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Navigation and robotics improved alignment compared with PSI and conventional instrument, while clinical outcomes were similar in TKA: a network meta-analysis

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Abstract

Purpose To achieve the desired alignment more accurately and improve postoperative outcomes, new techniques such as computer navigation (Navigation), patient-specific instruments (PSI) and surgical robots (Robot) are applied in Total Knee Arthroplasty (TKA). This network meta-analysis aims to compare the radiological and clinical outcomes among the above-mentioned techniques and conventional instruments (CON).

Methods A PRISMA network meta-analysis was conducted and study protocol was published online at INPLASY (INPLASY202060018). Three databases (PubMed, EMBASE and Cochrane) were searched up to June 1, 2020. Randomised controlled trials (RCTs) comparing any two of the four techniques were included. A Bayesian network meta-analysis was performed focusing on radiological and clinical outcomes. The odds ratio (OR) or mean difference (MD) in various outcomes were calculated, and the interventions were ranked by the surface under the cumulative ranking area (SUCRA) value.

Results Seventy-three RCTs were included, with a total of 4209 TKAs. Navigation and Robot could significantly reduce the occurrence of malalignment and malposition compared with PSI and CON, and Navigation could obtain higher medium-and-long-term KSS knee scores than CON. Robot had the greatest advantage in achieving the desired alignment accurately, followed by Navigation; Navigation had the greatest advantage in the KSS score.

Conclusion Navigation and Robot did improve the accuracy of alignment compared with PSI and conventional instrument in TKA, but the above four techniques showed no clinical significance in postoperative outcomes.

Level of evidence I

Keywords Total knee replacement · Total knee arthroplasty · Computer navigation · Robotics · Patient-specific instruments · Network meta-analysis

Abbreviations

TKA	Total knee arthroplasty
Navigation	Computer navigation
Robot	Surgical robots
PSI	Patient-specific instruments
CON	Conventional TKA
NMA	Network meta-analysis
RCTs	Randomised controlled trials
OR	Odds ratio
MD	Mean difference
SUCRA	Surface under the cumulative ranking area
PROM	Patient-reported outcome measures
MCID	Minimal clinically important difference
KSS	Knee Society Knee Scoring System
WOMAC	Western Ontario and McMaster University osteoarthritis index scores

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Introduction

The alignment and component position are key factors for the success of total knee arthroplasty (TKA) [12, 20, 24, 31, 35, 37]. To accurately achieve the desired alignment and component position, increasing new techniques have been applied in TKA, including computer navigation (Navigation) [9], patient-specific instruments (PSI) [36, 40] and surgical robots (Robot) [11]. In the past 20 years, there have been many reports on the comparison between these new techniques and conventional TKA (CON) with variable outcomes [1, 2, 6, 14, 17, 30, 34].

Up to now, there has been no literature conducting a comprehensive comparison and analysis of the above four surgical techniques. Network meta-analysis (NMA) can help to fill this gap. NMA is an extension of conventional pairwise meta-analysis. It can perform direct and indirect comparisons at the same time, even when the two measures have never been compared via head-to-head evaluation [22]. Besides, the best intervention measures can be evaluated by the value of surface under the cumulative ranking area (SUCRA) [10].

This study only included randomised controlled trials (RCTs) with level of evidence I, and conducted a thorough and comprehensive evaluation on the radiological and clinical outcomes of the four surgical techniques, i.e. Navigation, PSI, Robot, and CON, and attempted to rank the above surgical techniques. The authors hypothesised that Navigation, PSI, and Robot could improve the accuracy of alignment, but have no significant improvement on the clinical outcomes.

Methods

This NMA strictly complied with "PRISMA Extension Statement" [7]. The complete PRISMA checklist could be found in Appendix A. This NMA has been registered on the INPLASY (INPLASY202060018).

Search strategy

A comprehensive search was conducted in three databases (PubMed, EMBASE and Cochrane Library) from their inception to June 1, 2020 using a combination of MeSH terms and free words. Please refer to Appendix B for more details on search strategies.

Inclusion and exclusion criteria

Types of studies

This study only included RCTs; non-English articles, animal studies, cadaver studies, case reports, comments, letters, editorials, protocols, guidelines, unpublished articles, and review papers were excluded.

Types of participants

Patients who underwent primary TKA and were ≥ 18 years old were included, regardless of gender and race. Only the most recently published articles among the multiple articles on the same research subjects by the same author or team were included. However, if the study subjects or outcome indicators were different, they would be separately included in this NMA.

Types of interventions

RCTs containing two or more interventions of Navigation, PSI, Robot and CON were included in this NMA; the included studies were not limited to two-arm RCTs.

Types of outcomes

The radiological outcomes included: (1) mechanical axis outliers; (2) coronal femoral component angle outliers; (3) coronal tibial component angle outliers; (4) sagittal femoral component angle outliers; and (5) sagittal tibial component angle outliers. Deviations of more than 3° from the target value were defined as outliers. The clinical outcomes included: (1) short-term Knee Society Score (KSS) knee scores (follow-up period < 5 years); (2) short-term KSS function scores; (3) medium-and-long-term KSS knee scores (follow-up period ≥ 5 years); and (4) medium- and long-term KSS function scores.

Data extraction and quality assessment

Two reviewers (KL and LML) conducted the screening process of the article by reading the title and abstract, and then further evaluated the article by reading the full text. Data were extracted from the included literature according to the pre-designed table, including study characteristics, patient demographics and the risk of bias. If the data that needed to be included in the meta-analysis were lost or were only shown in the form of pictures, the authors would try to contact the author for further information. If no responses were received, data would be extracted by digital ruler software or excluded. Two investigators (KL and LML) used the Cochrane Risk of Bias Tool for RCTs to independently evaluate the bias of the included literature. Different opinions in the process were resolved by discussion or passed to a third person (LG).

Data analysis

An NMA was conducted for outcomes of the four surgical techniques in a Bayesian approach. Data were combined with a random-effects model and Markov Chain Monte

Carlo was implemented to the model. In the analysis process, the prior distribution was set as normal distribution and three chains were used for simulation. The number of iterations was set to 50,000, and the first 5000 were used for the annealing algorithm to eliminate the impact of the initial value. For binary and continuous variables, odds ratios (OR) and mean differences (MD) were selected, respectively. When the 95% confidence interval (95% CI) of OR contained 1 or the 95% CI of MD contained 0, the result was considered to have no statistical significance. The interventions were ranked by the SUCRA value, which showed the percentage of effectiveness of each treatment and ranged from 0 to 100%. Intervention with larger SUCRA values was generally considered to have a better effect [10]. A network graph was drawn to reflect the number and distribution of the included literature. Meanwhile, funnel plots were applied to reflect the publication bias of outcomes that included more than 10 RCTs. Inconsistency factor (IF) and node-splitting method were used to evaluate the consistency. The I^2 statistic was used to statistically assess the presence of heterogeneity. Subgroup analyses or sensitivity analyses were planned if necessary. The calculation was performed by WinBUGS (Version 1.4.3, Biostatistics the Medical Research Council, Cambridge, United Kingdom), R software (Version 4.0.2, R foundation for statistical Computing, Vienna, Austria), and Stata software (Version 15.0, Stata Corp, Texas, USA).

Results

A total of 73 RCTs with 4209 TKAs were included in this NMA (Fig. 1). The characteristics and risk of bias assessment of the included literature are shown in Table 1 and Fig. 2, respectively; the network graph was shown in Fig. 3. For more details on the included literature and the risk assessment of bias, see Appendix C.

Robot and Navigation were significantly better than PSI and CON in the control of lower limb alignment and component position (Table 2). Robot had the lowest probability of the outlier of lower limb alignment and component position, followed by Navigation (Table 3). Except for Navigation that had statistically significant difference compared to CON in medium-and-long-term knee scores, the four techniques showed no significant difference in KSS scores (Table 2). Navigation had the greatest probability of obtaining better KSS scores after surgery through ranking analysis (Table 3). The assessment revealed that heterogeneity and inconsistency were low for most outcomes (Appendix D). For more details on data analysis and publication bias, please refer to Appendix E and F, respectively.

Discussion

The most important finding of this study is that Navigation and Robot could significantly reduce the occurrence of malalignment and malposition compared with PSI and CON, but the above four techniques showed no clinical significance in postoperative outcomes.

Referring to the Knee Society roentgenographic evaluation system [5], this study evaluated alignment and component position from the following five aspects: mechanical axis outliers, coronal femoral component angle outliers, coronal tibial component angle outliers, sagittal femoral component angle outliers and sagittal tibial component angle outliers. The results showed that Robot and Navigation were significantly better than PSI and CON in the alignment and component position, and Robot had the lowest probability of outliers (Tables 2 and 3). Rhee et al. reported that Navigation could improve postoperative alignment compared with CON [34]. Van der List and Rebal also expressed the same view [33, 41]. The latest meta-analysis also agreed that Robot could significantly improve alignment and component position [1, 2, 29]. As of PSI, two latest meta-analyses also supported the views of this study [6, 17]. Besides, Pietsch et al. found a higher frequency of recuts with PSI [32]. Suggestions from PSI manufacturers for component sizes and positioning were often not accurate enough and intraoperative revision was required [4, 16, 38, 42]. Maybe these were the reasons why there was no significant difference between PSI and CON in alignment.

Knee Society clinical rating system [8] was adopted in this study to evaluate clinical outcomes; clinical scores were divided into short-term and medium-and-long-term. Except for significant difference in medium-and-long-term knee scores of Navigation compared to CON, these four techniques showed no significant difference in KSS scores. Navigation had the greatest probability of obtaining better KSS scores after surgery through ranking analysis (Tables 2 and 3). Navigation was better than CON in KSS and Western Ontario and McMaster University osteoarthritis index scores (WOMAC) during 5–8 years of follow-up [30]. Robot was also superior to CON in few postoperative clinical scores [29]. Kizaki and Mannan found that PSI did not significantly improve clinical scores compared with CON [13, 23]. The reason why so many studies showed no difference could be the commonly used scoring system nowadays, which is not sensitive enough [18]. Still, the statistical significance of patient reported outcome measures (PROM) does not necessarily represent clinical significance. Lee et al. believed that the minimal clinically important difference (MCID) of KSS knee score after TKA was 5.3–5.9 points [15], while Lizaur–Utrill's

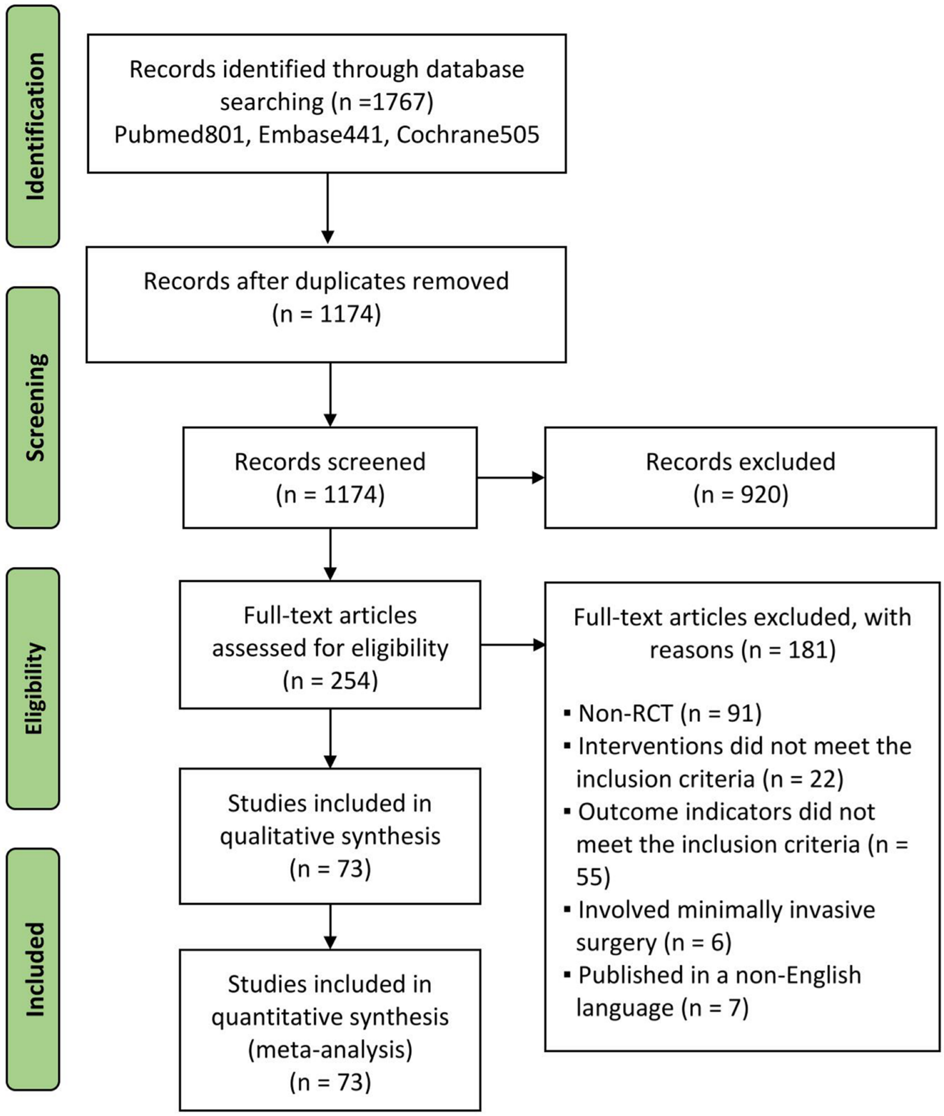


Fig. 1 PRISMA flow diagram for selection of included RCTs

research suggested it should be 9 points [19]. The statistical significances of Navigation with CON in medium-and-long-term knee scores (1.380 points) in this study were far from clinical significance. Navigation performed well in alignment and obtained higher scores in KSS scores, which validated the views that inaccurate alignment could result in poor clinical outcomes [12, 20, 24, 31, 35, 37]; after all, various factors could affect postoperative clinical outcomes, such as age, BMI, psychological status, soft tissue balance, component design, and rehabilitation.

This study has the following strengths compared with other meta-analyses. First, most of the previous articles were head-to-head two-arm studies. Second, the previous studies had either limited number of literatures [14, 34] or included non-RCTs, which enlarged the number [1, 2, 30]. Third, some previous articles focused only on medium-and-long-term clinical outcomes [14, 34], but RCTs with shorter follow-up are still meaningful for analysing the accuracy of alignment.

This study also has limitations. First, the prostheses in these included RCTs were different, and the navigation systems, robot systems, and PSI systems used were also diverse. Second, the biases of the included RCTs might also influence the results. Third, the indicators for evaluating clinical outcomes were various, so the authors could only the outliers and KSS scores to evaluate outcomes. Finally, there are few RCTs on Robot with long-term follow-up.

Navigation and Robot are much more expensive and require longer operation time than conventional TKA [18, 21, 39]. Besides, complications of these techniques are occasionally reported [3]. These disadvantages make the application of Navigation and Robot on normal primary TKA not so cost-efficient. However, for extremely challenging

Table 1 Characteristics of the included RCTs

Study ID	Country	Study design	Comparison	Sample size[a]		Age at surgery (year)		Gender (female/male)		BMI (kg/m^2)		Follow-up (months)	Outcomes[b]
				Experimental	Conventional	Experimental	Conventional	Experimental	Conventional	Experimental	Conventional		
d'Amato2019	Italy	RCT	Navigation/CON	60 (48)	60 (47)	68.8	71.1	30/30	30/30	NR	NR	123	1, 6, 7, 8, 9
Hsu2019	China	RCT	Navigation/CON	56	56	68.7 ± 5.8	68.7 ± 5.8	44/12	44/12	28.8 ± 4.1	28.8 ± 4.1	97	1, 2, 3, 4, 5
Selvanayagam2019	India	RCT	Navigation/CON	25	25	63.2	62.7	NR	NR	28.7	28.3	55	1, 6, 7
Xu2019	China	RCT	Navigation/CON	39	40	65.28 ± 6.77	65.33 ± 7.59	30/9	31/9	NR	NR	NR	1
Cip2018	Australia	RCT	Navigation/CON	100 (27)	100 (32)	79.3 ± 7.5	79.3 ± 7.1	21/6	24/8	29.4 ± 4.1	29.4 ± 3.5	144	6, 7, 8, 9
Kim2018	South Korea	RCT	Navigation/CON	296 (282)	296 (282)	59 ± 7	59 ± 7	223/59	223/59	28 ± 8	28 ± 8	180	1, 2, 3, 4, 5, 6, 7, 8, 9
Kinney2018	USA	RCT	Navigation/CON	25	25	66.4 ± 2.3	65.0 ± 2.0	13/12	16/9	30.4 ± 1.2	31.1 ± 1.2	NR	1, 2, 3
Petursson2018	Norway	RCT	Navigation/CON	87	80	67.9 ± 6.8	67.6 ± 6.6	51/36	51/29	27.7 ± 3.5	28.5 ± 3.8	24	6, 7
Gharaibeh2017	Australia	RCT	Navigation/CON	89	90	69.2 ± 8.7	69 ± 8.3	55/34	50/39	29.2 ± 4.8	29.6 ± 5.4	NR	1, 2, 3, 4, 5
Kim2017	South Korea	RCT	Navigation/CON	170 (162)	170 (162)	68.1 ± 7.5	68.1 ± 7.5	153/9	153/9	27 ± 3.3	27 ± 3.3	147	1, 2, 3, 4, 5, 6, 7, 8, 9
Ikawa2017	Japan	RCT	Navigation/CON	121	120	74.0 ± 6.8	74.1 ± 6.8	106/15	101/19	26.1 ± 3.7	26.8 ± 4.1	NR	2
Song2016	South Korea	RCT	Navigation/CON	45 (41)	43 (40)	65.4 ± 5.9	66.1 ± 8.1	29/10	31/10	NR	NR	120	1, 7, 9
Todesca2017	Italy	RCT	Navigation/CON	123	117	75.3 (median)	75.3 (median)	NR	NR	30.2 (median)	30.2 (median)	72 (median)	1, 3, 4, 5, 6, 7, 8, 9

Table 1 (continued)

Study ID	Country	Study design	Comparison	Sample size[a]		Age at surgery (year)		Gender (female/male)		BMI (kg/m^2)		Follow-up (months)	Outcomes[b]
				Experimental	Conventional	Experimental	Conventional	Experimental	Conventional	Experimental	Conventional		
Chen2015	Singapore	RCT	Navigation/CON	50	50	67 ± 9	67 ± 8	32/18	35/15	27 ± 3	29 ± 6	NR	1, 2, 3
Maderbacher2015	Germany	RCT	Navigation/CON	40	40	69.8 ± 8.7	69.5 ± 8.9	28/12	25/15	31.2 ± 5.3	32.0 ± 5.0	0.2	1, 2, 3
Cip2014	Australia	RCT	Navigation/CON	92	91	74.9 ± 8.6	76.1 ± 7.0	64/28	67/24	30.2 ± 5.4	28.5 ± 4.7	60	1, 2, 3, 5, 9
Gøthesen2014	Norway	RCT	Navigation/CON	95 (88)	94 (87)	68.3 ± 7.8	67.7 ± 6.8	58/37	59/35	NR	NR	12	1, 2, 3, 4, 5, 6, 7
Lützner2013	Germany	RCT	Navigation/CON	34	33	68.1 ± 9.0	66.9 ± 9.8	25/9	20/13	31.1 ± 5.3	31.0 ± 4.4	60	6, 7, 8, 9
Nam2014	USA	RCT	Navigation/CON	47	47	67.1 ± 7.5	66.1 ± 10.1	29/18	27/20	31.1 ± 5.9	31.2 ± 5.6	NR	1, 2, 3, 5
Smith2013	UK	RCT	Navigation/CON	60	57	67	67	26/34	27/30	NR	NR	12	1, 6, 7
Hoffart2012	Germany	RCT	Navigation/CON	98 (59)	97 (62)	70.9	69.2	71/27	68/29	29.1	30.3	60	6, 7, 8, 9
Kim2012	South Korea	RCT	Navigation/CON	520	520	68	68	452/68	452/68	27.8	27.8	129	1, 2, 3, 4, 5, 6, 7, 8, 9
Blakeney2011	Australia	RCT	Navigation/CON	36	70	NR	NR	NR	NR	NR	NR	NR	1
Schmitt2011	Germany	RCT	Navigation/CON	60	30	67.7 ± 6.44	69.6 ± 7.1	44/16	18/12	30.9 ± 4.64	31.6 ± 5.4	3	6, 7
Choong2009	Australia	RCT	Navigation/CON	57	54	70 (median)	69 (median)	40/17	27/27	29.5 (median)	29.5 (median)	NR	1
Seon2009	South Korea	RCT	Navigation/CON	43	42	67.2	67.6	41/2	38/4	NR	NR	24	1, 2, 3, 6

Table 1 (continued)

Study ID	Country	Study design	Comparison	Sample size[a]		Age at surgery (year)		Gender (female/male)		BMI (kg/m^2)		Follow-up (months)	Outcomes[b]
				Experimental	Conventional	Experimental	Conventional	Experimental	Conventional	Experimental	Conventional		
Van Strien2009	Netherland	RCT	Navigation/CON	36 (32)	21	71 ± 11.5	71 ± 11.5	NR	NR	28 ± 3.8	71 ± 11.5	12	1, 2, 3, 5, 6, 7
Weng2009	China	RCT	Navigation/CON	60	60	70 ± 6.3	70 ± 6.3	41/19	41/19	27.7 ± 4.0	27.7 ± 4.0	NR	1, 2, 3, 4, 5
Lützner2008	Germany	RCT	Navigation/CON	40	40	69 (median)	69 (median)	27/13	24/16	30.4 (median)	29.4 (median)	NR	1, 2, 3
Ensini2007	Italy	RCT	Navigation/CON	60	60	68.8 ± 6.3	71.1 ± 7.8	30/30	40/20	NR	NR	28	1, 2, 3, 4, 5
Kim2007	Korea	RCT	Navigation/CON	100	100	67.6	67.6	85/15	85/15	27.1	27.1	27	1, 2, 3, 4, 5, 6, 7
Martin2007	Austria	RCT	Navigation/CON	100	100	70.3 ± 8.2	71.1 ± 7.5	68/32	73/27	30.2 ± 4.8	28.2 ± 4.6	3	1, 2, 3, 5
Matziolis2007	Germany	RCT	Navigation/CON	32	28	71 ± 7	70 ± 9	NR	NR	30.5 ± 4.7	31.7 ± 6.4	6	1, 2, 3, 5
Mullaji2007	India	RCT	Navigation/CON	282	185	65.5	65.9	215/67	143/42	NR	NR	12	1
Maculé-Beneyto2006	Spain	RCT	Navigation/CON	102	84	71.6	72.3	NR	NR	30.4	31.4	NR	1
Han2006	Korea	RCT	Navigation/CON	27	28	72 ± 5.2	69 ± 6.6	27/0	27/1	27 ± 3.2	28 ± 3.1	NR	1,
Chin2005	Singapore	RCT	Navigation/CON	30	60	67.3	66.3	20/10	27/13	NR	NR	NR	1, 2, 3, 4, 5
Sparmann2003	Germany	RCT	Navigation/CON	120	120	67.4	66.1	88/32	79/41	NR	NR	NR	1, 2, 3, 4, 5
Giannotti2020	Italy	RCT	PSI/CON	20	20	71 ± 7.3	73 ± 7.5	16/4	10/10	NR	NR	2	6
Sariali2019	France	RCT	PSI/CON	40	40	67.7 ± 8.7	68.9 ± 9.2	33/7	24/16	29.7 ± 5.3	29.5 ± 4.5	24	1,2,3

Table 1 (continued)

Study ID	Country	Study design	Comparison	Sample size[a]		Age at surgery (year)		Gender (female/male)		BMI (kg/m^2)		Follow-up (months)	Outcomes[b]
				Experimental	Conventional	Experimental	Conventional	Experimental	Conventional	Experimental	Conventional		
Schotanus2019	Netherlands	RCT	PSI/CON	90 (83)	90 (80)	69 ± 8.0	65 ± 8.8	NR	NR	NR	NR	60	6,8
Teeter2019	Canada	RCT	PSI/CON	25 (20)	25 (22)	69.0 ± 8.4	69.4 ± 8.4	13/12	18/7	30.3 ± 4.7	30.7 ± 5.5	24	1,7
Turgeon2019	Canada	RCT	PSI/CON	25	29	63.8 ± 9.2	65.7 ± 9.2	18/7	22/7	33.6 ± 7.2	32.0 ± 6.0	24	1
Abane2018	France	RCT	PSI/CON	70 (67)	70 (65)	69.3 ± 9.6	69.8 ± 9.4	30/40	29/41	27.3 ± 4.0	27.2 ± 3.5	3	1, 2, 3, 4, 5, 6, 7
Maus2018	Germany	RCT	PSI/CON	59	66	68.1 ± 8.5	71.5 ± 8.1	22/26	43/23	31.8 ± 6.1	30.6 ± 5.3	3	1, 6, 7
Stolarczyk2018	Poland	RCT	PSI/CON	30 (29)	30 (29)	70.2 ± 5.9	69.6 ± 7.1	22/8	18/12	30.4 ± 4.4	31.6 ± 5.4	3	6, 7
Van Leeuwen2018	Norway	RCT	PSI/CON	44	50	67 ± 8.8	64 ± 6.9	30/14	32/18	31 ± 4.9	29 ± 4.6	24	1, 2, 3, 4, 5
Vide2017	Portugal	RCT	PSI/CON	47	48	67.8 ± 8.4	69.3 ± 6.5	32/15	33/15	31	30.3	NR	1
Boonen2016	Netherlands	RCT	PSI/CON	90 (82)	90 (81)	69.0 ± 8.0	65.0 ± 8.8	56/34	50/40	30.3	29.5	24	6
Huijbregts2016	Australia	RCT	PSI/CON	69	64	66.7 ± 9.1	69.0 ± 9.6	40/29	32/32	NR	NR	12	1, 2, 3, 4, 5
Abane2015	France	RCT	PSI/CON	70 (59)	70 (67)	67.8	70.4	27/43	40/30	28.8	28.6	3	1, 2, 3, 4, 5, 6, 7
Gan2015	China	RCT	PSI/CON	35	35	68.5 ± 4.8	67.8 ± 3.4	25/10	26/9	NR	NR	NR	1, 2, 3
Kotela2015	Poland	RCT	PSI/CON	52 (49)	60 (46)	66.1 ± 8.4	68.6 ± 9.9	33/16	33/13	30.0 ± 4.6	29.6 ± 5.6	12	6, 7
Molicnik2015	Slovenia	RCT	PSI/CON	19	19	67.1 ± 7.1	66.8 ± 6.7	17/2	14/5	31.9 ± 5.3	33.3 ± 5.5	NR	1
Kotela2014	Poland	RCT	PSI/CON	52 (49)	60 (46)	66.1 ± 8.4	68.6 ± 9.9	33/16	33/13	30.0 ± 4.6	29.6 ± 5.6	12	1, 2, 3, 4, 5
Pfitzner2014	Germany	RCT	PSI/CON	60	30	64	64	34/26	17/13	30	31	3	1, 2, 3, 5, 6, 7
Victor2014	Belgium	RCT	PSI/CON	64	64	67	66	43/21	43/21	NR	NR	NR	1, 2, 3, 4, 5
Woolson2014	USA	RCT	PSI/CON	22	26	66.1 ± 8.4	68.6 ± 9.9	33/16	33/13	NR	NR	12	1, 2, 3, 5, 6, 7
Boonen2013	Netherlands	RCT	PSI/CON	90 (86)	90 (82)	69.0 ± 8.0	65.0 ± 8.8	56/34	50/40	30.3	29.5	NR	1, 2, 3, 4, 5
Chareanchol-vanich2013	Thailand	RCT	PSI/CON	40	40	69.5	70.3	34/6	36/4	27.7	28.0	NR	1, 2, 3
Hamilton2013	USA	RCT	PSI/CON	26	26	68.1	67.6	12/14	19/7	30.9	31.1	NR	1, 2, 3, 4, 5
Parratte2013	France	RCT	PSI/CON	20	20	NR	NR	NR	NR	NR	NR	3	1
Roh2013	Korea	RCT	PSI/CON	50 (42)	50 (48)	70 ± 7.2	70 ± 5.1	39/3	43/5	27 ± 4.2	27 ± 2.7	NR	1, 2, 3, 4, 5
Kim2020	South Korea	RCT	Robot/CON	724	724	60 ± 7	61 ± 8	542/132	530/144	28 ± 9	29 ± 8	156	1, 2, 3, 4, 5, 6, 8
Liow2017	Singapore	RCT	Robot/CON	31	29	NR	NR	NR	NR	NR	NR	24	6, 7

Table 1 (continued)

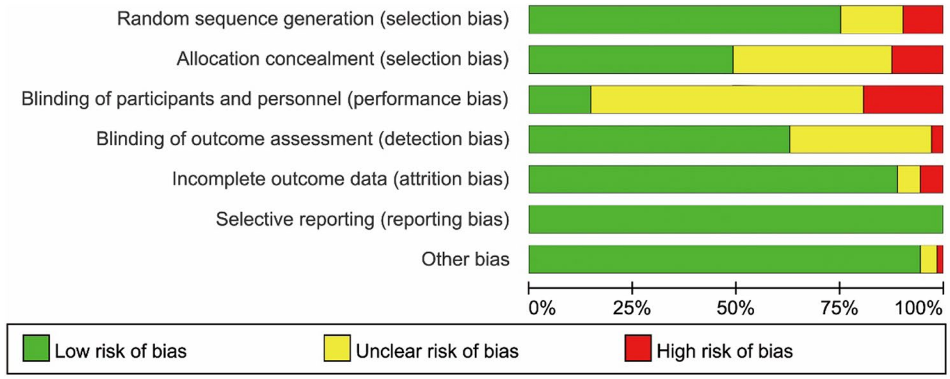
Study ID	Country	Study design	Comparison	Sample size[a]		Age at surgery (year)		Gender (female/male)		BMI (kg/m^2)		Follow-up (months)	Outcomes[b]
				Experimental	Conventional	Experimental	Conventional	Experimental	Conventional	Experimental	Conventional		
Liow2014	Singapore	RCT	Robot/CON	31	29	67.5 ± 8.6	68.37.7	NR	NR	27.5 ± 3.8	27.2 ± 4.9	6	2
Song2013	South Korea	RCT	Robot/CON	50 (29)	50 (24)	66.1 ± 7.1	64.8 ± 5.3	46/4	45/4	26.3 ± 2.7	26.2 ± 3.9	65	1, 2, 3, 4, 5
Song2011	South Korea	RCT	Robot/CON	30	30	67 ± 6.3	67 ± 6.3	30/0	30/0	27 ± 6.5	27 ± 6.5	16	1, 2, 3, 4, 5, 6, 7
Park2007	South Korea	RCT	Robot/CON	32	30	62.7 ± 6.51	67.8 ± 6.44	NR	NR	NR	NR	45	
Lionberger2014	USA	RCT	Navigation/PSI	Navigation:	30	Navigation:	NR	Navigation:	NR	Navigation:	NR	3	6, 7
				PSI:	30	PSI:	NR	PSI:	NR	PSI:	NR		
Ollivier2016	France	RCT	Navigation/PSI	Navigation:	40	Navigation:	72.2 ± 17.4	Navigation:	28/12	Navigation:	Navigation:27 ± 6.1	3	2, 3, 4, 5
				PSI:	40(33)	PSI:	76 ± 7.1	PSI:	PSI:28/12	PSI:	PSI:26.3 ± 6.9		
Zahn2020	Germany	RCT	Navigation/PSI/CON	Navigation:	75	Navigation:	67.2 ± 7.6	Navigation:	46/29	Navigation:	NR	3	1
				PSI:	75	PSI:	66.9 ± 7.3	PSI:	46/29	PSI:	NR		
				CON:	75	CON:	67.5 ± 7.3	CON:	43/32	CON:	NR		
Yan2015	China	RCT	Navigation/PSI/CON	Navigation:	30	Navigation:	66.7 ± 7.2	Navigation:	26/4	Navigation:	NR	3	1, 2, 3, 4, 5, 6, 7
				PSI:	30	PSI:	67.5 ± 8	PSI:	17/13	PSI:	NR		
				CON:	30	CON:	69.5 ± 8.4	CON:	24/6	CON:	NR		

$\bar{x} \pm s$ is adopted if the data conforms to normal distribution, and median is adopted if not

[a]Sample size: The values are given as the number of enrolled knees, with the number of followed cases (knees) in parentheses

[b]Outcomes: (1) mechanical axis outliers; (2) coronal femoral component angle outliers; (3) coronal tibial component angle outliers; (4) sagittal femoral component angle outliers; (5) sagittal tibial component angle outliers; (6) short-term KSS knee scores; (7) short-term KSS function scores; (8) medium-and-long-term KSS knee scores; (9) medium-and-long-term KSS function scores

Fig. 2 Risk of bias assessment of included RCTs



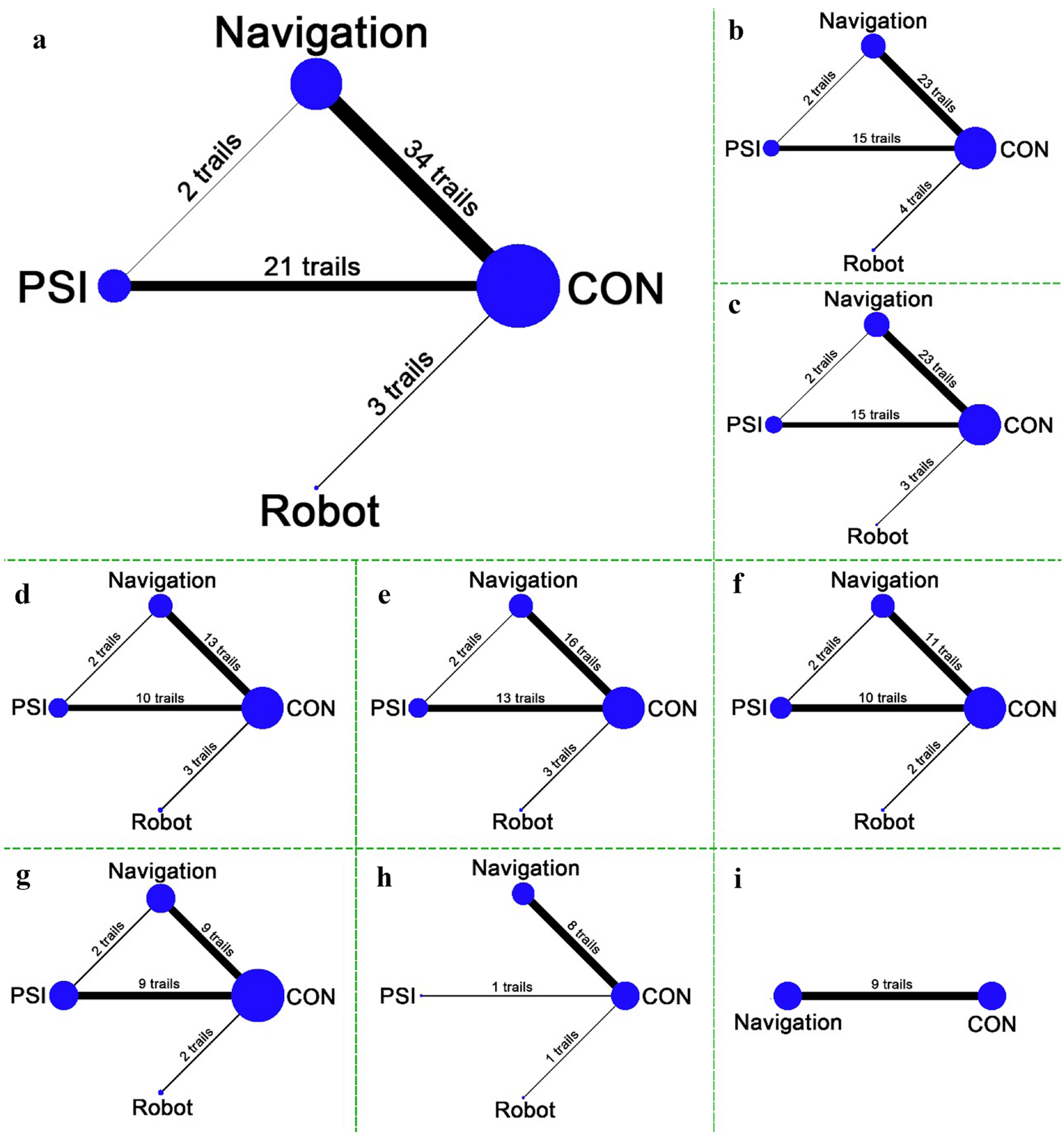


Fig. 3 Network graph of different outcomes. **a** Mechanical axis outliers; **b** coronal femoral component angle outliers; **c** coronal tibial component angle outliers; **d** sagittal femoral component angle outliers; **e** sagittal tibial component angle outliers; **f** short-term KSS knee scores; **g** short-term KSS function scores; **h** medium-and-long-term KSS knee scores; **i** medium-and-long-term KSS function scores

Table 2 Odds ratio/mean difference (95% CI) of the various interventions

Intervention	Mechanical axis outliers (OR)	Coronal femoral component angle outliers (OR)	Coronal tibial component angle outliers (OR)	Sagittal femoral component angle outliers (OR)	Sagittal tibial component angle outliers (OR)	Short-term KSS knee scores (MD)	Short-term KSS function scores (MD)	Medium-and-long-term KSS knee scores (MD)	Medium-and-long-term KSS function scores (MD)[a]
Navigation versus									
Robot	2.116 (0.788, 6.832)	3.630 (0.661, 29.830)	1.322 (0.192, 11.500)	1.774 (0.353, 12.590)	2.686 (0.727, 12.180)	1.220 (− 2.718, 5.814)	1.202 (− 5.270, 7.272)	0.347 (− 1.995, 3.179)	–
PSI	**0.458 (0.293, 0.713)**	0.633 (0.261, 1.531)	0.464 (0.195, 1.124)	**0.417 (0.175, 0.960)**	**0.394 (0.191, 0.824)**	1.399 (− 0.787, 3.882)	1.614 (− 1.887, 5.712)	1.264 (− 2.524, 5.268)	–
CON	**0.379 (0.281, 0.499)**	**0.348 (0.189, 0.606)**	**0.362 (0.200, 0.622)**	**0.420 (0.225, 0.746)**	**0.527 (0.321, 0.862)**	0.359 (− 1.205, 1.990)	1.326 (− 1.245, 4.108)	**1.380 (0.420, 2.718)**	3.004 (− 1.336, 7.344)
Robot versus									
PSI	**0.216 (0.065, 0.593)**	0.174 (0.020, 1.002)	0.349 (0.039, 2.544)	0.234 (0.032, 1.210)	**0.146 (0.032, 0.560)**	0.179 (− 4.322, 4.342)	0.392 (− 5.487, 7.375)	0.883 (− 3.472, 5.164)	–
CON	**0.179 (0.056, 0.462)**	**0.096 (0.012, 0.481)**	0.274 (0.033, 1.699)	0.236 (0.035, 1.072)	**0.196 (0.047, 0.660)**	− 0.861 (− 5.137, 2.803)	0.121 (− 5.209, 6.143)	1.00 (− 1.322, 3.349)	–
PSI versus									
CON	0.828 (0.573, 1.177)	0.551 (0.265, 1.088)	0.781 (0.370, 1.544)	1.008 (0.514, 1.942)	1.336 (0.747, 2.354)	− 1.048 (− 3.013, 0.729)	− 0.277 (− 3.427, 2.508)	0.140 (− 3.614, 3.850)	–

Bold results were statistically significant. The highest score for both KSS knee and KSS function are 100

[a]A pairwise meta-analysis was conducted

Table 3 Ranking probabilities of the various interventions (%)

Intervention	Mechanical axis outliers	Coronal femoral component angle outliers	Coronal tibial component angle outliers	Sagittal femoral component angle outliers	Sagittal tibial component angle outliers	Short-term KSS knee scores	Short-term KSS function scores	Medium-and-long-term KSS knee scores
Navigation	68.949	64.121	78.118	74.068	68.442	**77.150**	**78.572**	**80.989**
Robot	**97.641**	**96.712**	**79.728**	**89.436**	**97.475**	37.576	46.829	62.891
PSI	28.557	37.682	31.564	18.394	5.517	22.994	34.989	36.510
CON	4.853	1.485	10.589	18.102	28.567	62.281	39.611	19.610

A bold indicates a higher ranking probability

deformities [26], the advantages of Navigation and Robot may be more obvious [25–28].

Conclusion

Navigation and Robot did improve the accuracy of alignment compared with PSI and conventional instruments in TKA. Robot has the greatest advantage in achieving the desired alignment accurately, followed by Navigation; Navigation has the greatest advantage in postoperative clinical outcomes. However, the above four techniques showed no clinical significance in postoperative outcomes.

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Compliance with ethical standards

Conflict of interest All the authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors, and thus, ethical approval was not required.

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