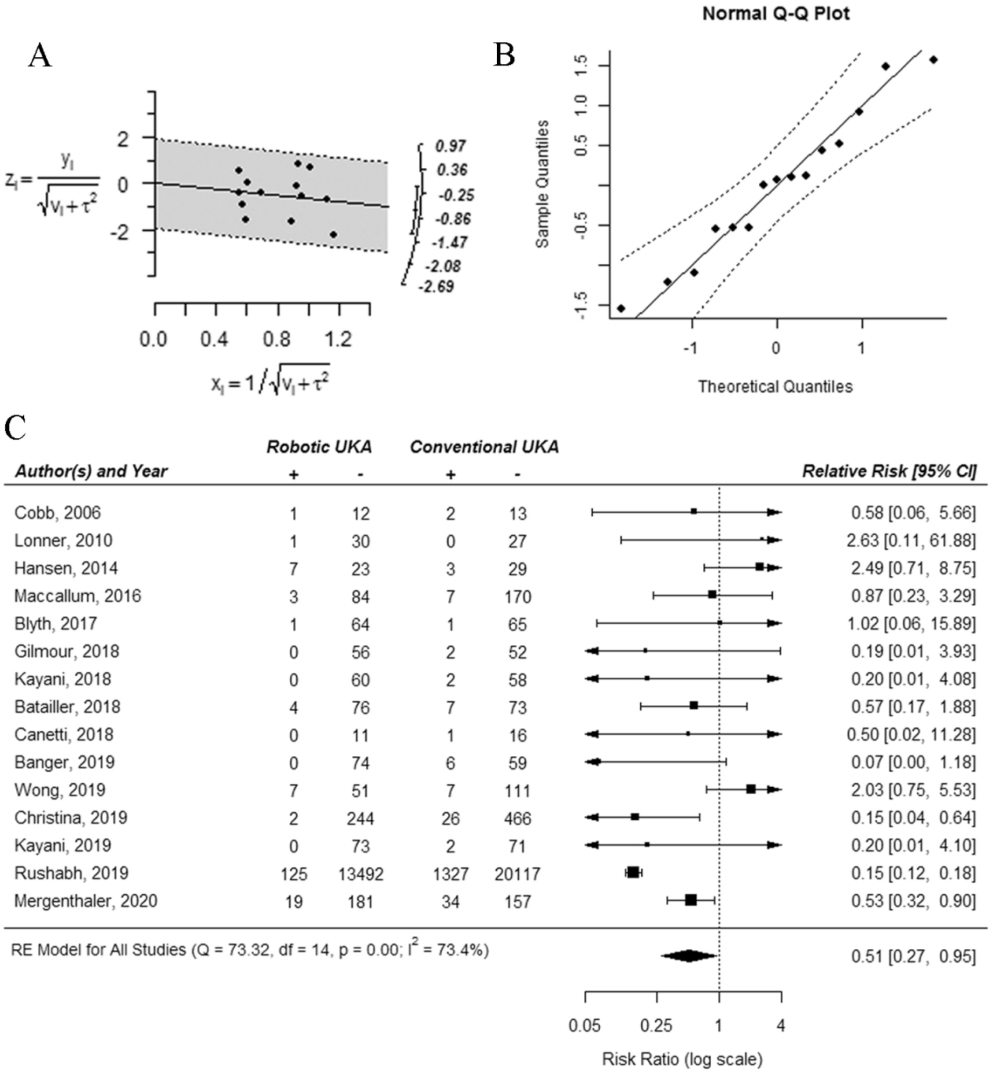
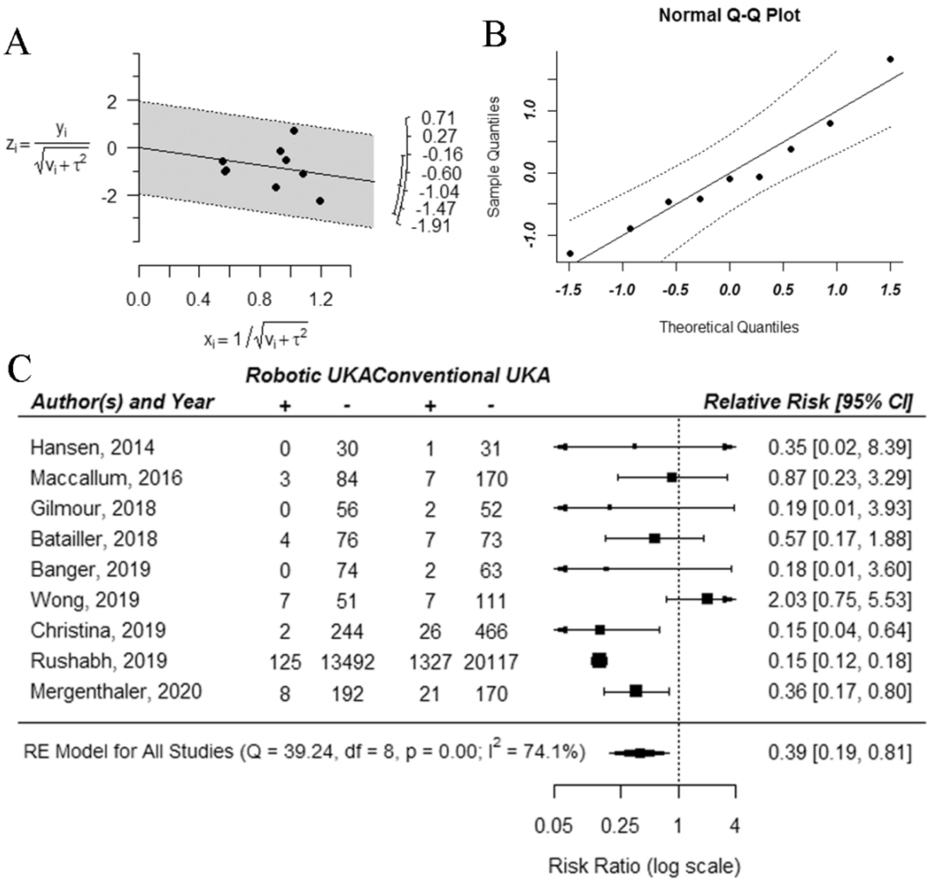


Figure 2. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.



Author(s) and Year	Robotic UKA +	Robotic UKA -	Conventional UKA +	Conventional UKA -	Relative Risk [95% CI]
Hansen, 2014	0	30	1	31	0.35 [0.02, 8.39]
Maccallum, 2016	3	84	7	170	0.87 [0.23, 3.29]
Gilmour, 2018	0	56	2	52	0.19 [0.01, 3.93]
Batailler, 2018	4	76	7	73	0.57 [0.17, 1.88]
Banger, 2019	0	74	2	63	0.18 [0.01, 3.60]
Wong, 2019	7	51	7	111	2.03 [0.75, 5.53]
Christina, 2019	2	244	26	466	0.15 [0.04, 0.64]
Rushabh, 2019	125	13492	1327	20117	0.15 [0.12, 0.18]
Mergenthaler, 2020	8	192	21	170	0.36 [0.17, 0.80]
RE Model for All Studies ($Q = 39.24$, $df = 8$, $p = 0.00$; $I^2 = 74.1\%$)					0.39 [0.19, 0.81]

Figure 3. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

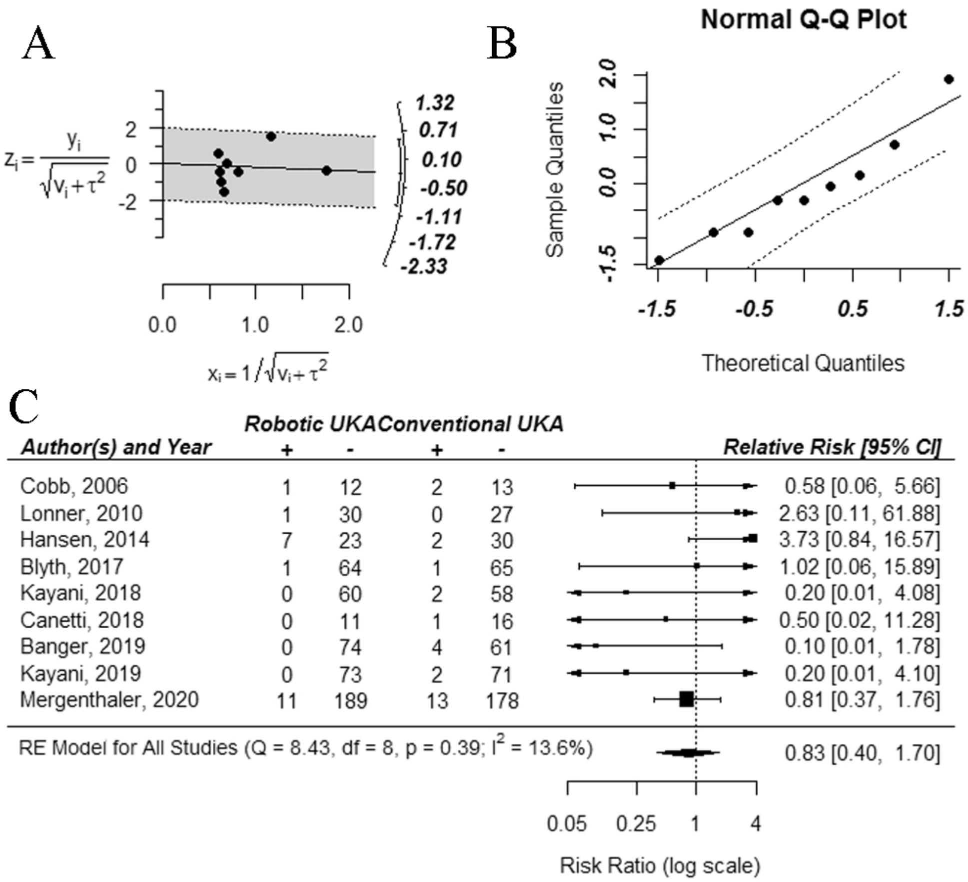


Figure 4. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of non-device specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

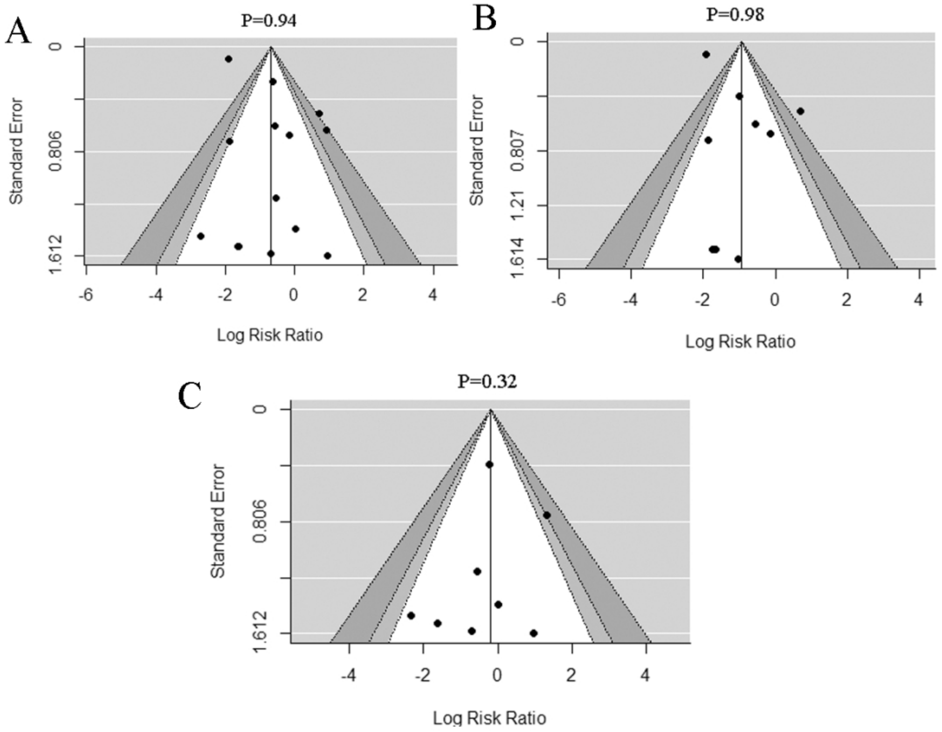


Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-device specific complications (C).

110x85mm (300 x 300 DPI)

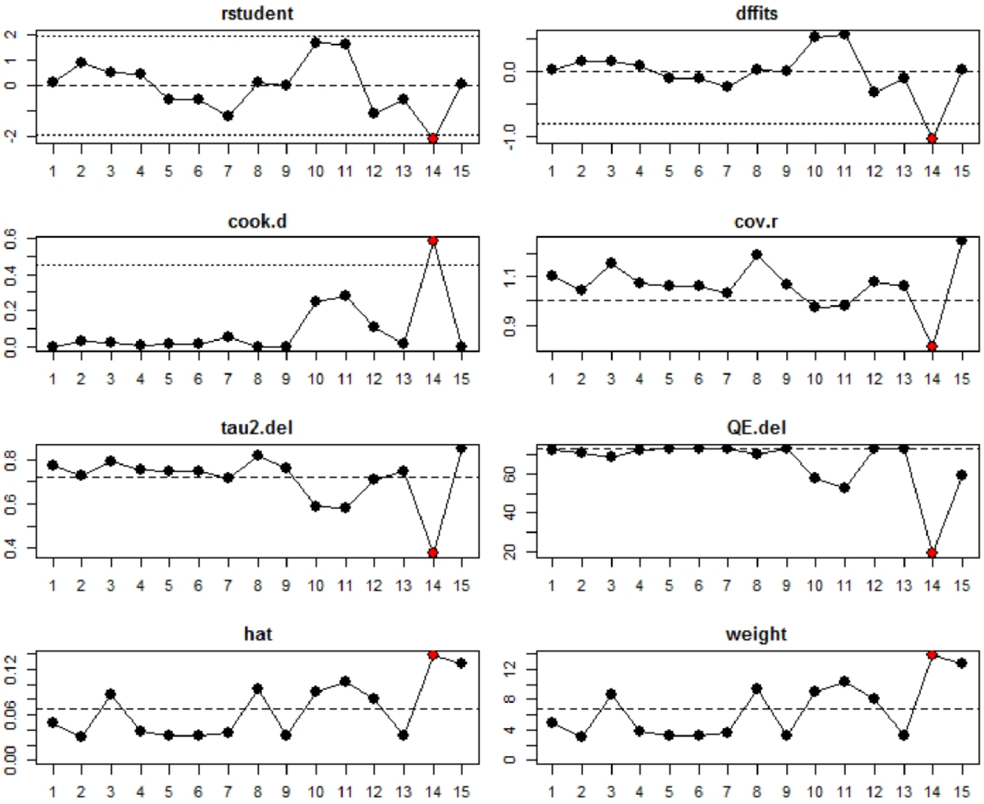


Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ2 (tau2.del) and test statistics (QE.del) for this random-effects model that was used for the analysis of the complications.

187x154mm (300 x 300 DPI)

Table S1. Assessment of the studies' qualities using the Newcastle-Ottawa Scale.

Order	Studys	Year	Country	Selection	Comparability	Exposure	Quality Score
2	Cobb *et al*	2006	UK	★★★★	★★	★★	★★★★★★★★
3	Lonner *et al*	2010	USA	★★★	★★	★	★★★★★★
15	Hansenet al	2014	USA	★★★	★	★	★★★★★
6	Maccallum *et al*	2016	USA	★★★	★★	★	★★★★★★
7	Blyth *et al*	2017	UK	★★★★	★★	★★	★★★★★★★★
8	Gilmour *et al*	2018	UK	★★★★	★★	★★	★★★★★★★★
11	Kayani *et al*	2018	UK	★★★	★★	★	★★★★★
13	Batailler *et al*	2018	France	★★★	★	★	★★★★★
14	Canetti *et al*	2018	France	★★★	★	★	★★★★★
12	Banger *et al*	2019	UK	★★	★★	★★	★★★★★★
17	Wong *et al*	2019	USA	★★★	★	★	★★★★★
19	Christina *et al*	2019	USA	★★★	★	★	★★★★★
20	Kayani *et al*	2019	UK	★★★	★★	★	★★★★★★
21	Rushabh *et al*	2019	USA	★★★	★	★	★★★★★
23	Mergenthaler *et al*	2020	France	★★★	★	★	★★★★★

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE		**Fewer complications and lower revision rates with robotic- assisted unicompartmental knee arthroplasty** A Systematic Review and Meta-Analysis	1
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Not exist
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3-4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	3
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	4
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	4
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	4

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	4
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Not done
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	5
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	5
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	8
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	9
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	9-10
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	10-11
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	11
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	11

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.

BMJ Open

Does robotic- assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A Systematic Review and Meta-Analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044778.R1
Article Type:	Original research
Date Submitted by the Author:	05-May-2021
Complete List of Authors:	Sun, Yifeng; First Affiliated Hospital of Shandong First Medical University Liu, Wei; First Affiliated Hospital of Shandong First Medical University Hou, Jian Hu, Xiuhua; First Affiliated Hospital of Shandong First Medical University Zhang, Wenqiang; First Affiliated Hospital of Shandong First Medical University
Primary Subject Heading:	Surgery
Secondary Subject Heading:	Surgery
Keywords:	Orthopaedic & trauma surgery < SURGERY, Adult surgery < SURGERY, Knee < ORTHOPAEDIC & TRAUMA SURGERY, Adult orthopaedics < ORTHOPAEDIC & TRAUMA SURGERY

Does robotic- assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A Systematic Review and Meta-Analysis

Yifeng Sun[1], Wei Liu[1], Jian Hou[2], Xiuhua Hu[1], Wenqiang Zhang[1*]

[1] Department of Orthopedic Surgery, The First Affiliated Hospital of Shandong First Medical University &Shandong Provincial Qianfoshan Hospital, Shandong Key Laboratory of Rheumatic Disease and Translational Medicine

[2]Jimo Traditional Chinese Hospital, Qingdao, Shandong 266200, PR China

*Correspondence and requests for materials should be addressed to Wenqiang Zhang (qfszwq@sina.com).

Abstract

Objective: We conducted a systematic review and meta-analysis of studies on patients who underwent unicompartmental knee arthroplasty (UKA) and compared the complications, revision rate, and non-implant specific complications between robotic-assisted and conventional UKA.

Design: Systematic review and meta-analysis.

Data sources: PubMed, Embase, Web of Science, and Cochrane databases were searched up to 30 June 2020

Eligibility criteria: Case-control studies comparing robotic-assisted and conventional UKA

Data extraction and synthesis: Data from all eligible articles were independently extracted by two authors. We analysed the differences in the outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence interval (CI) and pooled relative risk (RR]). Heterogeneity was assessed using the chi-square and I-square tests. All the analyses were performed using the 'metafor' package of the R 3.6.2 software.

Results: In all, 16 studies involving 50024 patients were included in the final meta-analysis. We found that robotic-assisted UKA had fewer complications (RR: 0.52, 95% CI: 0.28-0.96, P=0.036) and lower revision rates (RR: 0.42, 95% CI: 0.20-0.86, P=0.017) than conventional UKA. We observed no significant differences in the non-implant specific complications between the two surgical techniques (RR: 0.80, 95% CI: 0.61-1.04, P=0.96). No publication bias was found in this meta-analysis.

Conclusions: This study showed that robotic-assisted UKA had fewer complications and lower revision rates than the conventional procedure. More large-scale RCT studies with a longer follow-up duration for evaluating the efficacy of both treatments in this patient population are necessary in the future.

Strengths and limitations of this study

► We conducted a meta-analysis to find the best evidence to compare the robotic-arm assisted and manual unicompartmental knee arthroplasty (UKA).

► Long-term revision rates depend on the year of follow up; however, all the included studies had short-term follow up (3 months to 60 months). Hence, the results of revision rates are questionable.

► some studies were not RCTs and had small sample sizes, which increases the possibility of publication bias

►The relatively modest sample size might have led to an unavoidable risk of bias.

►Our results were unadjusted for other factors that might influence the outcomes related to knee function such as patient age and weight, the anterior cruciate ligament, soft tissue balance, composition and thickness of the polyethylene component, etc.

Keywords: Unicompartmental knee arthroplasty; Robotic arm-assisted UKA; Conventional UKA; Meta-analysis.

Abbreviations: Unicompartmental knee arthroplasty, UKA; Robotic arm-assisted UKA, RAUKA; Conventional UKA;

Introduction

Unicompartmental knee arthroplasty (UKA) is often performed for treating isolated compartmental knee osteoarthritis due to its minimally invasive approach and for bone resection required during surgery. However, higher rates of revision surgery (10%–20%) have been reported in patients undergoing UKA than in those undergoing total knee arthroplasty[1]. There might be multiple reasons for the higher failure rate, including poor patient selection and component design; some authors have also attributed it to malpositioning[2]. The use of robotic systems with promising short-term radiological outcomes of the implants and precision in bone cuts during UKA has significantly increased. In recent times, approximately 15–20% of robotic-assisted UKA surgeries have been developed to improve the clinical efficacy[3]. Most experts believe that the use of robotic-assisted UKA shows significantly better component angle alignment accuracy and functional outcomes, and higher satisfaction than that of conventional UKA. However, there is a considerable variation between the complication and revision rates reported in previous studies, which has made it difficult to estimate the safety outcomes of the two surgical techniques[4, 5].

The previous meta-analyses compared the effects and safety of the robotic-assisted and conventional UKA. In a meta-analysis by Fu et al. it was reported that the robotic-assisted system in UKA showed no decrease in the rate of adverse events compared to the conventional UKA. However, few articles (only 7 studies) were included in the meta-analysis, and the difference in the revision rates between the two techniques was not compared[6]. Another meta-analysis by Zhang et al. contradicted the conclusion about the adverse events by Fu et al. and reported that robotic-assisted UKA could significantly reduce the rate of complications; however, the results were also subject to the sample size and follow-up duration, which might influence the assessment of the difference in outcomes between robotic-assisted and conventional UKA[4]. Another recent latest meta-analysis did not reach a definitive conclusion regarding the complications[5]. Therefore, we conducted a systematic review and meta-analysis of studies with patients who underwent UKA to compare the rate of complications, revision rate, and non-implant specific complications between robotic-assisted and conventional UKA. Our hypothesis was that there would be no obvious differences in the complications and revision rates between the two groups.

Methods

Search strategy

We searched PubMed, Web of Science, Embase, and Cochrane databases using combinations of the following keywords: 'Unicompartmental Knee Arthroplasty', 'UKA', 'conventional UKA', 'traditional UKA', 'manual UKA', 'robotic-assisted UKA', 'non-robotically assisted UKA', 'complications', 'adverse events', and 'revision' (last updated on 30 June 2020). References of the identified reports were also retrieved and reviewed for other related studies. All studies were carefully and repeatedly evaluated. The study period, treatment information, the hospital, and any additional inclusion criteria were used to define duplicate or overlapping data.

Inclusion and exclusion criteria

Studies that met the following criteria were eligible for inclusion in this study: (1) original studies about unicompartmental knee arthroplasty; (2) comparison of robotic-assisted and conventional UKA; and (3) providing controls and effective data (included RCT, PCT, CC, Retrospective comparative study); (4) publication in English. Exclusion criteria were as follows: (1) literatures published as a talk, review, digest, letter, commentary, digest or case report; (2) model-based or cadaver studies; (3) duplicate or overlapping data; and (4) not case-control studies.

Data extraction and quality assessment

Data from all the eligible articles were independently extracted by two authors, who also discussed any disagreements and arrived at a consensus. Data retrieved from each study included the first author's name, year of publication, country, methods, number of patients, follow-up duration, complications, revision rate, and non-implant specific complications. Three experienced reviewers used the Modified Newcastle-Ottawa Quality Assessment Scale (NOS) to evaluate the quality of the selected studies. Studies of superior quality were assigned a score of 9, high quality studies a score ⩾6, moderate quality studies a score between 3 and 5, and low-quality studies a score <3[7].

Statistical analysis

We analysed the differences in outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence interval (CI) and pooled relative risk (RR]). Heterogeneity was assessed using the chi-square and I-square tests. Fixed effect models were employed when there was no significant heterogeneity ($I^2 \leq 50\%$, $P>0.10$); else, a random-effects model was used to obtain the pooled effects among the included studies. Galbraith plots were used to detect the potential sources of heterogeneity[8]. Normal quantile-quantile (Q-Q) plots were used to check for the deviation of the data from the confidence interval. Outlier and influence analyses were performed by inspecting the plots for externally standardised residues, DFFITS values, Cook's distances, covariance ratios, estimates of τ^2, and test statistics for residual heterogeneity when each study is excluded in turn, hat values, and weights for each study included in the analysis[9]. Publication bias was assessed by inspection of a contour-enhanced funnel plot, with contours at 90%, 95%, and 99% confidence intervals. All the analyses were performed using the 'metafor' packages of the R 3.6.2 software[10]. A 2-tailed $P<0.05$ was considered statistically significant.

Patient and public involvement

There was no patient and public involvement in this systematic review.

Results

Study characteristics

We initially identified 374 studies through our search of the PubMed, Embase, Web of Science, and CBM databases. Of these, 322 did not meet the inclusion criteria and were excluded following the review of the title and abstract. Of the 52 remaining studies that underwent a full-text review, 28 were excluded because they were not comparative trials. In addition, 8 full-text articles were excluded due to the following reasons: (1) data were incomparable or incomplete, and (2) data about the complications were not available. Finally, 16 studies involving 50,024 patients were included in the final meta-analysis. The study flow diagram is presented in Figure 1. Table 1 summarises the main characteristics of the 16 included studies. The quality assessment of the included studies is presented in detail in the supplementary material, and all the studies were evaluated as being of moderate-to-high quality (Table S1).

Table 1. Main characteristics of all articles included in the meta-analysis (RA-UKA: Robotic-assisted UKA; CONV-UKA: Conventional UKA)

Order	Studys	Year	Country	Design	No.knees RA-UKA	Follow-up (Month)	Complication	Revision	Robot Systems	Function scoring system
1	Cobb *et al*[11]	2006	UK	RCT	19 15	4.5M	1 2	NULL	Acrobot system (Acrobot Co.)	AKSS, WOMAC
2	Lonner *et al*[3]	2010	USA	PCT	31 27	3 M	1 0	NULL	Tactile Guidance System (MAKO Co.)	NULL
3	Hansen *et al*[12]	2014	USA	Case control	30 32	24M	7 3	0 1	RIO™ System (MAKO Co.)	Recovery time First, Ambulation
4	Maccallum *et al*[13]	2016	USA	PCT	87 177	32.4M	3 7	3 7	RIO™ System (Stryker Mako)	NULL
5	Blyth *et al*[14]	2017	UK	RCT	64 65	12M	1 1	NULL	Acrobot system (Acrobot Co.)	AKSS, AKSS
6	Gilmour *et al*[15]	2018	UK	RCT	58 54	24M	0 2	0 2	RIO™ System (MAKO Co.)	AKSS,OKS,FJS Pain VAS
7	Kayani *et al*[16]	2018	UK	PCT	60 60	1M	0 2	NULL	RIO™ System (MAKO Co.)	NULL
8	Batailler *et al*[17]	2018	France	Case control	80 80	19.7M	4 7	4 7	Navio system (Smith and Nephew Co.)	IKSS
9	Canetti *et al*[18]	2018	France	Retrospective cohort	11 17	39.3 M	0 1	NULL	Navio system (Smith and Nephew Co.)	IKSS
10	Banger *et al*[19]	2019	UK	RCT	74 65	60M	0 6	0 2	RIO™ System (MAKO Co.)	AKSS, JFS, Pain VAS, Stiffness, VAS,OKS
11	Wong *et al*[20]	2019	USA	Retrospective cohort	58 118	3M	7 7	7 7	RIO™ System (MAKO Co.)	SF-12, WOMAC, KSFS

12	**Cool *et al*[21]**	**2019**	**USA**	Retrospective comparative study	246 492	24M	2 26	2 26	NULL	NULL
13	Kayani *et al*[22]	2019	UK	PCT	73 73	3M	0 2	NULL	RIO™ System (MAKO Co.)	Pain scores, Opiate analgesia,Straight leg raise, Knee flexion
14	Vakharia *et al*[23]	2019	USA	Retrospective comparative study	13,617 21,444	36M	125 1327	125 1327	NULL	NULL
15	Mergenthaler *et al*[24]	2020	France	Case control	200 191	24M	19 34	8 21	Navio system (Smith and Nephew Co.)	KSS score
16	St Mart *et al*[25]	2020	Australia	Retrospective comparative study	2851 9561	46M	47 301	47 301	Mako-assisted Restoris (MAKO Co.)	NULL

RCT : Randomized Controlled Trial; PCT: Prospective cohort trial

Complications

Complications that lead to failure following UKA include bearing dislocation, aseptic loosening, polyethylene wear, periprosthetic fracture, progression of arthritis to the contralateral compartment, infection, bone-implant impingement, retaining of cement debris in the joint, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain pin-site infection and fracture, and other adverse events. All the 16 studies reported the data about complications, which mainly included prosthetic loosening, subsidence, dislocated polyethylene bearing, periprosthetic fracture, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain, etc. The chi-square and I-square test results showed statistical heterogeneity between the included studies ($P<0.01$; $I^2= 87.1\%$), and Galbraith plots showed that no studies were found to cause heterogeneity (Figure. 2A). The plotted points were close to a sloped straight line on the quantile-quantile (Q-Q) plot (Figure. 2B), which showed that there was no significant deviation from the confidence interval in our studies. Therefore, a random-effects model was used for the analysis. We found that robotic-assisted UKA had a lower rate of complications than conventional UKA (RR: 0.52, 95% CI: 0.28-0.96, P=0.0366; Figure. 2C).

Revision rate

Ten studies reported data regarding complications that required surgery between the two groups. The chi-square and I-square test results showed statistical heterogeneity among the included studies ($P<0.01$; $I^2= 90.3\%$), and Galbraith plots were used to determine the most heterogeneous studies; however, no studies were excluded (Figure. 3A). As seen from the Q-Q plot, there was no significant deviation from the confidence interval in our studies (Figure. 3B). Data pooled using a random-effects model indicated that robotic-assisted UKA had lower rates of revision surgery (RR: 0.42, 95% CI: 0.20-0.86, P=0.017; Figure. 3C).

Non- implant specific complications

Non-implant specific complications were reported in 10 studies, which mainly included infection, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain, pin-site infection and fracture in our meta-analysis. The chi-square and I-square test results indicated no statistical heterogeneity among the included studies ($P=0.49$; $I^2= 0.00\%$), and Galbraith plots (Figure. 4A) and quantile-quantile (Q-Q) plots (Figure. 4B) also showed that there was no statistical heterogeneity. We observed no significant differences in the non-implant-specific complications between the two groups by using a fixed-effects model (RR: 0.80, 95% CI: 0.61-1.04, P=0.96; Figure. 4C).

Publication bias

We assessed publication bias using Begg's test[26]. The contour-enhanced funnel plot for the meta-analysis of the complications for robotic-assisted versus conventional UKA was largely symmetric (P_{Begg}=0.96; Figure. 5A). Similar results were observed for the revision rate (P_{Begg}=0.78; Figure. 5B) and non-implant specific complications (P_{Begg}=1.16; Figure. 5C).

Outlier and influence analyses

The presence of outliers and influential cases can affect the validity and robustness of the conclusions from a meta-analysis. Figure 5 shows the standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ^2 (tau2.del), and test statistics (QE.del) for this random-effects model that was used for the analysis of the complications (Figure. 6). Study 14 (Vakharia,2019) was identified as a potential outlier, which led to the heterogeneity and also appeared to be an influential case. Since the study had a large sample size (35,061 patients, Robot =13,617; CONV =21,444), which makes it useful to study the national trends, and the hat values and weights values showed that this study comprised the largest proportion in the meta-analysis, it was not excluded, but the outlier was included in the meta-analysis. A similar impact was seen in the analysis of the revision rate. No outlier was included in the analysis of non-implant-specific complications.

Discussion

For more than 50 years, UKA has been performed to treat isolated compartmental knee arthritis. Despite many years of experience in performing UKA, some studies have reported that UKA has higher rates of failure compared to total knee arthroplasty (TKA)[27]. The newly designed robotic-assisted systems are believed to increase the precision and accuracy of unicompartmental knee arthroplasty, possibly leading to fewer complications and lower revision rates[28]. Many studies have evaluated the complications of robotic-assisted UKA; however, there are few studies about the complications of robotic-assisted UKA compared to conventional UKA. Researchers have reported conflicting results regarding the complication rate between robotic-assisted and conventional UKA. Hansen et al. and Blyth et al. did not find a significant difference in the rate of complications between the two techniques[12,14]. Wong et al. found that the RAA cohort had a higher early revision rate than the CONV group, while others reported that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA[20,23,25]. It is important to assess the complications of this new technology before it is widely used[21]. Therefore, we conducted a systematic review and meta-analysis to compare the complication rates, revision rate, and non-implant-specific complications between robotic-assisted and conventional UKA. The main finding of our meta-analysis is that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA; however, there are no significant differences in the non-implant specific complications. Thus, we acknowledge that robotic-assisted UKA had fewer complications and lower revision rates than the conventional procedure.

Many publications have explored the relationship between the component position and its impact on implant survival and patient satisfaction[29, 30]. Some authors believe that a reduction in the alignment errors of these components will ultimately have an impact on implant function or survival[31]. Some studies confirmed that the proportion of patients with tibial and femoral component implantation within 2° of the target position was significantly greater in the group that underwent robotic-assisted UKA, resulting in better long-term clinical scores and a lower implant failure rate[13, 32, 33]. Therefore, it could be demonstrated that the use of a robotic-assisted system in UKA can reduce implantation errors, leading to fewer complications and lower rates of revision surgery than conventional UKA. While the non-implant-specific complications are likely to be related to the procedure, fewer were considered to be directly related to the comparative study itself[11]. Mergenthaler reported that there was no complication due to the use of the robotic system[24]. Andrew believes that no further rigid fixation device is necessary, which reduces the potential complications such as infection, iatrogenic fractures, or soft tissue injury because of the robot's weight and movement[34]. However, there were no significant differences in the non-implant-specific complications between the two techniques in our meta-analysis. Therefore, no evidence suggested that the use of robotic-assisted UKA may add the non-implant-specific complications to this procedure.

Though robotic-assisted UKA is widely practiced and is the current trend in orthopaedic surgery, it has some shortcomings. Robotic-assisted UKA was found to significantly prolong the duration of surgery compared to conventional UKA (Figure. S7). Some studies have also documented that robotic arm-assisted UKA involves a higher cost[35, 36]. In addition, the device-related complications such as pin site fracture and infection cannot be ignored. We checked all articles included in the meta-analysis as to whether they included a statement on the funding or interest of the work presented. When such a statement was provided we categorised the information as an industry-funded study or authors having a financial conflict of interest. We found that the included articles were more likely to be industry-funded or written by authors with financial conflicts of interest (Figure. S8). Therefore, this information should not be overlooked, and more large-scale studies with non-commercial support for evaluating the efficacy of both treatments in this patient population are needed in the future.

There are several limitations to this meta-analysis. First, long-term revision rates depend on the year of follow up; however, all the included studies had short-term follow up (3 months to 60 months). Hence, the results of revision rates are questionable. Hence, future studies with a longer follow-up duration, preferably 10 years, are necessary to assess the complications and revision rates. Second, some studies were not RCTs and had small sample sizes, which increases the possibility of publication bias. Therefore, our results should be further confirmed by large-scale RCT studies. Thirdly, the types of RA-UKA performed in each study were different, as shown in Table 1. The different types used were Acrobot system, RIO™ System or Mako-assisted Restoris System, and Navio system. Rapid advances in robotic-assisted technology have led to the development of UKA over the past 10 years. Implant position, soft tissue balance, and radiographic components alignment appear to be gradually improved with the development of robotic-assisted systems. Considering the evolution of this technology and its possible impact on the outcomes, well-designed studies are necessary to advance our understanding of the impact of different robotic systems. Fourth, all the included studies were limited to the English literature; therefore, some related studies published in other languages that might have met the inclusion criteria could have been missed. Fifth, most of the studies in our meta-analysis have not reported the pin site complications and device-specific complications. Revisions secondary to pin site fracture were included in some studies; however, the sample size is small. Therefore, we did not conduct a systematic research on these specific complications and revisions. Although we attempted to identify and retrieve all additional unpublished information, some missing data were inevitable. In addition, our results were unadjusted for other factors that might influence complication outcomes such as patient age and weight, the anterior cruciate ligament, soft tissue balance, composition and thickness of the polyethylene component and others. Finally, given that there is no established functional scoring system to measure the postoperative function and due to the limited number of exact P-values, we did not evaluate the functional outcome in our meta-analysis (Table 1). However, many studies have reported shown that RA-UKA had a reliable, responsive, and reproducible postoperative function. Therefore, it is necessary to establish a universal system for assessing the postoperative function in patients with UKA.

Conclusions

To summarise, the data from this meta-analysis indicate that robotic-assisted UKA is associated with fewer complications and lower rates of revision surgery than conventional UKA. No evidence suggested that the use of robotic-assisted UKA might increase the rate of non-implant-specific complications with this procedure.

Therefore, this study showed that robotic-assisted UKA had fewer complications and lower revision rates than the conventional procedure. More large-scale RCT studies with a longer follow-up duration for evaluating the efficacy of both treatments in this patient population are necessary in the future.

Acknowledgments

We gratefully appreciate Shandong First Medical University for providing the statistical and technical assistance.

Author contributions

Yifeng Sun conceived the study and wrote the manuscript, Wenqiang Zhang analysed the data, and Wei Liu generated data. Xiuhua Hu and Jian Hou reviewed the manuscript.

Funding sources

This work was supported by the Natural Science Foundation of China (81702667) and Wu Jieping Medical Foundation (320.6750.18466), and Shandong Provincial Key Research and Development Project (GG201809250496).

Competing interests

The authors declare they have no conflict of interest.

Patient consent for publication

Not required.

Data sharing statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Ethics approval statement

Not applicable.

References

1. Labek G, Sekyra K, Pawelka W, Janda W, Agreiter M, Schlichtherle R, Stöckl B, Krismer M: outcome And Reproducibility Of Data Concerning The Oxford Medial Unicompartmental Knee Arthroplasty *Orthopaedic Proceedings* 2011; 93:131-.

2. Lang J, Mannava S, Floyd A, Goddard M, Smith B, Mofidi A, M. Seyler T, Jinnah R. Robotic systems in orthopaedic surgery. *The Journal of bone and joint surgery British volume* 2011;**93**: 1296-9.

3. Lonner JH, Moretti VM. The Evolution of Image-Free Robotic Assistance in Unicompartmental Knee Arthroplasty. *American journal of orthopedics* 2016;**45**: 249-54.

4. Zhang F, Li H, Ba Z, Bo C, Li K. Robotic arm-assisted vs conventional unicompartmental knee arthroplasty: A meta-analysis of the effects on clinical outcomes. *Medicine* 2019;**98**.

5. Chin BZ, Tan SSH, Chua KCX, Budiono GR, Syn NL, Oneill GK. Robot-Assisted versus Conventional Total and Unicompartmental Knee Arthroplasty: A Meta-analysis of Radiological and Functional Outcomes. *Journal of Knee Surgery* 2020.

6. Fu J, Wang Y, Li X, Yu B, Ni M, Chai W, Hao L, Chen J. Robot-assisted vs. conventional unicompartmental knee arthroplasty : Systematic review and meta-analysis. *Orthopade* 2018;**47**: 1009-17.

7. Wells G: The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Non-Randomised Studies in Meta-Analyses *Symposium on Systematic Reviews: Beyond the Basics* 2014.

8. Galbraith RF. Some Applications of Radial Plots. *Journal of the American Statistical Association* 1994;**89**: 1232-42.

9. Viechtbauer W, Cheung MWL. Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods* 2010;**1**: 112-25.

10. Viechtbauer W. Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software* 2010;**36**: 1-48.

11. Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, Barrett ARW, Davies BL. Hands-on robotic unicompartmental knee replacement - A prospective, randomised controlled study of the Acrobot system. *Journal of Bone and Joint Surgery-british Volume* 2006;**88**: 188-97.

12. Hansen DC, Kusuma SK, Palmer RM, Harris KB. Robotic Guidance Does Not Improve Component Position or Short-Term Outcome in Medial Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2014;**29**: 1784-9.

13. Maccallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic-assisted and

conventional unicompartmental knee arthroplasty. *European Journal of Orthopaedic Surgery and Traumatology* 2016;**26**: 93-8.

14. Blyth M, Anthony I, Rowe P, Banger M, Maclean A, Jones B. Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. *Bone and Joint Research* 2017;**6**: 631-9.

15. Gilmour A, Maclean A, Rowe P, Banger M, Donnelly I, Jones B, Blyth M. Robotic-Arm Assisted Versus Conventional Unicompartmental Knee Arthroplasty. The 2 year Clinical outcomes of a Randomised Controlled Trial. *Journal of Arthroplasty* 2018: S0883540318301980.

16. Kayani, Konan, T JR, Pietrzak, S S, Huq, Tahmassebi, S F, Haddad. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty. *Bone & Joint Journal* 2018.

17. Batailler C, White N, Ranaldi FM, Neyret P, Servien E, Lustig S. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2019;**27**: 1232-40.

18. Canetti R, Batailler C, Bankhead C, Neyret P, Servien E, Lustig S. Faster return to sport after robotic-assisted lateral unicompartmental knee arthroplasty: a comparative study. *Archives of Orthopaedic and Trauma Surgery* 2018;**138**: 1765-71.

19. Banger M, Blyth M, Jones B, MacLean A, Rowe P, Glasgow NG, Clyde GU. 5 Year Results Of A Randomised Trial Of Robotic Arm Assisted Vs Manual Unicompartmental Knee Arthoplasty.

20. Wong J, Murtaugh T, Lakra A, Cooper HJ, Shah RP, Geller JA. Robotic-assisted unicompartmental knee replacement offers no early advantage over conventional unicompartmental knee replacement. *Knee Surgery, Sports Traumatology, Arthroscopy* 2019;**27**: 2303-8.

21. Cool CL, Needham K, Khlopas A, Mont MA. Revision Analysis of Robotic Arm–Assisted and Manual Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2019;**34**: 926-31.

22. Kayani B, Konan S, Tahmassebi J, Rowan FE, Haddad FS. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty. *Journal of Bone and Joint Surgery-british Volume* 2019: 24-33.

23. Vakharia RM, Sodhi N, Cohen-Levy WB, Vakharia AM, Mont MA, Roche MW. Comparison of Patient Demographics and Utilization Trends of Robotic-Assisted and Non-Robotic-Assisted Unicompartmental Knee Arthroplasty. *The journal of knee surgery* 2019.

24. Mergenthaler G, Batailler C, Lording T, Servien E, Lustig S. Is robotic-assisted unicompartmental knee arthroplasty a safe procedure? A case control study. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2020.

25. St Mart JP, de Steiger RN, Cuthbert A, Donnelly W. The three-year survivorship of robotically assisted versus non-robotically assisted unicompartmental knee arthroplasty. *The bone & joint journal* 2020;**102-B**: 319-28.

26. Macaskill P, Walter SD, Irwig L. A comparison of methods to detect publication bias in meta‐analysis. *Statistics in medicine* 2001;**20**: 641-54.

27. Sun X, Su Z. A meta-analysis of unicompartmental knee arthroplasty revised to total knee arthroplasty versus primary total knee arthroplasty. *Journal of Orthopaedic Surgery and Research* 2018;**13**: 158.

28. Roche MW. Robotic-assisted unicompartmental knee arthroplasty: the MAKO experience. *Clinics in Sports Medicine* 2014;**33**: 123-32.

29. Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A. What is the optimal alignment of the tibial and femoral components in knee arthroplasty? An overview of the literature. *Acta*

orthopaedica 2014;**85**: 480-7.

30. Vandekerckhove P-J, Lanting B, Bellemans J, Victor J, MacDonald S. The current role of coronal plane alignment in total knee arthroplasty in a preoperative varus aligned population: an evidence based review. *Acta Orthop Belg* 2016;**82**: 129-42.

31. Kim KT, Lee S, Kim TW, Lee JS, Boo KH. The influence of postoperative tibiofemoral alignment on the clinical results of unicompartmental knee arthroplasty. *Knee surgery & related research* 2012;**24**: 85.

32. Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A. What is the optimal alignment of the tibial and femoral components in knee arthroplasty. *Acta Orthopaedica* 2014;**85**: 480-7.

33. Chatellard R, Sauleau V, Colmar M, Robert H, Raynaud G, Brilhault J. Medial unicompartmental knee arthroplasty: Does tibial component position influence clinical outcomes and arthroplasty survival? *Orthopaedics & Traumatology-surgery & Research* 2013;**99**.

34. Pearle AD, Oloughlin PF, Kendoff D. Robot-Assisted Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2010;**25**: 230-7.

35. Moschetti WE, Konopka JF, Rubash HE, Genuario JW. Can Robot-Assisted Unicompartmental Knee Arthroplasty Be Cost-Effective? A Markov Decision Analysis. *The Journal of arthroplasty* 2016;**31**: 759-65.

36. Sinha RK. Outcomes of robotic arm-assisted unicompartmental knee arthroplasty. *American journal of orthopedics (Belle Mead, NJ)* 2009;**38**: 20-2.

Figure legends

Figure 1. Flow diagram depicting the study selection procedure.

Figure 2. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 3. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 4. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of non-implant specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-implant specific complications (C).

Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ2 (tau2.del) and test statistics

(QE.del) for the random-effects model that was used for the analysis of the complications.

Figure S7. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of surgical time between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure S8. Industry funding and conflict of interest for manuscripts regarding robotic-arm assisted and conventional unicompartmental knee arthroplasty

Table

Table 1. Main characteristics of all articles included in the meta-analysis

Table S1. Assessment of the quality of included studies using the Newcastle-Ottawa Scale.

Figure 1. Literature search and study selection.

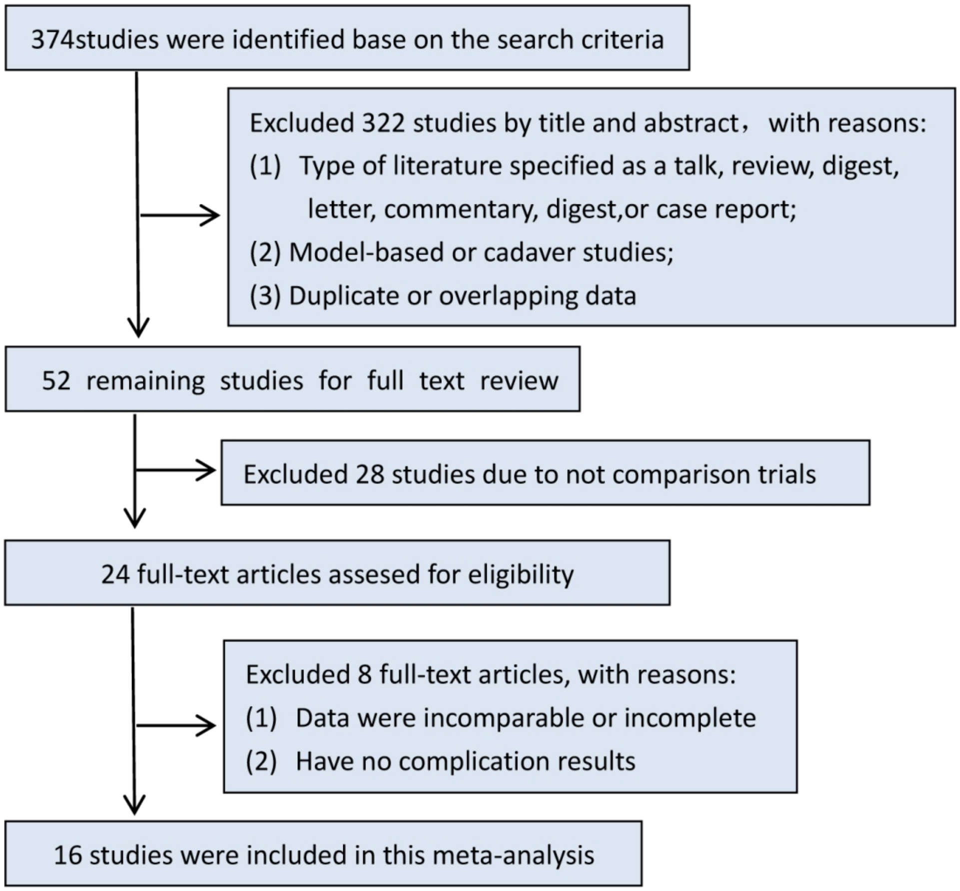


Figure 1. Flow diagram depicting the study selection procedure.

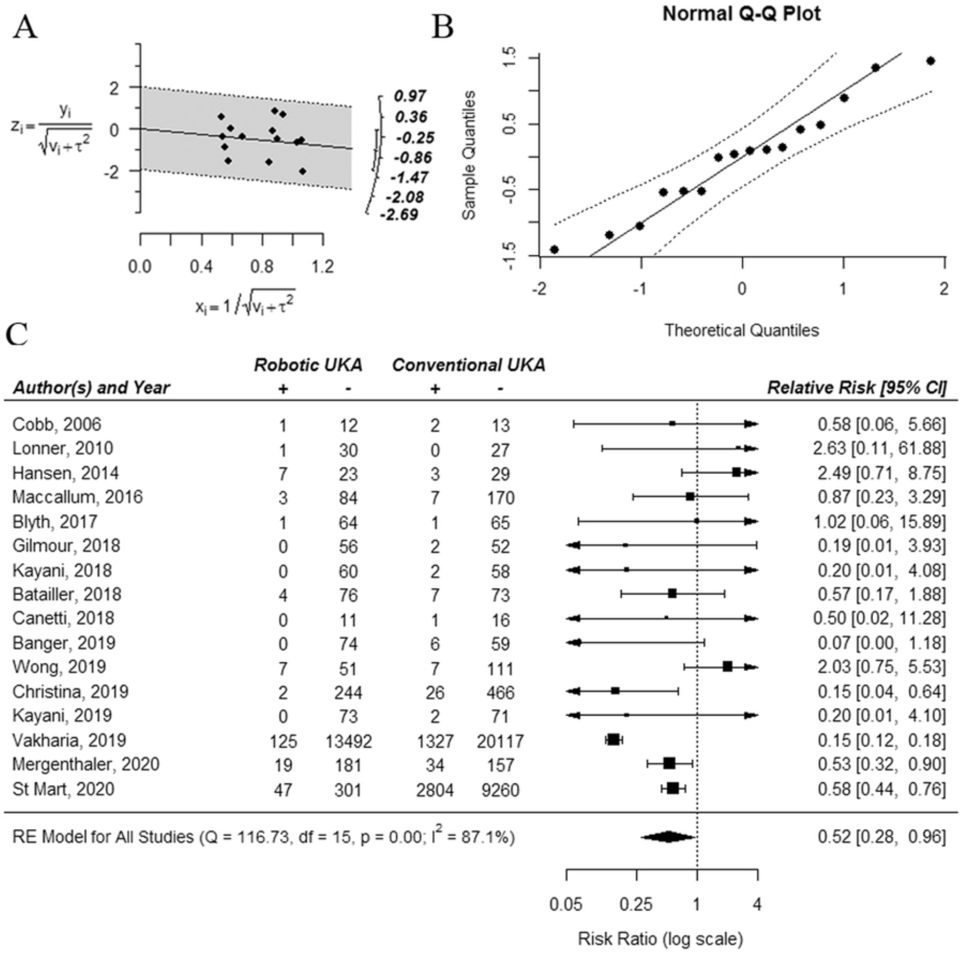


Figure 2. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

79x77mm (300 x 300 DPI)

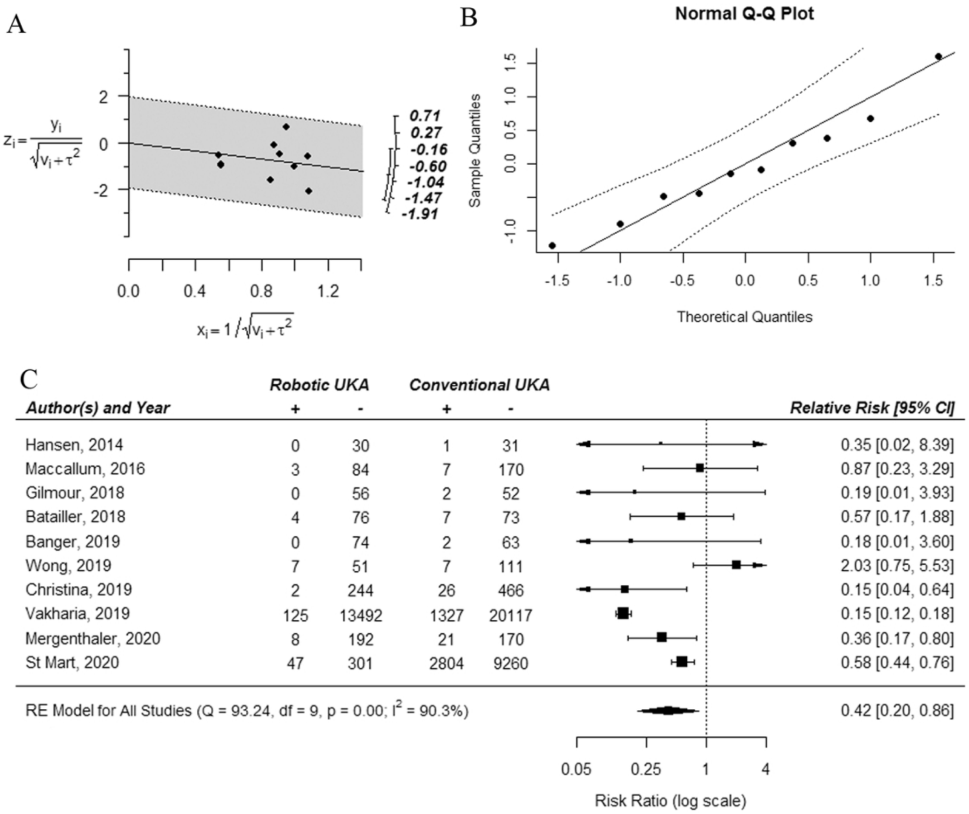


Figure 3. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

152x124mm (300 x 300 DPI)

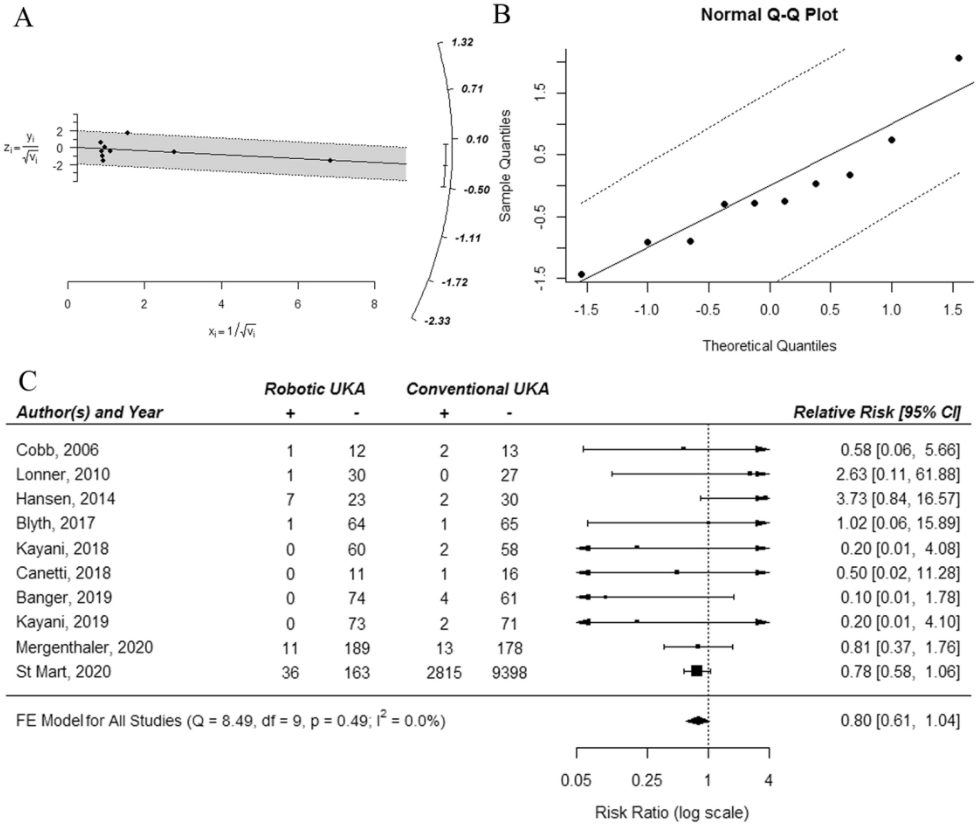


Figure 4. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of non-implant specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

147x124mm (300 x 300 DPI)

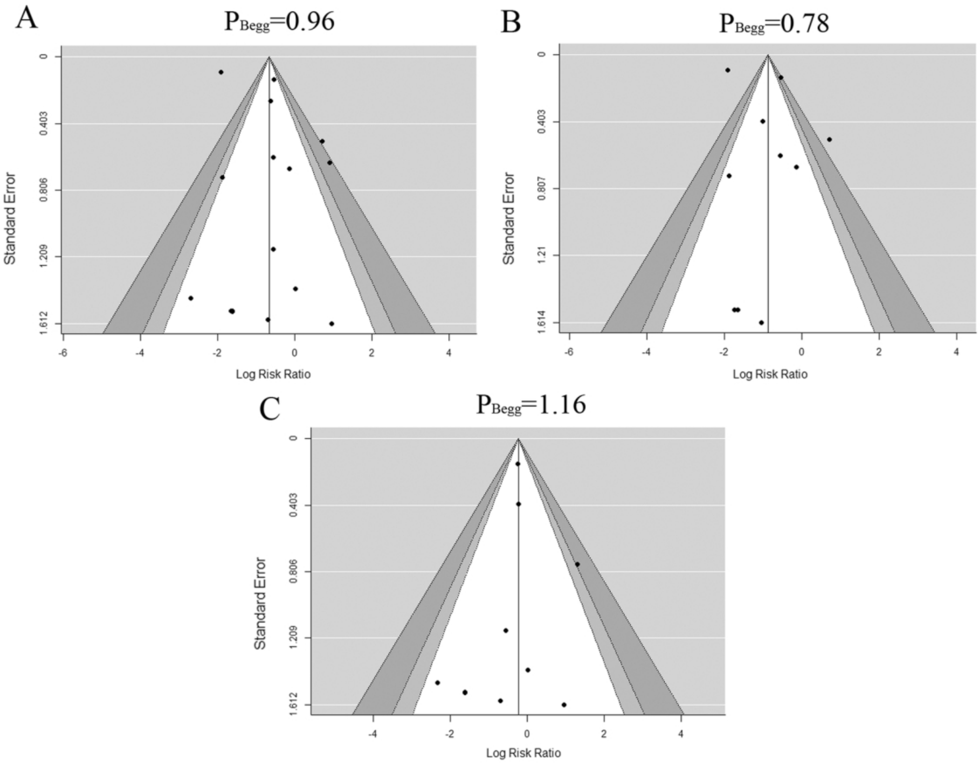


Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-implant specific complications (C).

150x118mm (300 x 300 DPI)

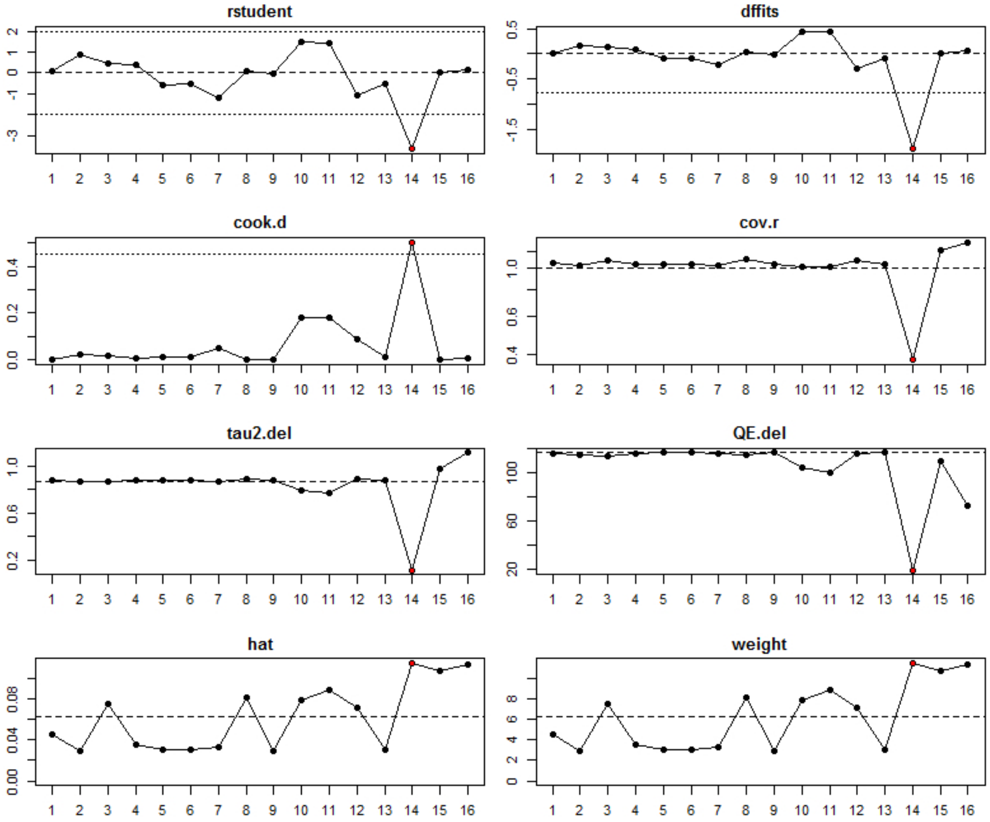
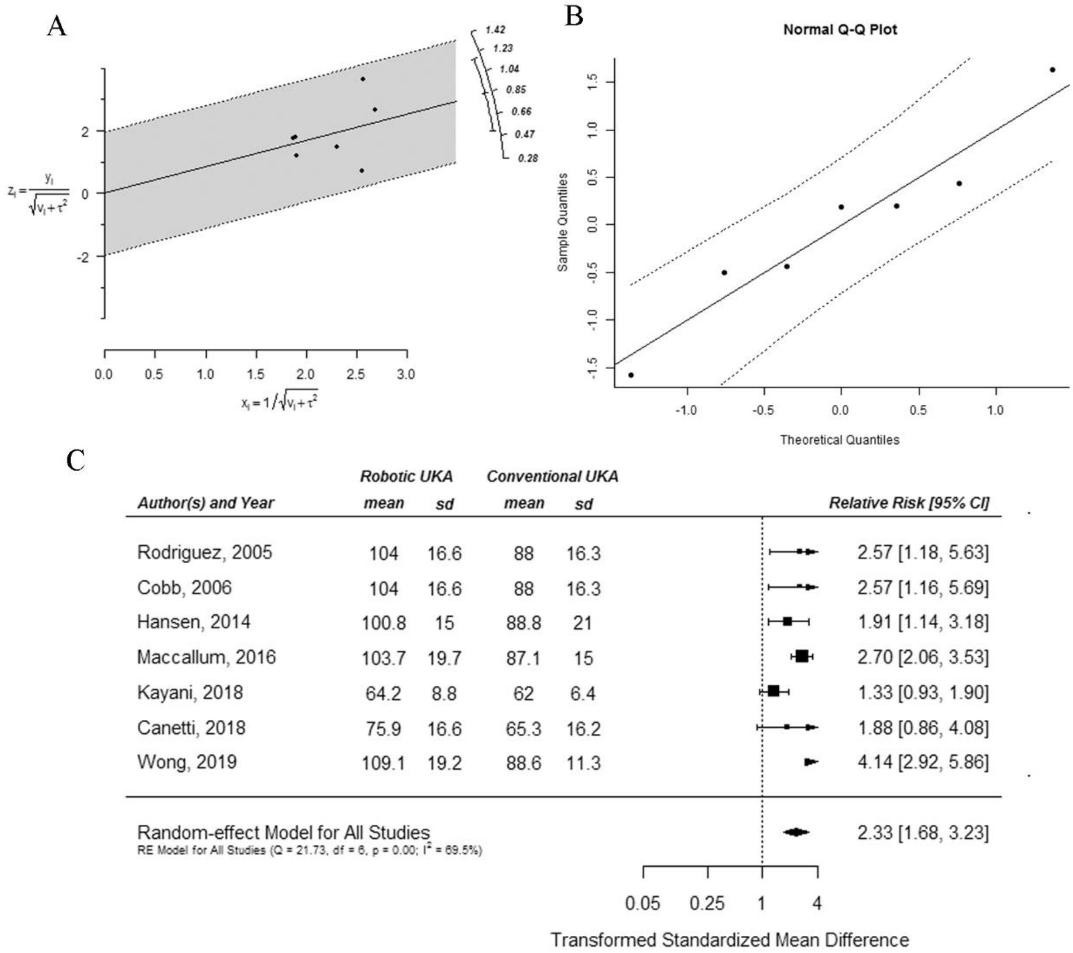


Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ2 (tau2.del) and test statistics (QE.del) for the random-effects model that was used for the analysis of the complications.

210x177mm (95 x 95 DPI)


A
2
0
-2
$z_i = \frac{y_i}{\sqrt{v_i + \tau^2}}$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$x_i = 1/\sqrt{v_i + \tau^2}$
1.42
1.23
1.04
0.85
0.66
0.47
0.28
B
Normal Q-Q Plot
Sample Quantiles
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Theoretical Quantiles
-1.0
-0.5
0.0
0.5
1.0
C
Robotic UKA
Conventional UKA
Author(s) and Year
mean
sd
mean
sd
Relative Risk [95% CI]
Rodriguez, 2005 104 16.6 88 16.3 2.57 [1.18, 5.63]
Cobb, 2006 104 16.6 88 16.3 2.57 [1.16, 5.69]
Hansen, 2014 100.8 15 88.8 21 1.91 [1.14, 3.18]
Maccallum, 2016 103.7 19.7 87.1 15 2.70 [2.06, 3.53]
Kayani, 2018 64.2 8.8 62 6.4 1.33 [0.93, 1.90]
Canetti, 2018 75.9 16.6 65.3 16.2 1.88 [0.86, 4.08]
Wong, 2019 109.1 19.2 88.6 11.3 4.14 [2.92, 5.86]
Random-effect Model for All Studies 2.33 [1.68, 3.23]
RE Model for All Studies (Q = 21.73, df = 6, p = 0.00; I² = 69.5%)
0.05
0.25
1
4
Transformed Standardized Mean Difference

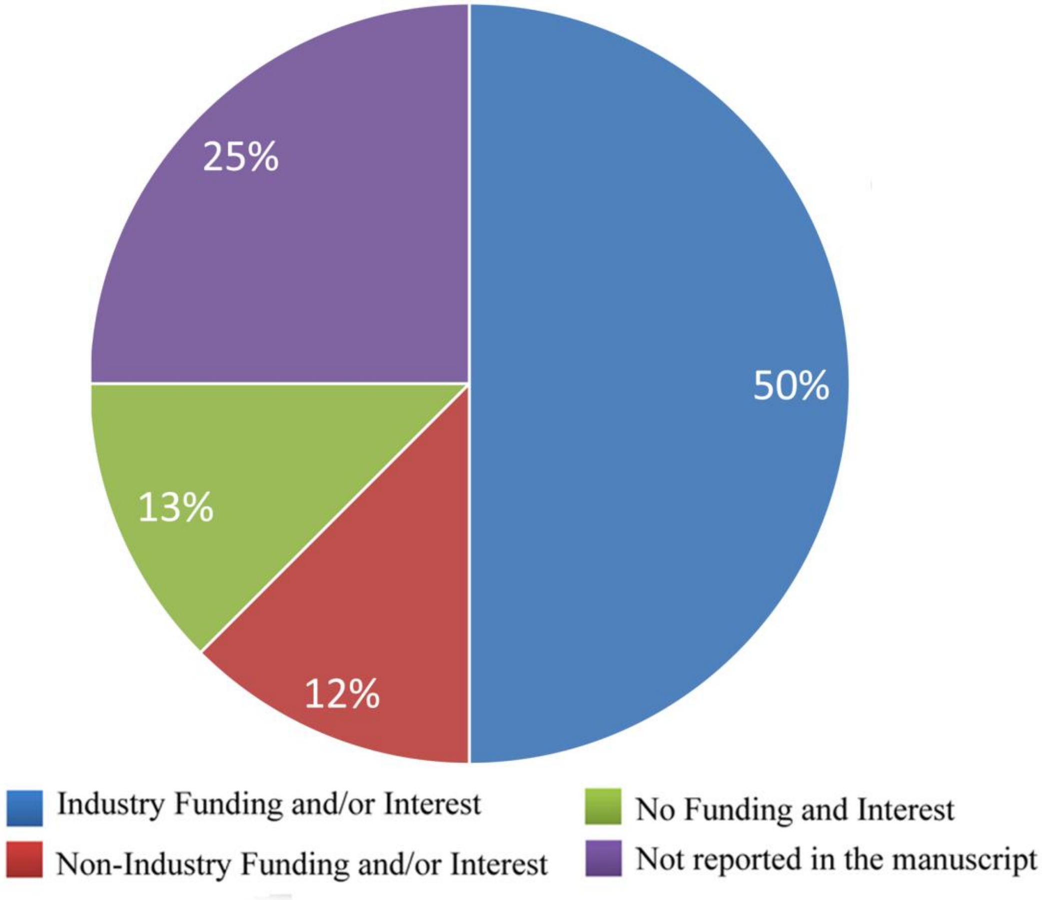

25%
50%
13%
12%
Industry Funding and/or Interest
No Funding and Interest
Non-Industry Funding and/or Interest
Not reported in the manuscript

Table S1. Assessment of the studies’ qualities using the Newcastle-Ottawa Scale.

Order	Studys	Year	Country	Selection	Comparability	Exposure	Quality Score
1	Cobb *et al*	2006	UK	★★★★	★★	★★	★★★★★★★★
2	Lonner *et al*	2010	USA	★★★	★★	★	★★★★★★
3	Hansen*et al*	2014	USA	★★★	★	★	★★★★★
4	Maccallum *et al*	2016	USA	★★★	★★	★	★★★★★★
5	Blyth *et al*	2017	UK	★★★★	★★	★★	★★★★★★★★
6	Gilmour *et al*	2018	UK	★★★★	★★	★★	★★★★★★★★
7	Kayani *et al*	2018	UK	★★★	★★	★	★★★★★
8	Batailler *et al*	2018	France	★★★	★	★	★★★★★
9	Canetti *et al*	2018	France	★★★	★	★	★★★★★
10	Banger *et al*	2019	UK	★★	★★	★★	★★★★★★
11	Wong *et al*	2019	USA	★★★	★	★	★★★★★
12	Christina *et al*	2019	USA	★★★	★	★	★★★★★
13	Kayani *et al*	2019	UK	★★★	★★	★	★★★★★★
14	Vakharia *et al*	2019	USA	★★★	★	★	★★★★★
15	Mergenthaler *et al*	2020	France	★★★	★	★	★★★★★
16	St Mart *et al*	2020	Australia	★★★	★	★	★★★★★

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE		**Does robotic- assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A Systematic Review and Meta-Analysis**	1
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Not exist
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	5

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Not done
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5-6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	10
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	9
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	9
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	10
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	10
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	10-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	12-13
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	13
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	13

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.

BMJ Open

Does robotic-assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A systematic review and meta-analysis

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-044778.R2
Article Type:	Original research
Date Submitted by the Author:	05-Jul-2021
Complete List of Authors:	Sun, Yifeng; First Affiliated Hospital of Shandong First Medical University Liu, Wei; First Affiliated Hospital of Shandong First Medical University Hou, Jian Hu, Xiuhua; First Affiliated Hospital of Shandong First Medical University Zhang, Wenqiang; First Affiliated Hospital of Shandong First Medical University
Primary Subject Heading:	Surgery
Secondary Subject Heading:	Surgery
Keywords:	Orthopaedic & trauma surgery < SURGERY, Adult surgery < SURGERY, Knee < ORTHOPAEDIC & TRAUMA SURGERY, Adult orthopaedics < ORTHOPAEDIC & TRAUMA SURGERY

Does robotic-assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A systematic review and meta-analysis

Yifeng Sun[1], Wei Liu[1], Jian Hou[2], Xiuhua Hu[1], Wenqiang Zhang[1,*]

[1]Department of Orthopedic Surgery, The First Affiliated Hospital of Shandong First Medical University & Shandong Provincial Qianfoshan Hospital, Shandong Key Laboratory of Rheumatic Disease and Translational Medicine

[2]Jimo Traditional Chinese Hospital, Qingdao, Shandong 266200, PR China

*Correspondence and requests for materials should be addressed to Wenqiang Zhang (qfszwq@sina.com).

Abstract

Objective: We conducted this systematic review and meta-analysis of studies on patients who underwent unicompartmental knee arthroplasty (UKA) to compare the complication rates, revision rates, and non-implant-specific complications between robotic-assisted and conventional UKA.

Design: Systematic review and meta-analysis.

Data sources: The PubMed, Embase, Web of Science, and Cochrane databases were searched up to 30 June 2020.

Eligibility criteria: Case-control studies comparing robotic-assisted and conventional UKA.

Data extraction and synthesis: Data from all eligible articles were independently extracted by two authors. We analysed the differences in outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence intervals (CIs) and pooled relative risks (RRs). Heterogeneity was assessed using the chi-square and I-square tests. All analyses were performed using the 'metafor' package of R 3.6.2 software.

Results: A total of 16 studies involving 50,024 patients were included in the final meta-analysis. We found that robotic-assisted UKA had fewer complications (RR: 0.52, 95% CI: 0.28-0.96, P=0.036) and lower revision rates (RR: 0.42, 95% CI: 0.20-0.86, P=0.017) than conventional UKA. We observed no significant differences in non-implant-specific complications between the two surgical techniques (RR: 0.80, 95% CI: 0.61-1.04, P=0.96). No publication bias was found in this meta-analysis.

Conclusions: This study provides evidence that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA; however, owing to important limitations, the results lack reliability, and more studies are required.

Strengths and limitations of this study

►We conducted a meta-analysis to find the best evidence comparing robotic-arm-assisted and manual unicompartmental knee arthroplasty (UKA).

►Long-term complications and revision rates depend on the follow-up duration; however, all included studies had a short follow-up period (3-60 months). Hence, the data on revision rates are not reliable.

►Some studies were not randomised controlled trials and had a small sample size, which increase the possibility of publication bias.

►The relatively modest sample size might have caused an unavoidable risk of bias.

►Our results were not adjusted for other factors that could influence outcomes related to knee function, such as patient age and weight, anterior cruciate ligament status, soft-tissue balance, and composition and thickness of the polyethylene component.

Keywords: Unicompartmental knee arthroplasty; Robotic-arm-assisted UKA; Conventional UKA; Meta-analysis.

Abbreviations: UKA, unicompartmental knee arthroplasty; RA-UKA, robotic-assisted unicompartmental knee arthroplasty; RCT, randomised controlled trial; PCT, prospective cohort trial; RR, relative risk; CI, confidence interval

PROSPERO registration number: CRD42021246927

Introduction

Unicompartmental knee arthroplasty (UKA) is often performed for treating isolated compartmental knee osteoarthritis owing to its minimally invasive nature and less bone resection required during surgery. However, higher rates of revision surgery (10-20%) have been reported in patients undergoing UKA than in those undergoing total knee arthroplasty[1]. There could be multiple reasons for the higher failure rate, including poor patient selection and component design, whereas some authors have identified malpositioning as the cause[2]. The use of robotic systems, which offer promising short-term radiological outcomes of implants and precision in bone cuts, during UKA has considerably increased. Currently, approximately 15-20% of UKA surgeries are being performed with the assistance of robotic systems, with improved clinical efficacy[3]. Most experts believe that robotic-assisted UKA provides significantly better component angle alignment accuracy and functional outcomes, as well as higher patient satisfaction, than conventional UKA. However, there are considerable variations in the complication and revision rates reported in previous studies, which make it difficult to estimate the safety outcomes of the two surgical techniques[4, 5].

Previous meta-analyses have compared the effects and safety of robotic-assisted and conventional UKA. In a meta-analysis by Fu et al., it was reported that robotic-assisted UKA showed no decrease in the rate of adverse events compared with conventional UKA. However, few articles (only seven studies) were included in the meta-analysis, and the difference in the revision rates between the two techniques was not reported[6]. Another meta-analysis by Zhang et al. contradicted the conclusion about adverse events by Fu et al., reporting instead that robotic-assisted UKA could significantly reduce the rate of complications; however, the results were also subject to limitations in sample size and follow-up duration, which might influence the assessment of the difference in outcomes between robotic-assisted and conventional UKA[4]. Another recent meta-analysis did not reach a definitive conclusion about complications[5]. Therefore, we conducted this systematic review and meta-analysis of studies on patients who underwent UKA to compare the complication rates, revision rates, and non-implant-specific complications between robotic-assisted and conventional UKA. We hypothesized that there would be no obvious differences in complication and revision rates between the two techniques.

Methods

Search strategy

We searched the PubMed, Web of Science, Embase, and Cochrane databases using combinations of the following keywords: ‘unicompartmental knee arthroplasty’, ‘UKA’, ‘conventional UKA’, ‘traditional UKA’, ‘manual UKA’, ‘robotic-assisted UKA’, ‘non-robotically assisted UKA’, ‘complications’, ‘adverse events’, and ‘revision’ (last updated on 30 June 2020). The references of the identified reports were also retrieved and reviewed to find other related studies. All studies were carefully and repeatedly evaluated. The study period, treatment information, hospital, and any additional inclusion criteria were used to identify duplicate or overlapping data.

Inclusion and exclusion criteria

Studies that met the following criteria were considered eligible for inclusion in this study: (1) original studies about UKA, (2) studies that compared robotic-assisted and conventional UKA, (3) studies that provided controls and effective data (including randomised controlled trials [RCTs], prospective cohort trials, case-control studies, and retrospective comparative studies), and (4) studies published in English. The exclusion criteria were as follows: (1) studies published as talks, reviews, digests, letters, commentaries, or case reports; (2) model-based or cadaver studies; (3) duplicate or overlapping studies; and (4) not case-control studies.

Data extraction and quality assessment

The data from all eligible articles were independently extracted by two authors, who discussed any disagreements to reach a consensus. The data retrieved from each study included the first author's name, year of publication, country, methods, number of patients, follow-up duration, complications, revision rate, and non-implant-specific complications. Three experienced reviewers used the modified Newcastle-Ottawa quality assessment scale to evaluate the quality of the selected studies. A score of 9 was assigned to studies of superior quality, between 6 and 8 to high-quality studies, between 3 and 5 to moderate-quality studies, and <3 to low-quality studies[7].

Statistical analysis

We analysed the differences in outcomes between robotic-assisted and conventional UKA by calculating the corresponding 95% confidence intervals (CIs) and pooled relative risks (RRs). Heterogeneity was assessed using the chi-square and I-square tests. Fixed-effect models were employed when there was no significant heterogeneity ($I^2 \leq 50\%$, $P > 0.10$); otherwise, a random-effects model was used to obtain the pooled effects among the included studies. Galbraith plots were used to detect potential sources of heterogeneity[8]. Normal quantile-quantile (Q-Q) plots were used to check for deviation of data from the CI. Outlier and influence analyses were performed by inspecting the plots for externally standardised residues, DFFITS values, Cook's distances, covariance ratios, estimates of τ^2, test statistics for residual heterogeneity when each study was excluded in turn, hat values, and weights for each study included in the analysis[9]. Publication bias was assessed by inspecting a contour-enhanced funnel plot, with contours at 90%, 95%, and 99% CIs. All analyses were performed using the 'metafor' package of R 3.6.2 software[10]. A two-tailed P value of <0.05 was considered statistically significant.

Patient and public involvement

There was no patient and public involvement in this systematic review.

Results

Study characteristics

We initially identified 374 studies through the search of the PubMed, Embase, Web of Science, and Cochrane databases. Of these, 322 studies did not meet the inclusion criteria and were excluded after reviewing the titles and abstracts. Of the 52 remaining studies that were subjected to a full-text review, 28 were excluded because they were not comparative studies. In addition, eight full-text articles were excluded for the following reasons: (1) data were incomparable or incomplete and (2) data about complications were not available. Finally, 16 studies involving 50,024 patients were included in the final meta-analysis. The flow diagram of study selection is presented in Figure 1. Table 1 summarises the main characteristics of the 16 included studies. The quality assessment of the included studies is presented in detail in the Supplementary Material, and all the studies were evaluated as being of moderate to high quality (Table S1).

Table 1. Main characteristics of all articles included in the meta-analysis

Order	Studys	Year	Country	Design	No.knees RA-UKA	Follow-up (Month)	Complication	Revision	Robot Systems	Function scoring system
1	Cobb *et al*[11]	2006	UK	RCT	19 15	4.5M	1 2	NULL	Acrobot system (Acrobot Co.)	AKSS, WOMAC
2	Lonner *et al*[3]	2010	USA	PCT	31 27	3 M	1 0	NULL	Tactile Guidance System (MAKO Co.)	NULL
3	Hansen *et al*[12]	2014	USA	Case control	30 32	24M	7 3	0 1	RIO™ System (MAKO Co.)	Recovery time First, Ambulation
4	Maccallum *et al*[13]	2016	USA	PCT	87 177	32.4M	3 7	3 7	RIO™ System (Stryker Mako)	NULL
5	Blyth *et al*[14]	2017	UK	RCT	64 65	12M	1 1	NULL	Acrobot system (Acrobot Co.)	AKSS,
6	Gilmour *et al*[15]	2018	UK	RCT	58 54	24M	0 2	0 2	RIO™ System (MAKO Co.)	AKSS,OKS,FJS Pain VAS
7	Kayani *et al*[16]	2018	UK	PCT	60 60	1M	0 2	NULL	RIO™ System (MAKO Co.)	NULL
8	Batailler *et al*[17]	2018	France	Case control	80 80	19.7M	4 7	4 7	Navio system (Smith and Nephew Co.)	IKSS
9	Canetti *et al*[18]	2018	France	Retrospective cohort	11 17	39.3 M	0 1	NULL	Navio system (Smith and Nephew Co.)	IKSS
10	Banger *et al*[19]	2019	UK	RCT	74 65	60M	0 6	0 2	RIO™ System (MAKO Co.)	AKSS, JFS, Pain VAS, Stiffness, VAS,OKS
11	Wong *et al*[20]	2019	USA	Retrospective cohort	58 118	3M	7 7	7 7	RIO™ System (MAKO Co.)	SF-12, WOMAC, KSFS

12	**Cool *et al*[21]**	**2019**	**USA**	Retrospective comparative study	246 492	24M	2 26	2 26	NULL	NULL
13	Kayani *et al*[22]	2019	UK	PCT	73 73	3M	0 2	NULL	RIO™ System (MAKO Co.)	Pain scores, Opiate analgesia,Straight leg raise, Knee flexion
14	Vakharia *et al*[23]	2019	USA	Retrospective comparative study	13,617 21,444	36M	125 1327	125 1327	NULL	NULL
15	Mergenthaler *et al*[24]	2020	France	Case control	200 191	24M	19 34	8 21	Navio system (Smith and Nephew Co.)	KSS score
16	St Mart *et al*[25]	2020	Australia	Retrospective comparative study	2851 9561	46M	47 301	47 301	Mako-assisted Restoris (MAKO Co.)	NULL

RA-UKA, robotic-assisted unicompartmental knee arthroplasty; RCT, randomised controlled trial; PCT, prospective cohort trial

Complications

Complications that lead to failure of UKA include bearing dislocation, aseptic loosening, polyethylene wear, periprosthetic fracture, progression of arthritis to the contralateral compartment, infection, bone-implant impingement, retained cement debris in the joint, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain, pin-site infection and fracture, and other adverse events. All 16 studies reported data about complications, which mainly involved prosthetic loosening, subsidence, polyethylene bearing dislocation, periprosthetic fracture, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, and persistent pain. The chi-square and I-square test results showed statistical heterogeneity between the included studies ($P < 0.01$, $I^2 = 87.1\%$), and Galbraith plots showed that no single study caused heterogeneity (Figure 2A). The plotted points were close to a sloped straight line on the Q-Q plot (Figure 2B), which showed that there was no significant deviation from the CI in the included studies. Therefore, a random-effects model was used for the analysis. We found that robotic-assisted UKA had a lower rate of complications than conventional UKA (RR: 0.52, 95% CI: 0.28-0.96, P=0.0366; Figure 2C).

Revision rate

Ten studies reported data about complications that required surgery in the two groups. The chi-square and I-square test results showed statistical heterogeneity among the included studies ($P<0.01$, $I^2=90.3\%$), and Galbraith plots were used to determine the most heterogeneous studies; however, no studies were excluded (Figure 3A). As seen from the Q-Q plot, there was no significant deviation from the CI in the studies (Figure 3B). Data pooled using a random-effects model indicated that robotic-assisted UKA had a lower rate of revision surgery (RR: 0.42, 95% CI: 0.20-0.86, P=0.017; Figure 3C).

Non-implant-specific complications

Non-implant-specific complications were reported in 10 studies, which mainly involved infection, knee ankylosis, wound complications, deep haematoma, infection, thrombosis, persistent pain, and pin-site infection and fracture in our meta-analysis. The chi-square and I-square test results indicated no statistical heterogeneity among the included studies ($P=0.49$, $I^2=0.00\%$), and Galbraith plots (Figure 4A) and Q-Q plots (Figure 4B) also showed no statistical heterogeneity. We observed no significant differences in non-implant-specific complications between the two groups in comparisons using a fixed-effects model (RR: 0.80, 95% CI: 0.61-1.04, P=0.96; Figure 4C).

Publication bias

We assessed publication bias using Begg's test[26]. The contour-enhanced funnel plot for the meta-analysis of complications of robotic-assisted versus conventional UKA was largely symmetric (P_{Begg}=0.96; Figure 5A). Similar results were observed for the revision rate (P_{Begg}=0.78; Figure 5B) and non-implant-specific complications (P_{Begg}=1.16; Figure 5C).

Outlier and influence analyses

The presence of outliers and influential studies can affect the validity and robustness of conclusions from a meta-analysis. Figure 5 shows the standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ^2 (tau2.del), and test statistics (QE.del) for the random-effects model that was used for the analysis of complications (Figure 6). The study by Vakharia et al. was identified as a potential outlier that led to heterogeneity and seemed to be an influential study. As the study had a large sample size (35,061 patients, robotic-assisted=13,617; conventional=21,444), making it useful for analysing national trends, and the hat values and weights showed that this study comprised the largest proportion of patients in the meta-analysis, it was not excluded from the meta-analysis. A similar result was observed in the analysis of the revision rate. No outlier was included in the analysis of non-implant-specific complications.

Discussion

For more than 50 years, UKA has been performed to treat isolated compartmental knee arthritis. Despite many years of experience in performing UKA, some studies have reported that UKA has higher rates of failure than total knee arthroplasty[27]. Newly designed robotic-assisted systems are believed to increase the precision and accuracy of UKA, possibly leading to fewer complications and lower revision rates[28]. Many studies have evaluated the complications of robotic-assisted UKA; however, there are few studies on the complications of robotic-assisted UKA compared with those with conventional UKA. Researchers have reported conflicting results about the complication rates between robotic-assisted and conventional UKA. Hansen et al. and Blyth et al. did not find a significant difference in the rate of complications between the two techniques[12,14]. Wong et al. found that the robotic-arm-assisted arthroplasty cohort had a higher early revision rate than the conventional group, whereas other studies reported that robotic-assisted UKA had fewer complications and lower revision rates than conventional UKA[20,23,25]. It is important to assess the complications of this new technology before it can be widely used[21]. Therefore, we conducted this systematic review and meta-analysis to compare the complication rates, revision rates, and non-implant-specific complications between robotic-assisted and conventional UKA. The main finding of our meta-analysis was that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA; however, there were no significant differences in non-implant-specific complications. Thus, our study confirms that robotic-assisted UKA has fewer complications and lower revision rates than the conventional procedure.

Many studies have explored the relationship between the component position and its impact on implant survival and patient satisfaction[29, 30]. Some authors believe that a reduction in alignment errors of these components will ultimately affect implant function or survival[31]. Some studies confirmed that the proportion of patients with tibial and femoral component implantation within 2° of the target position was significantly greater in the group that underwent robotic-assisted UKA, resulting in better long-term clinical scores and a lower implant failure rate[13, 32, 33]. Therefore, it could be inferred that the use of a robotic-assisted system in UKA can reduce implantation errors, leading to fewer complications and lower rates of revision surgery than conventional UKA. Although non-implant-specific complications are likely to be related to the procedure, fewer complications were considered to be directly related to the comparative study itself[11]. Mergenthaler et al. reported no complications related to the use of the robotic system[24]. Pearle et al. suggested that no further rigid fixation device is necessary, which reduces potential complications such as infection, iatrogenic fractures, or soft-tissue injury caused by the weight and movement of the robot[34]. However, there were no significant differences in non-implant-specific complications between the two techniques in our meta-analysis. Therefore, there is no evidence that the use of robotic systems can add to the non-implant-specific complications of UKA.

Although robotic-assisted UKA is widely performed and is the current trend in orthopaedic surgery, it has some shortcomings. Robotic-assisted UKA was found to significantly prolong the duration of surgery compared with conventional UKA (Figure S1). Some studies have also documented that robotic-arm-assisted UKA has a higher cost[35, 36]. In addition, the device-related complications, such as pin-site fracture and infection, are non-negligible. We checked all articles included in the meta-analysis for a statement on funding or conflicts of interest related to the work. When such a statement was provided, we categorised the study as an industry-funded study or involving authors with financial conflicts of interest. We found that the included articles were more likely to be industry funded or written by authors with financial conflicts of interest (Figure S2). Therefore, this information should not be overlooked, and more large-scale, non-commercially supported studies evaluating the efficacy of the two treatments in this patient population are needed in the future.

This meta-analysis has several limitations. First, long-term revision rates depend on the duration of follow-up; however, all included studies had a short follow-up period (3-60 months). Hence, the data on revision rates are not reliable. Future studies with a longer follow-up duration, preferably 10 years, are necessary to assess complications and revision rates. Second, some studies were not RCTs and had a small sample size, which increase the possibility of publication bias. Therefore, our results should be further confirmed by large-scale RCTs. Third, the types of robotic-assisted UKA performed in each study were different, as shown in Table 1. The different types of robotic systems used were the Acrobot, RIO™ or Mako-assisted Restoris, and Navio systems. Rapid advances in robotic-assisted technology have led to improvements in UKA over the past 10 years. Implant position, soft-tissue balance, and radiographic component alignment seem to have gradually improved with the development of robotic-assisted systems. Considering the evolution of this technology and its possible impact on outcomes, well-designed studies are necessary to advance the understanding of the impact of different robotic systems. Fourth, all included studies were limited to the English literature; therefore, some related studies published in other languages that might have met the inclusion criteria could have been missed. Fifth, most of the studies in our meta-analysis did not report pin-site and device-specific complications. Revision surgeries secondary to pin-site fracture were reported in some studies; however, the sample size was small. Therefore, we did not conduct a systematic analysis on these specific complications and revisions. Although we attempted to identify and retrieve all additional unpublished information, some missing data were inevitable. In addition, our results were not adjusted for other factors that could influence complications, such as patient age and weight, anterior cruciate ligament status, soft-tissue balance, and composition and thickness of the polyethylene component. Sixth, some of the included studies did not mention the reasons for loss to follow-up or lack details about revision surgery. However, these might have no effect on the analysis. Finally, when events such as complications and revisions occur over a non-fixed period, it is common to use hazard ratios as the statistic of interest. As the 'metafor' package has no function for using hazard ratios as the statistic of interest, we used RRs as the statistic of interest across all studies.

Conclusions

To summarise, this meta-analysis study indicates that robotic-assisted UKA is associated with fewer complications and lower rates of revision surgery than conventional UKA. No evidence suggests that the use of robotic systems might increase the rate of non-implant-specific complications of UKA.

Therefore, the study provides evidence that robotic-assisted UKA has fewer complications and lower revision rates than conventional UKA; however, owing to important limitations, the results lack reliability, and more studies are required.

Acknowledgements

We thank the Shandong First Medical University for providing statistical and technical assistance.

Author contributions

Yifeng Sun conceived the study and wrote the manuscript. Wenqiang Zhang analysed the data. Wei Liu generated data. Xiuhua Hu and Jian Hou reviewed the manuscript.

Funding sources

This work was supported by the Natural Science Foundation of China (81702667), Wu Jieping Medical Foundation (320.6750.18466), and Shandong Provincial Key Research and Development Project (GG201809250496).

Competing interests

The authors declare no conflicts of interest.

Patient consent for publication

Not required.

Data sharing statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Ethics approval statement

This study is a systematic review and meta-analysis, there was no Ethics Committee(s) or Institutional Board(s) involvement in this study.

References

1. Labek G, Sekyra K, Pawelka W, Janda W, Agreiter M, Schlichtherle R, Stöckl B, Krismer M: outcome And Reproducibility Of Data Concerning The Oxford Medial Unicompartmental Knee Arthroplasty *Orthopaedic Proceedings* 2011; 93:131-.

2. Lang J, Mannava S, Floyd A, Goddard M, Smith B, Mofidi A, M. Seyler T, Jinnah R. Robotic systems in orthopaedic surgery. *The Journal of bone and joint surgery British volume* 2011;**93**: 1296-9.

3. Lonner JH, Moretti VM. The Evolution of Image-Free Robotic Assistance in Unicompartmental Knee Arthroplasty. *American journal of orthopedics* 2016;**45**: 249-54.

4. Zhang F, Li H, Ba Z, Bo C, Li K. Robotic arm-assisted vs conventional unicompartmental knee arthroplasty: A meta-analysis of the effects on clinical outcomes. *Medicine* 2019;**98**.

5. Chin BZ, Tan SSH, Chua KCX, Budiono GR, Syn NL, Oneill GK. Robot-Assisted versus Conventional Total and Unicompartmental Knee Arthroplasty: A Meta-analysis of Radiological and Functional Outcomes. *Journal of Knee Surgery* 2020.

6. Fu J, Wang Y, Li X, Yu B, Ni M, Chai W, Hao L, Chen J. Robot-assisted vs. conventional unicompartmental knee arthroplasty : Systematic review and meta-analysis. *Orthopade* 2018;**47**: 1009-17.

7. Wells G: The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Non-Randomised Studies in Meta-Analyses *Symposium on Systematic Reviews: Beyond the Basics* 2014.

8. Galbraith RF. Some Applications of Radial Plots. *Journal of the American Statistical Association* 1994;**89**: 1232-42.

9. Viechtbauer W, Cheung MWL. Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods* 2010;**1**: 112-25.

10. Viechtbauer W. Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software* 2010;**36**: 1-48.

11. Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, Barrett ARW, Davies BL. Hands-on robotic unicompartmental knee replacement - A prospective, randomised controlled study of the Acrobot system. *Journal of Bone and Joint Surgery-british Volume* 2006;**88**: 188-97.

12. Hansen DC, Kusuma SK, Palmer RM, Harris KB. Robotic Guidance Does Not Improve Component Position or Short-Term Outcome in Medial Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2014;**29**: 1784-9.

13. Maccallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic-assisted and conventional unicompartmental knee arthroplasty. *European Journal of Orthopaedic Surgery and Traumatology* 2016;**26**: 93-8.

14. Blyth M, Anthony I, Rowe P, Banger M, Maclean A, Jones B. Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. *Bone and Joint Research* 2017;**6**: 631-9.

15. Gilmour A, Maclean A, Rowe P, Banger M, Donnelly I, Jones B, Blyth M. Robotic-Arm Assisted Versus Conventional Unicompartmental Knee Arthroplasty. The 2 year Clinical outcomes of a

Randomised Controlled Trial. *Journal of Arthroplasty* 2018: S0883540318301980.

16. Kayani, Konan, T JR, Pietrzak, S S, Huq, Tahmassebi, S F, Haddad. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty. *Bone & Joint Journal* 2018.

17. Batailler C, White N, Ranaldi FM, Neyret P, Servien E, Lustig S. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2019;**27**: 1232-40.

18. Canetti R, Batailler C, Bankhead C, Neyret P, Servien E, Lustig S. Faster return to sport after robotic-assisted lateral unicompartmental knee arthroplasty: a comparative study. *Archives of Orthopaedic and Trauma Surgery* 2018;**138**: 1765-71.

19. Banger M, Blyth M, Jones B, MacLean A, Rowe P, Glasgow NG, Clyde GU. 5 Year Results Of A Randomised Trial Of Robotic Arm Assisted Vs Manual Unicompartmental Knee Arthoplasty.

20. Wong J, Murtaugh T, Lakra A, Cooper HJ, Shah RP, Geller JA. Robotic-assisted unicompartmental knee replacement offers no early advantage over conventional unicompartmental knee replacement. *Knee Surgery, Sports Traumatology, Arthroscopy* 2019;**27**: 2303-8.

21. Cool CL, Needham K, Khlopas A, Mont MA. Revision Analysis of Robotic Arm–Assisted and Manual Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2019;**34**: 926-31.

22. Kayani B, Konan S, Tahmassebi J, Rowan FE, Haddad FS. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty. *Journal of Bone and Joint Surgery-british Volume* 2019: 24-33.

23. Vakharia RM, Sodhi N, Cohen-Levy WB, Vakharia AM, Mont MA, Roche MW. Comparison of Patient Demographics and Utilization Trends of Robotic-Assisted and Non-Robotic-Assisted Unicompartmental Knee Arthroplasty. *The journal of knee surgery* 2019.

24. Mergenthaler G, Batailler C, Lording T, Servien E, Lustig S. Is robotic-assisted unicompartmental knee arthroplasty a safe procedure? A case control study. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 2020.

25. St Mart JP, de Steiger RN, Cuthbert A, Donnelly W. The three-year survivorship of robotically assisted versus non-robotically assisted unicompartmental knee arthroplasty. *The bone & joint journal* 2020;**102-B**: 319-28.

26. Macaskill P, Walter SD, Irwig L. A comparison of methods to detect publication bias in meta-analysis. *Statistics in medicine* 2001;**20**: 641-54.

27. Sun X, Su Z. A meta-analysis of unicompartmental knee arthroplasty revised to total knee arthroplasty versus primary total knee arthroplasty. *Journal of Orthopaedic Surgery and Research* 2018;**13**: 158.

28. Roche MW. Robotic-assisted unicompartmental knee arthroplasty: the MAKO experience. *Clinics in Sports Medicine* 2014;**33**: 123-32.

29. Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A. What is the optimal alignment of the tibial and femoral components in knee arthroplasty? An overview of the literature. *Acta orthopaedica* 2014;**85**: 480-7.

30. Vandekerckhove P-J, Lanting B, Bellemans J, Victor J, MacDonald S. The current role of coronal plane alignment in total knee arthroplasty in a preoperative varus aligned population: an evidence based review. *Acta Orthop Belg* 2016;**82**: 129-42.

31. Kim KT, Lee S, Kim TW, Lee JS, Boo KH. The influence of postoperative tibiofemoral alignment on the clinical results of unicompartmental knee arthroplasty. *Knee surgery & related research* 2012;**24**: 85.

32. Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A. What is the optimal alignment of the tibial and femoral components in knee arthroplasty. *Acta Orthopaedica* 2014;**85**: 480-7.

33. Chatellard R, Sauleau V, Colmar M, Robert H, Raynaud G, Brilhault J. Medial unicompartmental knee arthroplasty: Does tibial component position influence clinical outcomes and arthroplasty survival? *Orthopaedics & Traumatology-surgery & Research* 2013;**99**.

34. Pearle AD, Oloughlin PF, Kendoff D. Robot-Assisted Unicompartmental Knee Arthroplasty. *Journal of Arthroplasty* 2010;**25**: 230-7.

35. Moschetti WE, Konopka JF, Rubash HE, Genuario JW. Can Robot-Assisted Unicompartmental Knee Arthroplasty Be Cost-Effective? A Markov Decision Analysis. *The Journal of arthroplasty* 2016;**31**: 759-65.

36. Sinha RK. Outcomes of robotic arm-assisted unicompartmental knee arthroplasty. *American journal of orthopedics (Belle Mead, NJ)* 2009;**38**: 20-2.

Figure legends

Figure 1. Flow diagram depicting the study selection procedure.

Figure 2. (A) Galbraith plot, (B) quantile-quantile (Q-Q) plot, and (C) forest plot for the comparison of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 3. (A) Galbraith plot, (B) quantile-quantile (Q-Q) plot, and (C) forest plot for the comparison of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 4. (A) Galbraith plot, (B) quantile-quantile (Q-Q) plot, and (C) forest plot for the comparison of non-implant-specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-implant-specific complications (C).

Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ2 (tau2.del), and test statistics (QE.del) for the random-effects model that was used for the analysis of the complications are shown.

Figure S1. (A) Galbraith plot, (B) quantile-quantile (Q-Q) plot, and (C) forest plot for the comparison of surgical time between robotic-assisted and conventional unicompartmental knee arthroplasty.

Figure S2. Industry funding and conflict of interest in studies on robotic-arm-assisted and conventional unicompartmental knee arthroplasty.

Tables

Table 1. Main characteristics of all articles included in the meta-analysis

Table S1. Assessment of the quality of the included studies using the Newcastle-Ottawa scale

Figure 1. Literature search and study selection.

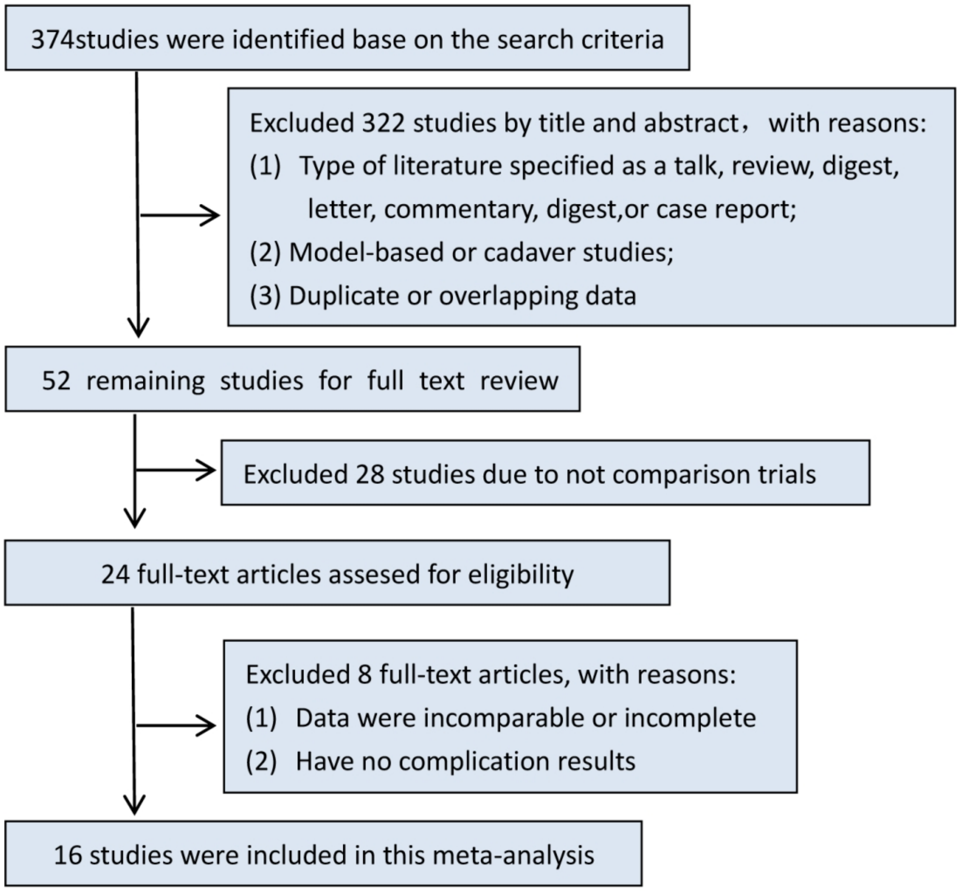
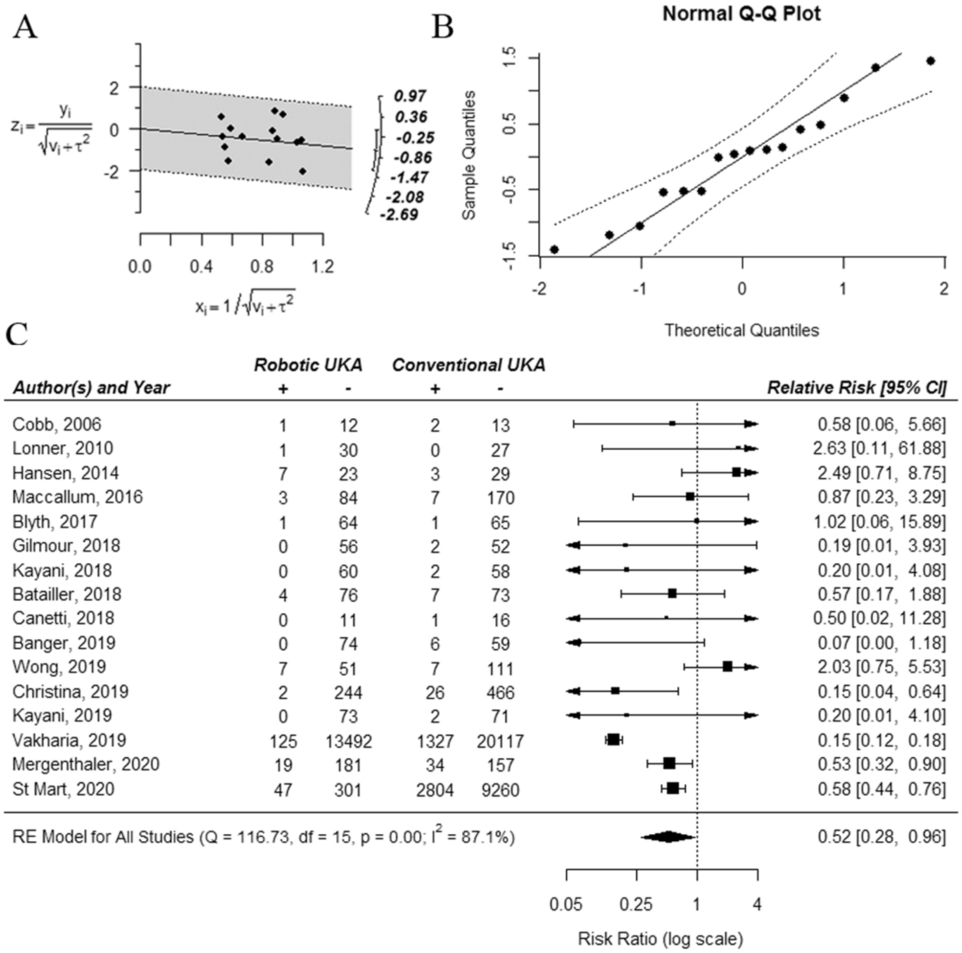


Figure 1. Flow diagram depicting the study selection procedure.



	Robotic UKA		Conventional UKA		
Author(s) and Year	+	-	+	-	*Relative Risk [95% CI]*
Cobb, 2006	1	12	2	13	0.58 [0.06, 5.66]
Lonner, 2010	1	30	0	27	2.63 [0.11, 61.88]
Hansen, 2014	7	23	3	29	2.49 [0.71, 8.75]
Maccallum, 2016	3	84	7	170	0.87 [0.23, 3.29]
Blyth, 2017	1	64	1	65	1.02 [0.06, 15.89]
Gilmour, 2018	0	56	2	52	0.19 [0.01, 3.93]
Kayani, 2018	0	60	2	58	0.20 [0.01, 4.08]
Batailler, 2018	4	76	7	73	0.57 [0.17, 1.88]
Canetti, 2018	0	11	1	16	0.50 [0.02, 11.28]
Banger, 2019	0	74	6	59	0.07 [0.00, 1.18]
Wong, 2019	7	51	7	111	2.03 [0.75, 5.53]
Christina, 2019	2	244	26	466	0.15 [0.04, 0.64]
Kayani, 2019	0	73	2	71	0.20 [0.01, 4.10]
Vakharia, 2019	125	13492	1327	20117	0.15 [0.12, 0.18]
Mergenthaler, 2020	19	181	34	157	0.53 [0.32, 0.90]
St Mart, 2020	47	301	2804	9260	0.58 [0.44, 0.76]
RE Model for All Studies (Q = 116.73, df = 15, p = 0.00; I^2 = 87.1%)					0.52 [0.28, 0.96]

Figure 2. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

79x78mm (600 x 600 DPI)

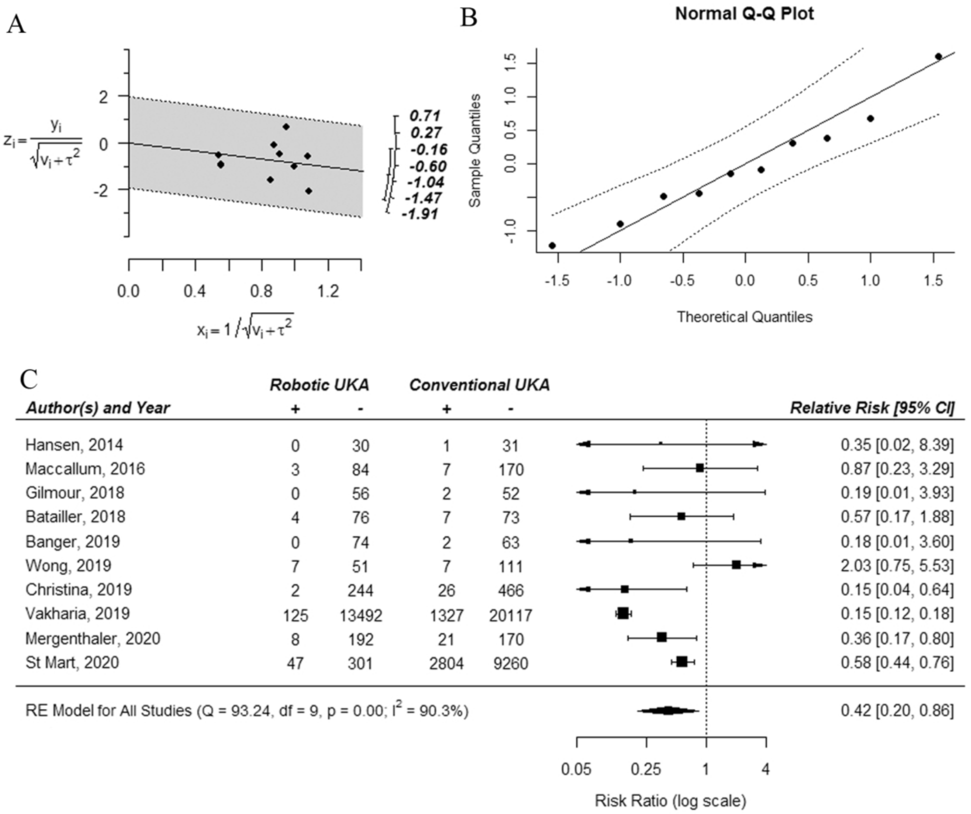


Figure 3. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of revision rate between robotic-assisted and conventional unicompartmental knee arthroplasty.

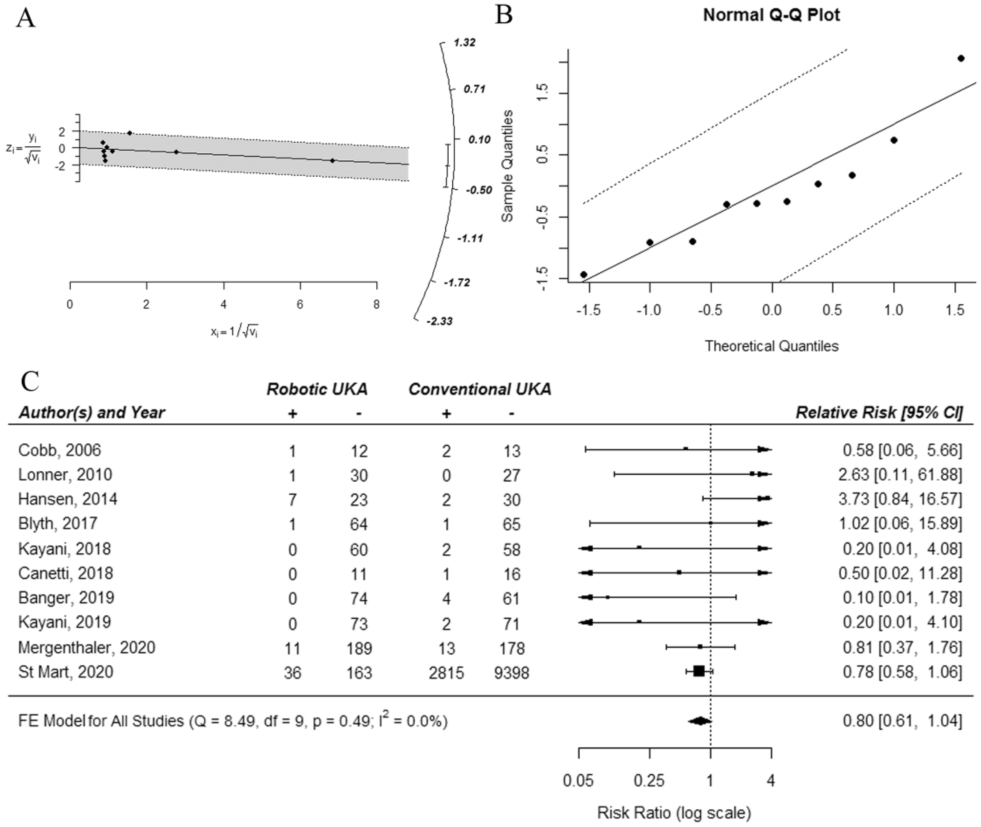


Figure 4. (A) Galbraith plot, (B) Quantile-Quantile (Q-Q) plot, and (C) Forest plot for the meta-analysis of non-implant specific complications between robotic-assisted and conventional unicompartmental knee arthroplasty.

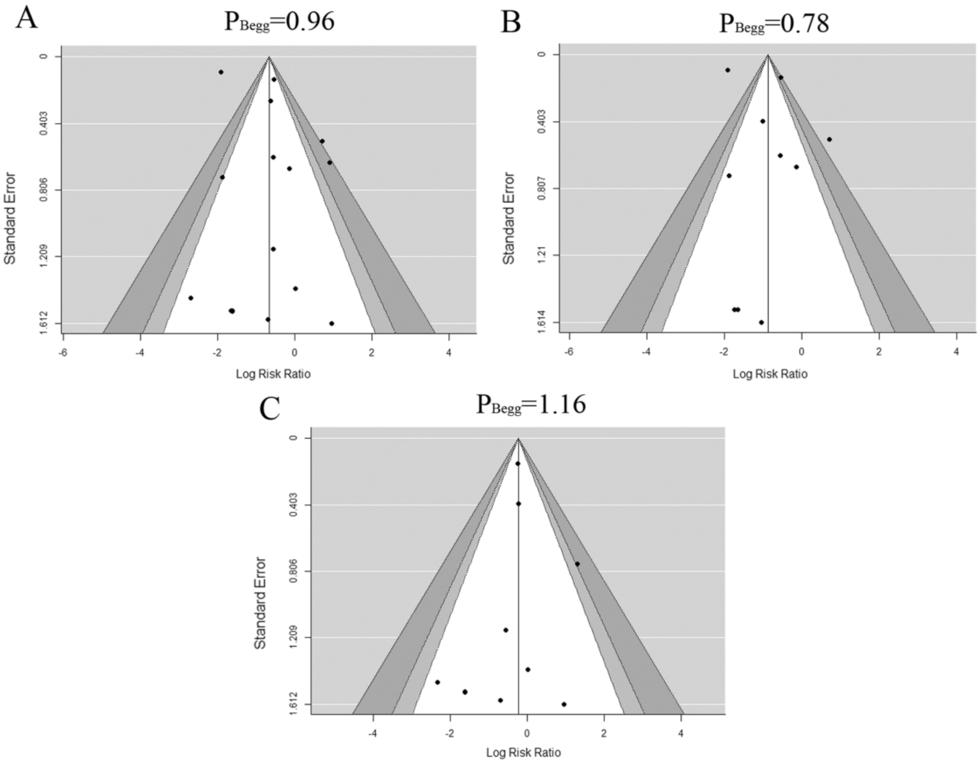


Figure 5. Contour-enhanced funnel plots of the included studies showing no evidence of publication bias in complications (A), revision rate (B) and non-implant specific complications (C).

150x118mm (600 x 600 DPI)

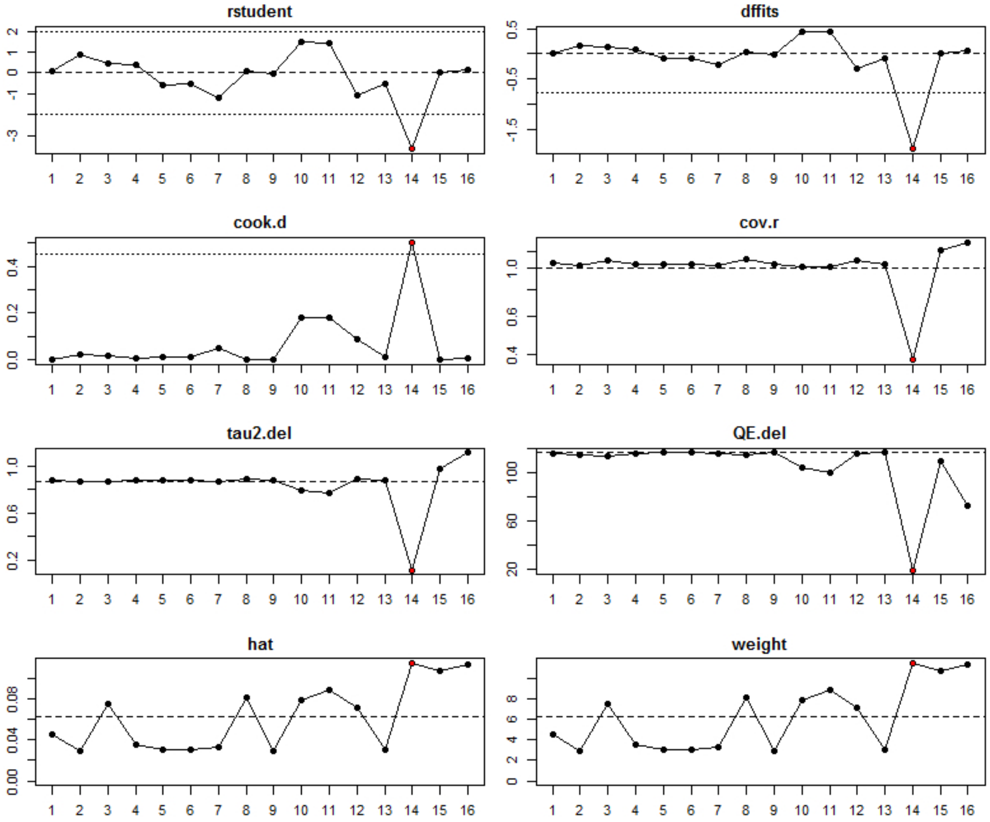
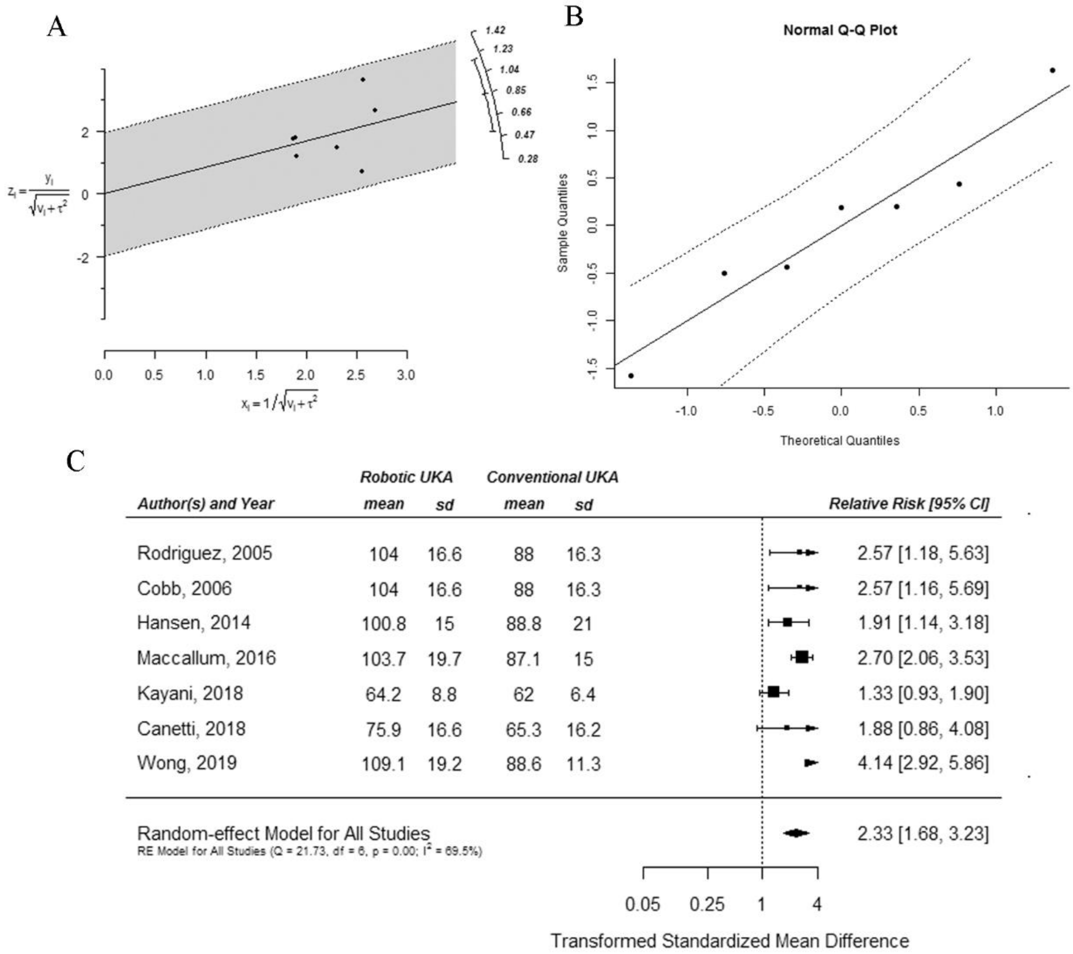


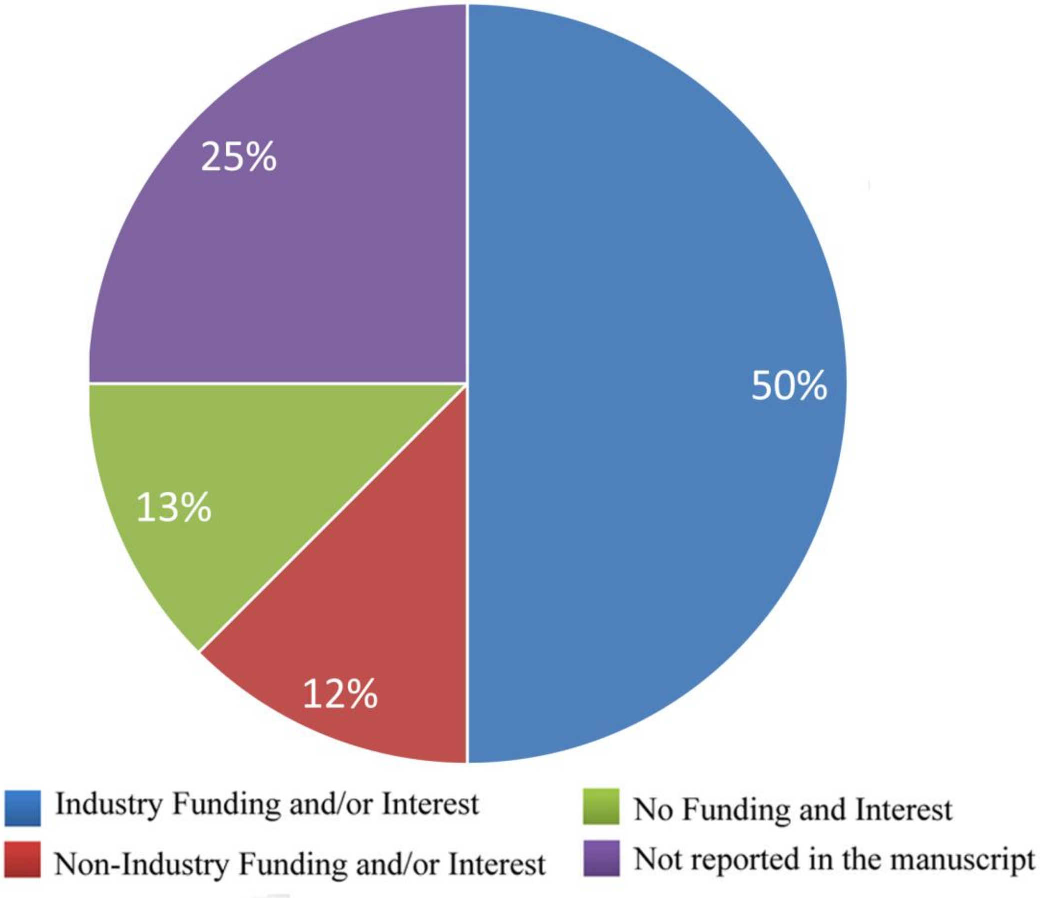
Figure 6. Outlier and influence analyses. The standardised residuals (rstudent), DFFITS (dffits), Cook's distances (cook.d), covariance ratios (cov.r), estimates of τ2 (tau2.del) and test statistics (QE.del) for the random-effects model that was used for the analysis of the complications.

210x177mm (95 x 95 DPI)

Table S1. Assessment of the studies’ qualities using the Newcastle-Ottawa Scale.

Order	Studys	Year	Country	Selection	Comparability	Exposure	Quality Score
1	Cobb *et al*	2006	UK	★★★★	★★	★★	★★★★★★★★
2	Lonner *et al*	2010	USA	★★★	★★	★	★★★★★★
3	Hansen*et al*	2014	USA	★★★	★	★	★★★★★
4	Maccallum *et al*	2016	USA	★★★	★★	★	★★★★★★
5	Blyth *et al*	2017	UK	★★★★	★★	★★	★★★★★★★★
6	Gilmour *et al*	2018	UK	★★★★	★★	★★	★★★★★★★★
7	Kayani *et al*	2018	UK	★★★	★★	★	★★★★★
8	Batailler *et al*	2018	France	★★★	★	★	★★★★★
9	Canetti *et al*	2018	France	★★★	★	★	★★★★★
10	Banger *et al*	2019	UK	★★	★★	★★	★★★★★★
11	Wong *et al*	2019	USA	★★★	★	★	★★★★★
12	Christina *et al*	2019	USA	★★★	★	★	★★★★★
13	Kayani *et al*	2019	UK	★★★	★★	★	★★★★★★
14	Vakharia *et al*	2019	USA	★★★	★	★	★★★★★
15	Mergenthaler *et al*	2020	France	★★★	★	★	★★★★★
16	St Mart *et al*	2020	Australia	★★★	★	★	★★★★★


A
1.42
1.23
1.04
0.85
0.66
0.47
0.28
2
0
-2
$z_i = \frac{y_i}{\sqrt{v_i + \tau^2}}$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$x_i = 1/\sqrt{v_i + \tau^2}$
B
Normal Q-Q Plot
Sample Quantiles
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Theoretical Quantiles
-1.0
-0.5
0.0
0.5
1.0
C
Robotic UKA
Conventional UKA
Author(s) and Year
mean
sd
mean
sd
Relative Risk [95% CI]
Rodriguez, 2005 104 16.6 88 16.3 2.57 [1.18, 5.63]
Cobb, 2006 104 16.6 88 16.3 2.57 [1.16, 5.69]
Hansen, 2014 100.8 15 88.8 21 1.91 [1.14, 3.18]
Maccallum, 2016 103.7 19.7 87.1 15 2.70 [2.06, 3.53]
Kayani, 2018 64.2 8.8 62 6.4 1.33 [0.93, 1.90]
Canetti, 2018 75.9 16.6 65.3 16.2 1.88 [0.86, 4.08]
Wong, 2019 109.1 19.2 88.6 11.3 4.14 [2.92, 5.86]
Random-effect Model for All Studies 2.33 [1.68, 3.23]
RE Model for All Studies (Q = 21.73, df = 6, p = 0.00; I² = 69.5%)
0.05
0.25
1
4
Transformed Standardized Mean Difference


25%
50%
13%
12%
Industry Funding and/or Interest
Non-Industry Funding and/or Interest
No Funding and Interest
Not reported in the manuscript

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE		**Does robotic- assisted unicompartmental knee arthroplasty have lower complication and revision rates than the conventional procedure? A Systematic Review and Meta-Analysis**	1
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	Not exist
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	5

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Not done
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5-6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	7
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	10
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	9
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	9
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	10
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	10
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	10-11
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	12-13
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	13
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	13

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.