Kinematic versus mechanical alignment for primary total knee replacement: A systematic review and meta-analysis

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1. Introduction

Total knee replacement (TKR) is an effective method for the treatment of severe osteoarthritis of the knee.¹ One of the foundations of a successful TKR is the restoration of knee alignment.² Currently, there are two primary alignment methods used in TKR, mechanical alignment (MA) and kinematic alignment (KA). The goal of the MA technique is to restore the hip-knee-ankle angle so that the overall limb alignment is restored to a neutral position.³ While MA in TKR has been widely shown to improve functional outcomes and pain relief, studies have reported that around 15–20% of patients using MA in TKR are dissatisfied with their results.^{4,5} More accurate prosthetic positioning by using computer-assisted surgery has also not been shown to significantly improve satisfaction or functional outcomes of MA.⁶ It is postulated that MA of the knee can alter ligament positioning and tension, leading to undesirable stress on a higher joint line and ultimately poorer surgical outcomes.²

Due to the shortcomings of MA, the use of KA in TKR has increased in popularity since its introduction in 2006.⁷ While MA mainly focuses on the 2D alignment of the components of knee, KA considers all 3 functional axes in which the knee moves.⁸ The goal of KA is to restore the alignment and kinematics of the prosthetic knee so that it is the same or comparable to that of the pre-arthritis knee.² This can potentially improve ligament positioning as the prosthetic components will match each patient's individual anatomy.⁹ To date, many studies have found KA in TKR to also be effective in restoring functional outcomes and reducing postoperative pain.^{4,8,10} However, KA may be linked to an increased risk of early implant failure due to increased contact stresses on the tibiofemoral and patellofemoral joints.¹¹

Thus, to address limitations in the current literature this meta-analysis was conducted with the primary aim of comparing the functional outcomes of KA and MA in TKR. The secondary aims were to compare the radiological outcomes and complication rates of both techniques.

2. Methods

2.1. Literature search strategy

For this study, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed. Electronic searches were performed using PubMed, Ovid Medline, Cochrane Database of Systematic Reviews (CDSR), Cochrane Central Register of Controlled Trials (CCTR), and Database of Abstracts of Review of Effectiveness (DARE), from their dates of inception to January 2018. To maximise sensitivity of the search strategy we combined the terms “knee”, “arthroplasty”, “replacement”, “kinematic”, “kinematically”, “mechanical”, “mechanically” and “alignment” when searching in the title, abstract, keywords and MeSH fields. The reference list of all retrieved articles was manually reviewed to further identify potentially relevant studies.

2.2. Selection criteria

Eligible studies for this systematic review and meta-analysis included those in which the cohort of patients were all adults and undergoing primary TKR surgery using the KA or MA technique. The studies were only included if they directly compared the KA and MA techniques for TKR. The outcomes compared included clinical and functional scores, operative details, radiological outcomes and complication rates. If an institution published duplicate studies with increased length of follow-up and accumulating patient numbers, the most recent data was used for quantitative analysis. However, if certain outcomes were only reported in the earlier study they were included for the meta-analysis of that outcome. All publications included were limited to those in the English language and involving human subjects. Conference presentations, case reports, reviews, editorials, and expert opinions were excluded.

2.3. Data extraction and critical appraisal

All the relevant data was extracted from the article text, figures and

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tables. Two investigators (J.X and J.L) independently reviewed and extracted data from the retrieved articles. Discrepancies between the two reviewers were resolved by discussion with senior authors to reach a consensus. The study characteristics extracted include study year, country and number of patients undergoing TKR with KA and MA. The functional outcomes reported include distance walked prior to discharge, Western Ontario McMaster Universities Arthritis Index (WOMAC) score, Oxford Knee Score (OKS), Knee Society Function Score (KSFS), Knee Society Score (KSS), Combined Knee Society Score (CKSS) and flexion range of motion (ROM). Radiographic outcomes include the hip-knee-ankle (HKA) angle, femoral component relative to mechanical axis (FCRTMA), tibial component relative to mechanical axis (TCRTMA), joint line orientation angle (JLOA), femoral component flexion (FCF) and tibial component score (TCS). Total complications and reoperations were also reported. The risk of bias for all included studies were assessed according to the Cochrane Collaboration's tool.¹²

2.4. Statistical analysis

Outcomes were analysed, with the relative risk (RR) or weighted mean difference (WMD) used as the summary statistic. The I^2 statistic was used to estimate the percentage of total variation across studies, owing to heterogeneity rather than chance, with values greater than 25% considered as substantial heterogeneity.¹³ A substantial heterogeneity warranted the usage of a random effect model, whereas otherwise, a fixed effect model was used. Sensitivity analysis was performed by leave-one-out analysis. Publication bias was assessed by funnel plots. All statistical analysis was performed using Review Manager 5.3 software (Cochrane Collaboration, Software Update, Oxford, United Kingdom).

3. Results

3.1. Quality of studies

A total of 912 studies were identified by searching five electronic databases using our search strategy (Fig. 1). After duplicate studies were excluded, a total of 707 studies remained for further screening. By

examining the study abstracts, 668 studies were excluded leaving 42 potentially relevant articles. Following the application of the inclusion criteria, a total of 8 studies were selected for quantitative analysis. These studies included a total of 330 patients undergoing KA in TKR and 335 patients undergoing MA in TKR.

Of all the included studies, 7 studies^{8–10,14–17} were randomised controlled trials using prospectively collected data and 1 study¹⁸ was a retrospective observational study. The outcomes of the risk of bias assessment for these studies are summarised in Table 1. All studies either had low or unclear risk of bias for random sequence generation, allocation concealment, incomplete outcome data and selective reporting. In 1 study, there was a high risk of bias for blinding of participants and personnel, and blinding of outcome assessment.

The mean patient age in the KA cohort ranged from 65 to 75 years while the mean patient age in the MA cohort ranged from 66 to 76 years. The proportion of females in the KA cohort ranged from 6.3% to 37.9% while the proportion of females in the MA cohort ranged from 12% to 36.3%. The mean follow-up time ranged from 6 months to 2 years. The study characteristics are summarised in Table 2.

3.2. Operation details

The mean operation time for the KA group was significantly shorter than that of the MA group (weighted mean difference (WMD): -15.44 , 95% confidence interval (CI): -27.16 to -3.71 , $I^2 = 60\%$, $P = 0.01$) (Fig. 2). However, there was no significant difference in the hospital length of stay between KA and MA groups (WMD: 1.0 , 95% CI: -0.16 to 2.16 , $I^2 = 0\%$, $P = 0.09$).

3.3. Assessment of functional outcomes

Four studies reported KSFS and found it to be significantly higher in the KA group when compared to the MA group (WMD: 6.62 , 95% CI: 2.11 to 11.12 , $I^2 = 0\%$, $P = 0.004$) (Fig. 3). Two studies compared CKSS between KA and MA groups and found it to be significantly greater in the KA group (WMD: 15.24 95% CI: 5.41 to 25.07 , $I^2 = 49\%$, $P = 0.002$). From the four studies reporting flexion ROM, it was found that the KA group had greater ROM when compared to the MA group

Fig. 1. PRISMA flow chart for systematic review and meta-analysis comparing kinematic alignment and mechanical alignment for primary total knee replacement.

Table 1
Risk of bias assessment for all included studies according to the Cochrane Collaboration's tool.

Author	Year	Random Sequence Generation	Allocation Concealment	Blinding of Participant and Personnel	Blinding of Outcome Assessment	Incomplete Outcome Data	Selective Reporting
Matsumoto	2017	Unclear	Low	Unclear	Unclear	Unclear	Low
Ji	2016	Unclear	Unclear	Unclear	Unclear	Unclear	Low
Waterson	2016	Low	Low	Unclear	Unclear	Low	Low
Young	2016	Low	Low	Low	Low	Low	Low
Calliess	2016	Unclear	Unclear	High	High	Low	Low
Belvedere	2015	Unclear	Unclear	Unclear	Unclear	Unclear	Low
Dossett	2014	Unclear	Low	Low	Low	Low	Low
Dossett	2012	Unclear	Low	Low	Low	Low	Low

Table 2
Characteristics and demographics of studies included in the systematic review and meta-analysis.

Author	Year	Country	Study Type	No. patients		No. females		Mean age (years)		Follow up (months)
				KA	MA	KA	MA	KA	MA	
Matsumoto	2017	Japan	RCT	30	30	NR	NR	75.3	76.1	12
Ji	2016	South Korea	OS	65	65	> 90%	> 90%	71 ± 4.1	70 ± 5.2	NR
Waterson	2016	UK	RCT	36	35	NR	NR	NR	NR	12
Young	2016	New Zealand	RCT	49	50	25	26	72 ± 6.5	70 ± 7.5	24
Calliess	2016	Germany	RCT	100	100	61	57	67 ± 8	70 ± 8	12
Belvedere	2015	Italy	RCT	6	11	NR	NR	NR	NR	6
Dossett	2014	USA	RCT	44	44	3	6	66 ± 7.7	66 ± 8.6	24
Dossett	2012	US	RCT	41	41	2	6	65 ± 8	66 ± 8.2	6

(OS, observational study; RCT, randomised controlled trial; KA, kinematic alignment; MA, mechanical alignment).

(WMD: 4.11°, 95% CI: 0.81 to 7.42, $I^2 = 45\%$, $P = 0.01$). Two studies reported distance walked prior to discharge and found no significant difference between the KA and MA groups (WMD: 22.33 feet, 95% CI: −37.36 to 82.03, $I^2 = 55\%$, $P = 0.46$). The total WOMAC score was reported in three studies with no significant difference between KA and MA groups. (WMD: −7.17, 95% CI: −17.61 to 3.27, $I^2 = 89\%$, $P = 0.18$). Two studies compared the OKS between KA and MA groups but found no significant difference (WMD: 3.69, 95% CI: −2.16 to 9.54, $I^2 = 82\%$, $P = 0.22$). From the five studies reporting KSS, there was no significant difference between KA and MA groups (WMD: 3.15, 95% CI: −1.82 to 8.13, $I^2 = 64\%$, $P = 0.21$).

3.4. Assessment of radiological outcomes

From the eight total studies, four compared the HKA for KA and MA groups but no significant difference was found between the groups (WMD: −0.11, 95% CI: −1.94 to 1.72, $I^2 = 95\%$, $P = 0.91$) (Fig. 4). From two studies, the FCRTMA for KA and MA groups was found to be similar (WMD: −0.29, 95% CI: −3.82 to 3.24, $I^2 = 97\%$, $P = 0.87$).

Two studies compared the TCRTMA for KA and MA groups but no significant difference was found between the groups (WMD: −0.05, 95% CI: −4.46 to 4.36, $I^2 = 98\%$, $P = 0.98$). JLOA was reported in three studies, but there was no significant difference between the KA and MA groups (WMD: −0.45, 95% CI: −5.23 to 4.32, $I^2 = 99\%$, $P = 0.85$). From three studies that reported FCF, there was no significant difference between KA and MA groups (WMD: 0.81, 95% CI: −1.88 to 3.50, $I^2 = 94\%$, $P = 0.56$). Three studies compared the TCS for KA and MA groups but also found no significant difference between the groups (WMD: 0.39, 95% CI: −1.96 to 2.75, $I^2 = 93\%$, $P = 0.74$).

3.5. Assessment of complications

From all the studies the complication rates were all pooled. There were no significant differences in the complication rate for KA compared to MA (5.2% vs 4.6%, RR: 1.12, 95% CI: 0.47 to 2.66, $I^2 = 0\%$, $P = 0.80$) (Fig. 5). Reoperation rate was reported in 3 of the studies. This rate was found to be similar for both KA and MA groups (4.7% vs 4.6%, RR: 1.01, 95% CI: 0.41 to 2.46, $I^2 = 0\%$, $P = 0.99$).

Mean operation time

Hospital length of stay

Fig. 2. Forest plot of operation details, including mean operation time and hospital length of stay.

Knee Society Function Score

Combined Knee Society Score

Flexion range of motion

Distance walked prior to discharge

Total WOMAC Score

Oxford Knee Score

Knee Society Score

Fig. 3. Forest plot of functional outcomes, including KSFS, CKSS, flexion range of motion, distance walked prior to discharge, total WOMAC score, OKS and KSS.

Hip-Knee-Ankle angle

Femoral component relative to mechanical axis

Tibial component relative to mechanical axis

Joint line orientation angle

Femoral component flexion

Tibial component score

Fig. 4. Forest plot of radiological outcomes, including HKA angle, FCRTMA, TCRTMA, JLOA, FCF and TCS.

4. Discussion

There is ongoing discussion as to what the optimal knee alignment should be after a TKR. This study found that the functional outcomes of the KA technique were better than that of the MA technique with a greater Combined Knee Society Score, Knee Society Function Score and flexion range of motion in the KA group. There was also a shorter mean

operation time in the KA group when compared to that of the MA group. However, there were no significant differences between the KA and MA group for radiological outcomes, complication rates and re-operation rates.

The improved functional outcomes obtained with KA in TKA may be due to its ability to restore the knee to its original pre-arthritis alignment.¹⁹ By restoring the knee to its native alignment, the KA technique

Total complication rate

Reoperation rate

Fig. 5. Forest plot of total complication rate and reoperation rate.

preserves the original level of the knee joint line and surrounding soft tissue.²⁰ As the goal of the KA technique is to maintain the original anatomy of the patient, there is also generally no need for any soft tissue release during the procedure.⁸ It has also been suggested that the patient-specific instrumentation used more commonly in KA than MA may contribute to improved function outcomes.¹⁰ However, other studies have found patient-specific instrumentation to produce no functional improvements when compared to conventional techniques in MA TKR procedures.²¹ We also found no significant differences in the radiological outcomes for KA and MA. This contrasts with findings from another systematic review which found that the FCRTMA was more valgus and the TCRTMA was more varus with KA when compared to MA.²² This may be due to differences in the method of quantitative analysis, with their study including data from both Dossett studies in the meta-analysis even though the two studies used the same patient cohort.^{8,10} In our analysis, we only included the most complete data from either of the two studies.^{8,10}

With the MA technique, the goal is to restore the knee to a neutral position, where the femoral and tibial mechanical axes are in line with each other (HKA angle of 0°).³ This was conventionally considered to be a major factor in optimising the survival of a knee implant. However, there have been a plethora of studies indicating that implant failure rates are not correlated with deviation from neutral alignment and up to 20% of primary TKR patients are unsatisfied following MA in TKR.^{4,5} Along with that, the vast majority of the population do not have neutrally aligned knees, with 32% of males and 17% of females having a natural mechanical alignment that is greater than 3° varus.^{3,23} Thus during MA in TKR, most patients have significant alterations in the alignment of the knee from its pre-arthritis native state.^{2,23} This can place undue stress on the joint line along with the supporting ligaments.² Depending on the alteration of the joint line, this may require lateral retinaculum and collateral ligament releases to restore tracking of the patella and ROM in the knee.^{3,8} The combination of these factors may explain our finding of poorer functional outcomes with MA when compared to KA.

There are also disadvantages of the KA technique for TKR. Increased varus tilt in the knee following KA has been shown to significantly increase contact stresses and wear on the medial compartment of the knee.²⁴ This occurs even if the ideal kinematic alignment is attained.²⁴ Also, there is variation in the natural alignment of every knee and thus in KA there is an increased risk of inconsistent positioning of the implant, which may increase the stress on the prosthetic knee.²⁵ The increased wear on the prosthetic joint can cause loosening of the implant

and reduce its durability. Despite concerns of implant survivorship with KA, recent studies have found high implant survival rates of 97.5% at 6 years post-operation, which is comparable to that of the MA technique.²⁰ However, this follow-up period is still relatively short, and thus long-term implant survival with KA requires further elucidation. Also, while the use of KA in TKR is effective in a large portion of the population, restoring native alignment may not be possible in certain patients. For example, KA in patients with profound preoperative metaphyseal malalignment can increase the risk of outlier alignment and catastrophic implant failure.²

Our current meta-analysis is limited by a few factors. There was significant heterogeneity across the studies included. This may be due to differences in operative technique, surgeon skill level, implants used, post-operative rehabilitation and the innate heterogeneity in the population. Furthermore, the follow-up periods for all the studies varied quite significantly, making it difficult to make conclusions about the long-term outcomes of KA or MA in TKR. This analysis also did not look at long-term implant survival, which is an important factor to consider when determining the effectiveness of the KA or MA technique. Along with that, only 8 studies were included, which provides a relatively small cohort to analyse. This prevented certain variables from being quantitatively analysed due to the lack of data.

5. Conclusions

In conclusion, we found that KA in TKR may produce better functional outcomes than MA and have shorter operation times. However, there were no differences between both techniques regarding radiological outcomes and complication rates. Further research in larger sample sizes are required to validate these findings and examine long-term outcomes.

Conflicts of interest

There were no conflicts of interest for any of the authors.

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