Systematic Review / Meta-analysis

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Comparison of the effect of open-box versus closed-box prostheses on blood loss following total knee arthroplasty: a meta-analysis

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Purpose: Postoperative blood loss is a common complication following total knee arthroplasty (TKA). The authors aimed to analyze the significance of open versus closed-box prostheses in reducing blood loss after TKA.

Methods: PubMed, Cochrane, Scopus, and Web of Science were searched. Observational studies and clinical trials comparing the effect of open-box versus closed-box prostheses on blood loss following TKA were included. The primary outcome was total blood loss following TKA. Secondary outcomes included average transfused units and total operation time. Continuous data were represented as mean difference (MD) and CI, while dichotomous data were presented as odds ratio (OR) and CI. RevMan software version 5.4 was used to conduct the analysis.

Results: Four studies with a total number of 687 patients were included. The pooled analysis showed a statistically significant association between closed-box and decreased total blood loss following TKA compared with open-box (MD = 173.19, 95% CI = 88.77–257.61, *P* value <0.0001). Similar findings were reported in unilateral TKA (MD = 190.63, 95% CI = 70.91–310.35, *P* value = 0.002), and bilateral TKA (MD = 160.79, 95% CI = 61.70–359.86, *P* value = 0.001). There was no significant difference between open and closed-box regarding average transfused units (MD = 0.02, 95% CI = −0.07–0.11, *P* value = 0.68), blood transfusion rate (OR = 1.38, 95% CI = 0.85–2.26, *P* value = 0.20), length of stay (MD = 0.06, 95% CI = −0.27 to 0.38, *P* value = 0.74), and total operation time (MD = 1.08, 95% CI = −4.62 to 6.79, *P* value = 0.71).

Conclusion: Closed-box reduces the total blood loss following unilateral and bilateral TKA. More studies are warranted to explore the benefits of Closed-box in patients with high bleeding susceptibility.

Keywords: blood loss, closed box, open box, prosthesis, total knee arthroplasty

Introduction

Total Knee arthroplasty (TKA) is an effective treatment for end-stage knee arthroplasty that failed to respond to conservative treatment. TKA aims to ameliorate pain and improve the quality of life[1]. The 20-year survival rate has reached 85% following TKA with cementless tibial trays[2]. However, many complications could occur; including bleeding, wound complications, thromboembolic disease, and others[3]. Prasad *et al.*[4] 2007 calculated the mean estimated blood loss following TKA to be 1073 ml and it was significantly higher in females[5]. Other risk factors include advanced age, low BMI, and higher acetylsalicylic acid ratings[5].

Excessive blood loss necessitates transfusions. A study done in Saudi Arabia calculated the incidence rate of blood transfusion following unilateral TKA to be 27.7%, while bilateral TKA was 73.7%[6]. It is important to note that transfusions carry a significant risk of transmission of blood-borne infections[7], febrile reactions[8], allergic reactions[9], volume overload[10], and alteration of electrolytes[11]. Due to the high rates of transfusion following TKA and its potential complications, multiple preventive measures have been developed to decrease the rates of transfusions, including preoperative haemoglobin optimization, femoral canal obturation, and tranexamic acid administration. The previous measures have managed to significantly decrease the rates of transfusions following TKA[12].

HIGHLIGHTS

- Closed box has less bleeding compared to open box.
- Both had similar findings in other parameters.

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In addition to the previously mentioned preventive measures, it is important to consider the type of knee prosthesis utilized in TKA. A study proved that posterior-stabilized (PS) TKA was associated with higher blood loss compared with cruciate-retaining (CR) TKA; this is explained by the fact that in PS there is more cancellous bone cutting and additional blood loss from venous sinuses within[13]. Another study has found no significant association between increased blood loss when comparing both techniques[14].

In a closed-box prosthesis, the cancellous bone at the distal femur is covered, while in an open-box prosthesis, there is an uncovered region at the intercondylar fossa, which may serve as a source of bleed[15]. There have been recent studies comparing postoperative blood loss in closed versus open-box prostheses. In our study, we aimed to perform a meta-analysis to compare the effect of open-box versus closed-box prostheses on blood loss following TKA.

Methods

This systematic review and meta-analysis were performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[16], Supplemental Digital Content 1, http://links.lww.com/MS9/A339. The Meta-analysis has been rated as high quality according to the AMSTAR 2 (Assessing the methodological quality of systematic reviews) Guidelines[17], Supplemental Digital Content 2, http://links.lww.com/MS9/A340.

Search strategy

A literature search of the following databases (PubMed, Scopus, and Web of Science) on the 3 July 2022, using key terms such as "open box prosthesis", "closed box prosthesis", "blood loss after total knee arthroplasty", "arthroplasties", "knee replacement arthroplasty", "total knee arthroplasty", "unicompartmental knee arthroplasty", "unicondylar knee arthroplasty", "unicondylar knee replacement", "partial knee arthroplasty", "partial knee replacement" was performed to identify studies of interest.

Inclusion and exclusion criteria

The protocol of the review was published on PROSPERO (CRD42023456786) before the literature search https://www.crd.york.ac.uk/prospero/#recordDetails. We screened studies by titles and abstracts according to the following criteria:

Inclusion criteria

Any randomized control trials or observational studies that compared the effect of open-box prosthesis versus closed-box prosthesis on total blood loss after knee arthroplasty with no restrictions to age and language.

Exclusion criteria

Case reports, case series, reviews, editorials, and animal studies.

Study selection

Two independent reviewers (R.H.E. and P.C.) screened the titles and abstracts of the studies according to our criteria. If a consensus is not achieved, a third independent reviewer was assigned to resolve the conflict.

Data extraction and quality assessment

Members of our team were each assigned several studies for data extraction, where each study was extracted by two reviewers independently. The data was then compared to confirm accuracy.

For the baseline and summary, the following data were extracted from the eligible studies: the first author of the study, year of publication, study design, duration of the study, number of participants, age of participants, sex of participants, BMI of participants, baseline haemoglobin of participants, and prevalence of laterality.

For the outcomes, the following data were extracted: total blood loss, average transfused units, blood transfusion rate, length of stay, and total operation time.

The quality was assessed utilizing Newcastle–Ottawa Scale (NOS) items[18], with a total score of nine points, to evaluate the quality of observational studies. Each study was ranked as good, fair or poor quality according to its score.

Data synthesis

Data were analyzed using RevMan software, version 5.4. Continuous data were presented as mean difference (MD) with 95% CI. Dichotomous data were presented as Odds Ratio (OR) with 95% CI. If no heterogeneity was observed, results were presented in a fixed effect model and a random effect model was used if significant heterogeneity was observed. Sensitivity analysis (leave-one-out test and subgroup analysis) will be used to resolve the heterogeneity if detected. Results were considered significant if P value was less than 0.05.

Results

Summary of studies

After a comprehensive search of the literature, 131 studies resulted, and then 119 were eligible for title and abstract screening after the removal of duplicates. Of the 119, 115 were irrelevant and 4 studies were eligible for full-text screening. Finally, four studies[15,19,20] were included in the meta-analysis after the full-text screening, as shown in the PRISMA in (Fig. 1), summary of the included studies is shown in Table 1.

Total blood loss was reported in three studies while the average transfused units, blood transfusion rate, length of stay, and total operation time were reported in two studies. The outcomes were compared between the open-box and closed-box knee arthroplasty and subgroup analysis was done to the total blood loss according to whether the knee arthroplasty is unilateral or bilateral. The overall quality assessment showed good quality in three studies while only one was of fair quality (see table, supplemental content, which illustrates the quality assessment, Supplemental Digital Content 3, http://links.lww.com/MS9/A341).

The total number of patients included in the study is patients were 687, including 331 patients in the open-box group, and 356 patients in the closed-box group, other baseline data are shown in Table 2.

Outcomes

Total blood loss

The pooled analysis showed a statistically significant association between the closed box and decreased total blood loss compared

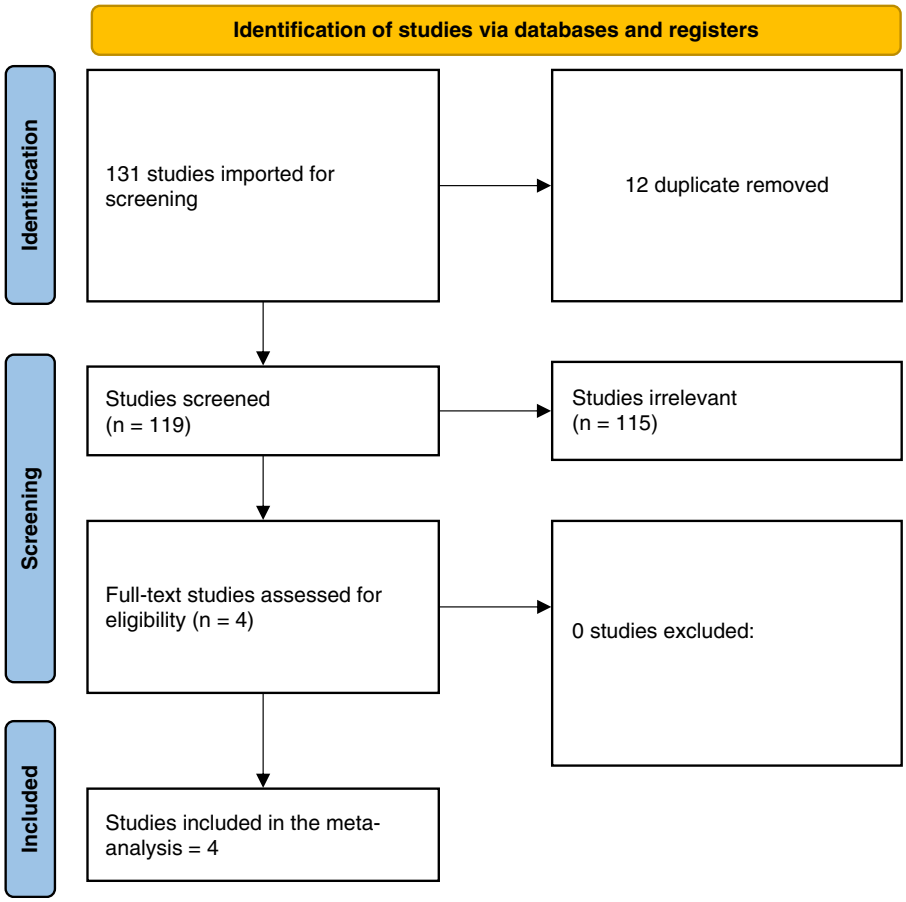

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

with the open box (MD = 173.19, 95% CI = 88.77–257.61, *P* value <0.0001). We observed no significant heterogeneity among studies (*P* = *0.63*, I^2 = 0%) as shown in Figure 2.

Subgroup analysis

Total blood loss subgroup: The pooled analysis showed a statistically significant association between the closed box and decreased total blood loss in the subgroup of unilateral knee arthroplasty compared with the open box (MD = 190.63, 95% CI = 70.91–310.35, *P* value = 0.002). We observed no significant heterogeneity among studies in this subgroup (*P* = 0.89 I^2 = 0%), as shown in Figure 3.

The pooled analysis showed a statistically significant association between the closed box and decreased total blood loss in the subgroup of bilateral knee arthroplasty (MD = 160.79, 95% CI = 61.70–359.86, *P* value = 0.001). We observed no significant heterogeneity among studies in this subgroup (*P* = 0.46, I^2 = 0%), as shown in Figure 3.

Average transfused units

The pooled analysis showed no statistically significant difference between open box and closed box (MD = 0.02, 95% CI = – 0.07 to 0.11, *P* value = 0.68). We observed no significant heterogeneity among studies (*P* = 0.24, I^2 = 27%), as shown in Figure 4.

Blood transfusion rate

The pooled analysis showed no statistically significant difference between open box and closed box (OR = 1.38, 95% CI = 0.85–2.26, *P* value = 0.20). We observed no significant heterogeneity among studies (*P* = 0.36, I^2 = 0%), as shown in Figure 5.

Length of stay

The pooled analysis showed no statistically significant difference between open box and closed box (MD = 0.06, 95% CI = – 0.27 to 0.38, *P* value = 0.74). We observed no significant heterogeneity among studies (*P* = 0.81, I^2 = 0%), as shown in Figure 6.

Total operation time

The pooled analysis showed no statistically significant difference between open box and closed box (MD = 1.08, 95% CI = – 4.62 to 6.79, *P* value = 0.71). We observed no significant heterogeneity among studies (*P* = 0.62, I^2 = 0%), as shown in Figure 7.

Discussion

Our study reported a statistically significant association between closed-box and decreased total blood loss following TKA

Table 1

Summary of the included studies.

ID	Study design	Duration of the study	Study arms	End points	Conclusion
Ma *et al.*[15]	Retrospective study	January2017–July2020 (42 months)	Those who were diagnosed with knee osteoarthritis and underwent primary unilateral or one-stage bilateral TKA by using PFC Sigma PS150 (closed-box prosthesis) or Vanguard (open-box prosthesis) knee systems and had complete data of laboratory indexes on postoperative day (POD) 1, POD 3, and POD 5 were the interested population.	The baseline was comparable between groups, except higher preoperative levels of haemoglobin (134.43 g/l versus 126.51 g/l, $P=0.003$) and haematocrit (39.92% versus 37.37%, $P=0.000$) observed in the one-stage bilateral open-box group. The differences of postoperative coagulation function monitored by TT, PT, APTT, and INR were clinically irrelevant between groups. For patients receiving unilateral TKA, significantly higher value of decreased haemoglobin (26.06 g/l versus 21.05 g/l, $P=0.025$) and significantly larger amount of total blood loss (920.34 ml versus 723.19 ml, $P=0.013$) were observed in the open-box group. For patients receiving one-stage bilateral TKA, the open-box prosthesis was observed to cause more haemoglobin drop (37.81 g/l versus 32.02 g/l, $P=0.071$) and total blood loss (1327.26 ml versus 1177.42 ml, $P=0.247$) compared to the closed-box prosthesis, though the differences were not significant. The transfusion rate and the average transfused RBC units were not significantly different between the open-box group and the closed-box group no matte whether the patients were from the unilateral TKA group or from one-stage bilateral TKA group.	The use of open-box prosthesis caused more haemoglobin drop and total blood loss than closed-box pros- thesis after primary unilateral or one-stage bilateral TKA, resulting in comparable transfusion rate and average trans- fused RBC units between groups.
Laoruengthana *et al.*[20]	Prospective randomized controlled trial	January2015–January2016 (12 months)	The 228 patients undergone primary unilateral TKA were randomized to determine between open-box and closed-box pros- thesis. Among each group, a second randomization was applied to categorize the patients into (1) no use of TXA (No-TXA), (2) intra-articular TXA use (IA-TXA) and (3) intravenous TXA use (IV-TXA)	The open-box TKA had 85.60 and 63.29 ml ($P=0.02$ and $P<0.01$) more CBL and DV compared to closed-box TKA. The IA-TXA and IV-TXA significantly reduced CBL by 190.75 and 162.01 ml ($P<0.01$ and $P<0.01$) and reduced DV by 129.07 and 61.04 ml ($P<0.01$ and $P=0.01$), respectively, when compared to No-TXA. Patients who received IA and IV-TXA had ANUBT of 0.21 and 0.23 unit, which was significantly lower than 0.42 unit of No-TXA group ($P=0.03$).	Use of the different prosthesis designs could significantly affect CBL and DV following TKA. However, the use of either design resulted in a comparable ANUBT. Regardless of prosthetic type, either IA- or IV-TXA could significantly reduce the CBL and ANUBT when compared to No-TXA.
Rattanaprichavej *et al.*[20]	Retrospective study	June 2015–May 2018 (35 months)	Demographic and perioperative data of patients who underwent SBTKA using either a closed-box or an open-box femoral component of posterior-stabilized fixed-bearing (PS FB) knee system were retrospectively reviewed. The calculated blood loss (CBL) and blood transfusion rate were compared by using Student *t*-test and confirmed with multivariate regression analysis.	There was no significant difference in preoperative parameters between 54 closed-box and 56 open-box PS FB TKAs. The CBL of the closed-box TKA group was 135.23 ml less (95% CI, –215.30 to –55.16; $P=0.001$) than that of the open-box TKA group. However, the blood transfusion rates of the closed- and open-box TKA groups were not significantly different (24.1% and 38.5%, $P=0.11$). For each additional minute of total operative time, 3.75 ml (95% CI, 1.75–5.76; $P<0.001$) of blood loss was anticipated. For each	The use of closed- and open-box knee prostheses resulted in a significant difference in blood loss in SBTKA. Pro- longed operative time also significantly increased CBL. Therefore, strategies to control the bleeding surface and shorten operative duration may be considered if blood loss is of special concern. The preoperative haemoglobin was the only factor that affects the probability of blood transfusion in SBTKA.

				additional mg/dl of preoperative haemoglobin, 71% ($P < 0.001$) reduction of blood transfusion probability was predicted.	
Jiang *et al.*[19]	Retrospective study	June 2005–December 2006 (18 months)	108 patients with primary knee osteoarthritis were treated with TKR. The postoperative blood loss and perioperative blood loss were compared between groups.	The postoperative blood loss was (890 ± 352), (1694 ± 528), (1068 ± 386) and (2065 ± 622) ml in groups A1, A2, B1 and B2, respectively. There was no significant difference between groups A1 and B1 ($P > 0.05$). There was significant difference between groups A2 and B2 ($P < 0.05$). The total blood loss was (1095 ± 329), (2082 ± 594), (1274 ± 415) and (2459 ± 734) mL in groups A1, A2, B1 and B2, respectively. There was no significant difference between groups A1 and B1 ($P > 0.05$). There was significant difference between groups A2 and B2 ($P < 0.05$).	Closed-box knee prosthesis may play roles on reducing postoperative blood loss. The main influential factor for postoperative blood loss is operation techniques which includes reducing operation time and stanching thoroughly during operation.

ANUBT, average number of units of blood transfused; APTT, activated Partial thromboplastin time; DV, drain volume; PT, prothrombin time; RBC, red blood cell; SBTKA, Simultaneous bilateral total knee arthroplasty; TKA, total knee arthroplasty; TKR, total knee replacment; TT, thrombin time; TXA, Tranexamic acid.

Table 2

Baseline characteristics of included studies

	No. patients in each group		Age (years)		Sex (*n*)				BMI		Baseline haemoglobin		Laterality	
					Open box		Closed box							
ID	Open Box	Closed box	Open Box	Closed box	Female	Male	Female	Male	Open box	Closed box	Open box	Closed box	Open box	Closed box
Ma *et al.*[15]	108	135	Unilateral: 69.30 ± 10.26 bilateral: 66.36 ± 7.93	Unilateral:66.92 ± 7.24 bilateral: 66.60 ± 7.62	Unilateral:47 bilateral:32	Unilateral:19 bilateral:10	Unilateral: 72 bilateral:42	Unilateral: 16 bilateral:5	Unilateral: 26.71 ± 3.08 bilateral:27.24 ± 3.90	Unilateral: 27.56 ± 4.11 bilateral:27.95 ± 4.76	Unilateral: 130.14 ± 13.48 bilateral: 134.43 ± 12.78	Unilateral: 130.66 ± 12.56 bilateral: 126.51 ± 11.33	Unilateral TKA: 66 bilateral TKA:42	Unilateral TKA: 88 bilateral TKA:47
Laoruengthana *et al.*[20]	113	113	No-TXA:63.38 ± 7.13 IA-TXA: 63.95 ± 7.70 IV-TXA:64.83 ± 6.97	No-TXA:64.41 ± 7.12 IA-TXA: 65.53 ± 8.36 IV-TXA:63.38 ± 8.43	No-TXA:29 IA-TXA: 30 IV-TXA:32	No-TXA:9 IA-TXA: 8 IV-TXA:6	No-TXA: 31 IA-TXA: 33 IV-TXA:34	No-TXA: 7 IA-TXA: 5 IV-TXA:4	No-TXA:27.15 ± 3.94 IA-TXA: 28.03 ± 4.51 IV-TXA:27.49 ± 5.20	No-TXA:27.02 ± 3.41 IA-TXA: 26.99 ± 3.83 IV-TXA:27.96 ± 5.25	No-TXA:12.53 ± 1.45 IA-TXA:12.56 ± 1.32 IV-TXA:12.09 ± 1.26	No-TXA:12.04 ± 1.02 IA-TXA:11.78 ± 1.15 IV-TXA:12.31 ± 1.25	Unilateral TKA: 113	Unilateral TKA: 113
Rattanaprichavej *et al.*[20]	56	54	62.2 ± 7.0	61.7 ± 7.2	53	3	53	1	26.8 ± 3.6	26.1 ± 5.7	12.4 ± 1.3	12.5 ± 1.0	Bilateral TKA: 56	Bilateral TKA: 54
Jiang *et al.*[19]	54	54	59–81	41–76	46	8	47	7	___	___	___	___	Unilateral TKA: 27 bilateral TKA:27	Unilateral TKA: 27 bilateral TKA:27

TKA, total knee arthroplasty.

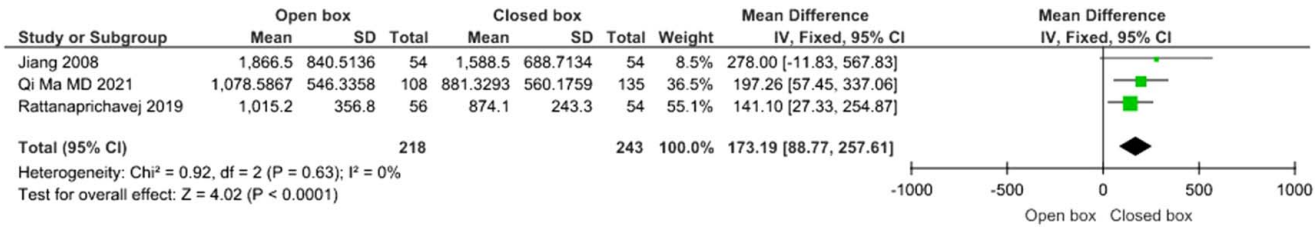

Figure 2. Total blood loss outcome.

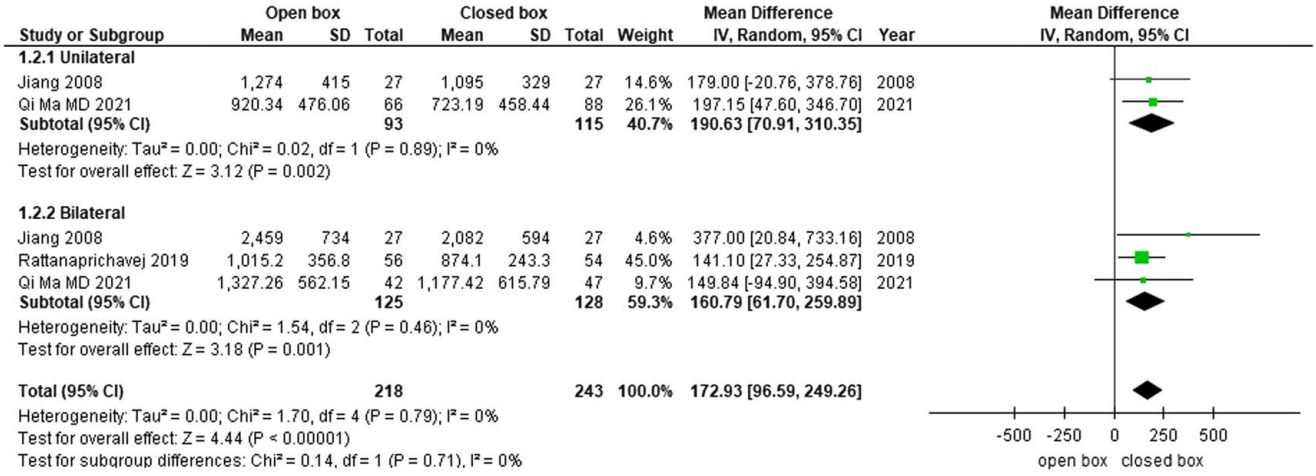

Figure 3. Total blood loss subgroup analysis.

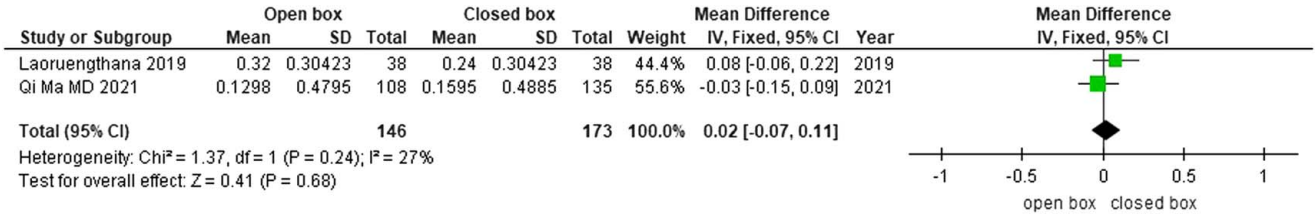

Figure 4. Average transfused units outcome.

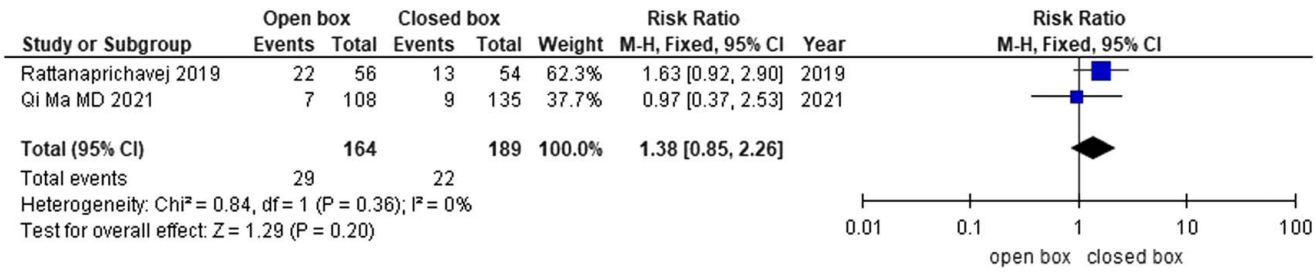

Figure 5. Blood transfusion rate outcome.

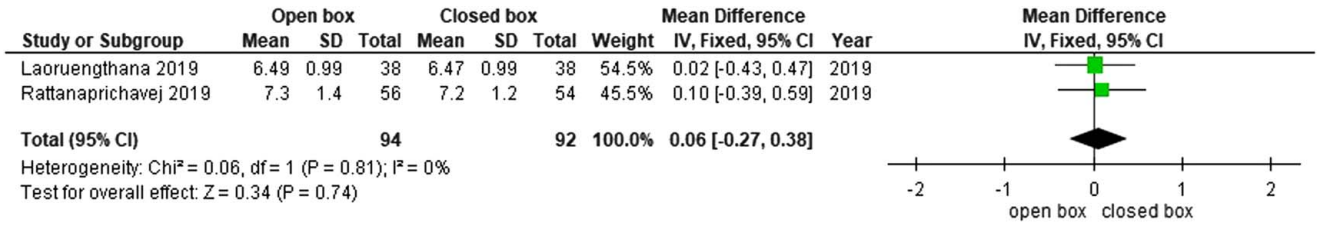

Figure 6. Length of stay outcome.

compared with open-box. Similar findings were reported in unilateral and bilateral TKA. There was not a significant difference between closed-box and open-box regarding average transfused units, blood transfusion rate, length of stay, and total operation time.

Periprosthetic fractures are a complication of TKA and it is managed via a retrograde locking intramedullary nail. It is important to note that closed-box prostheses do not allow access to the medullary canal through the intercondylar notch[21]. This hinders the management of periprosthetic fractures and it should be considered when deciding between both designs of the prosthesis.

All of the studies included in our analysis[15,19,20] have concluded that closed-box TKA had a significantly less amount of blood loss than open-box TKA. However, Ma *et al.*[15] concluded that there was only a significantly less amount of blood loss in patients performing unilateral closed-box TKA over patients performing bilateral closed-box TKA. Meanwhile, Jiang *et al.*[19] concluded that there was only a significantly less amount of blood loss in patients performing bilateral closed-box TKA over patients performing unilateral closed-box TKA.

Prolonged operative time could lead to complications; as proved by Peersman *et al.*[22] who showed that increased operative time is associated with increased infection rate following TKA. In another study conducted by Young *et al.*[23], it was shown that prolonged operative time leads to increased rates of revision surgery. Fortunately, our analysis showed that there was not a significant difference between closed-box and open-box prostheses regarding the total operative time.

Papalia *et al.*[24], and Rattanaprichavej *et al.*[20] concluded that intraoperative blood loss is significantly associated with increased length of hospital stay. Han *et al.*[25] reported that postoperative haemoglobin is one of the predictors of length of stay. Nonetheless, our study has shown a significant difference in blood loss between both types of prosthesis and an insignificant difference in the length of hospital stay; Both Rattanaprichavej *et al.*[20] and Ma *et al.*[15] concluded that there was no significant difference between open-box TKA and closed-box TKA in total operative time.

Bilateral TKA is associated with higher rates of blood transfusions compared with unilateral TKA, as stated by Agarwala *et al.*[26]. However, our findings showed that closed-box reduced blood loss in both unilateral and bilateral TKA. It is important to note that the blood transfusion rate and the average transfused units weren't significantly impacted by the type of prosthesis as mentioned by Laoruengthana *et al.*[20], Rattanaprichavej *et al.*[20], and Ma *et al.*[15]; Raising the question that the benefit of closed-box might be more valuable in patients vulnerable to blood loss following TKA for example females, elderly, and patients with a high BMI[27].

Future implications

Our meta-analysis demonstrated that, in terms of overall blood loss, closed-box arthroplasty is preferable to open-box arthroplasty. Consequently, closed-box knee arthroplasty should be utilized more frequently.

Strengths and limitations

Our analysis detected no heterogeneity among the studies. In addition to that, a good sample size was present, as 687 patients were included in our analysis. However, our study showed some limitations. For example, most of the included studies were non-randomized observational, and only one randomized clinical trial was included. Thus, prospective multicenter randomized studies are warranted, emphasizing the potential benefits of closed-box surgery in patients susceptible to intraoperative bleeding. Furthermore, the effect of the type of surgical drain utilized should be accounted for, as it could affect the rate of blood transfusion perioperatively in TKR.

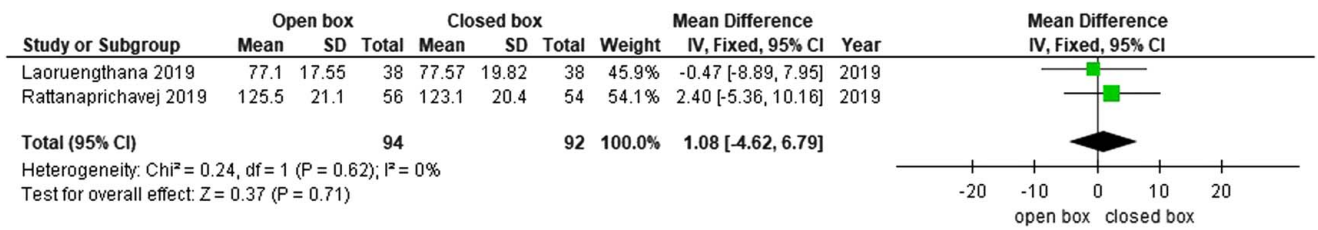

Figure 7. Total operation time outcome.

Conclusion

Our analysis reported a statistically significant association between closed-box and decreased total blood loss following TKA compared with open-box. Similar findings were reported in unilateral and bilateral TKA. Conversely, no significant difference between closed-box and open-box was detected regarding average transfused units, blood transfusion rate, length of stay, or total operation time. However, it is necessary to conduct future clinical trials to explore the benefits of closed-box in patients with high susceptibility to intraoperative haemorrhage.

Ethics approval

Not applicable as it is a systematic review and meta-analysis study.

Consent

Not applicable as it is a systematic review and meta-analysis study.

Source of funding

The authors declare they have no fund.

Author contribution

R.H.E.: screening, analysis and writing. K.R.M.: supervision and writing. Y.E.D.: writing. A.H.: quality assessment and writing. A.M.H., P.C. and J.S.: screening and data extraction.

Conflicts of interest disclosure

The authors declare no conflict of interest.

Research registration unique identifying number (UIN)

A protocol is submitted to prospero ID: CRD42023456786.

Guarantor

Jaffer Shah and Rowan H. Elhalag.

Availability of data and material

Data and material are available within the manuscript.

Provenance and peer review

Not commissioned, externally peer-reviewed.

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