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Strategies for minimizing blood loss during craniosynostosis surgeries: A Bayesian network meta-analysis

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Abstract

Children with craniosynostosis might require surgical management to prevent serious complications such as increased intracranial pressure and developmental delays. The surgical poses the risk of blood loss, which could lead to post-surgical complications that may necessitate blood transfusions and increase perioperative morbidity. The aim of this meta-analysis was to explore strategies for minimizing blood loss during craniosynostosis surgeries. A systematic literature search was performed on PubMed, Scilit, Scopus, and Web of Science for studies published as of March 7, 2024. Studies were deemed eligible if they reported intraoperative blood loss during surgeries employing the following techniques: first-pass fluid outflow drainage optimization (1pFODO), second-pass fluid outflow drainage optimization (2pFODO), cranial vault remodeling (CVR), endoscopic strip craniectomy (ES), strip craniectomy (SC), and frontal orbital advancement and remodeling (FOAR). Bayesian network meta-analysis was employed to compare these techniques using a random-effects model, where pooled estimates were expressed as standard mean difference (SMD) and its 95% confidence interval (95% CI). Five studies were included in the systematic review and meta-analysis after screening 1,473 initially identified records. A total of 296 patients aged 3.1 to 96 months were recruited across studies from various countries, including South Korea, the United States, Turkey, and the United Kingdom. Blood loss during surgery varied from 1.4±4.5 mL to 151.3±51.2 mL. Compared to CVR, the SMDs for 2pFODO, 1pFODO, SC, and ES were -0.99 (95%CI: -140 to 120), -1.1 (95%CI: -91 to 83), -1.5 (95%CI: -66 to 61), and -2.8 (95%CI: -91 to 83), respectively. ES and SC had the highest rank probabilities for being the best techniques in minimizing blood loss, with probability value of 0.464 and 0.305, respectively. When the analysis focused specifically on non-syndromic cases, ES showed the greatest reduction in blood loss compared to CVR (SMD: -2.8 (95%CI: -174.5 to 163.4), with a probability score of 0.315. In conclusion, ES performs the best in minimizing blood loss in both mixed and non-syndromic cases. Surgeons may consider other factors when selecting a surgical technique, such as cephalic index, skull maturity, reoperation rate, surgical complexity, and long-term neurodevelopmental outcomes.

Keywords: Blood loss, blood transfusion, craniosynostosis, cranial repair, suture

Introduction

Craniosynostosis, characterized by the premature fusion of one or more cranial sutures, affects approximately 5.9 in 10,000 live births [1]; however, the incidence could be 1 in 1500 births [2].

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This reflects the need for timely surgical intervention, typically within the first year of life, to prevent serious complications, including increased intracranial pressure, developmental delays, and altered head shape [3]. The demographic analysis of craniosynostosis cases reveals that 78.9% of the patients are male, with the most commonly affected sutures being sagittal (54.9%), metopic (25.3%), and coronal (14.0% unilateral, 1.4% bilateral) [2]. Surgical techniques such as total calvarial remodeling and fronto-orbital advancement are considered standard treatments for this congenital anomaly. However, these procedures are inherently associated with significant blood loss, necessitating transfusion of allogeneic blood products in the majority of cases [4-6]. Despite advancements in surgical and anesthetic techniques, the prevalence of substantial intraoperative and postoperative bleeding remains a critical concern.

Blood loss during craniosynostosis surgeries can exceed the total blood volume of the infant, raising the risk of complications such as transfusion-related acute lung injury and transfusion-associated circulatory overload [7,8]. Furthermore, the practice of allogeneic transfusion, while sometimes unavoidable, carries the risk of immune-mediated reactions and infectious disease transmission, which can lead to increased morbidity and extended hospital stays [7,8]. Given these risks, there is an urgent need for evidence-based strategies to minimize blood loss and optimize transfusion management in craniosynostosis surgeries. Current clinical practices vary widely, with no standardized guidelines available, highlighting the need for a comprehensive approach to blood management in this patient population. The World Health Organization's recent recommendations on patient blood management (PBM) advocate for the implementation of optimal strategies to enhance patient outcomes [9].

The aim of this meta-analysis was to evaluate and compare various strategies for minimizing blood loss during craniosynostosis surgeries using Bayesian network meta-analysis. By synthesizing existing data, this meta-analysis intended to identify effective interventions that can lead to improved surgical outcomes and reduced transfusion-related complications. The findings could serve as a foundation for establishing best-practice guideline, ultimately enhancing the safety and efficacy of craniosynostosis management and contributing to better healthcare practices for affected infants.

Methods

Study design and protocol registration

This meta-analysis followed the preferred reporting items for systematic reviews and meta-analysis protocol (PRISMA) guidelines [1]. The research question was "What are the most effective strategies for minimizing blood loss during craniosynostosis surgeries?". The study protocol was registered following the initial records identification on PROSPERO with the registration number CRD42024604676 on November 1, 2024.

Database and search strategies

The systematic literature review was performed on March 7, 2024, and involved searching across four databases: PubMed, Scilit, Scopus, and Web of Science. The literature search was carried out with keywords using Boolean operators 'AND' and 'OR' as detailed in **Table 1**. The search strategies followed the recommendation of previously published report [10].

Table 1. Keyword combinations used in different databases in this meta-analysis

Database	Keywords combination	Hits
PubMed	allintitle: craniosynostosis AND ("1pFODO" OR "2pFODO" OR "cranial vault remodeling" OR "endoscopic strip craniectomy" OR "strip craniectomy" OR "FOAR") AND ("blood loss" OR "transfusion" OR "hemostasis" OR "hemorrhage")	441
Scopus	TITLE ((craniosynostosis) AND ("1pFODO" OR "2pFODO" OR "cranial vault remodeling" OR "endoscopic strip craniectomy" OR "strip craniectomy" OR "FOAR") AND ("blood loss" OR "transfusion" OR "hemostasis" OR "hemorrhage"))	471
WoS	(craniosynostosis) AND ("1pFODO" OR "2pFODO" OR "cranial vault remodeling" OR "endoscopic strip craniectomy" OR "strip craniectomy" OR "FOAR") AND ("blood loss" OR "transfusion" OR "hemostasis" OR "hemorrhage")	460

Database	Keywords combination	Hits
Scilit	(craniosynostosis) AND ("1pFODO" OR "2pFODO" OR "cranial vault remodeling" OR "endoscopic strip craniectomy" OR "strip craniectomy" OR "FOAR") AND ("blood loss" OR "transfusion" OR "hemostasis" OR "hemorrhage")	101

1pFODO: first-pass fluid outflow drainage optimization; 2pFODO: second-pass fluid outflow drainage optimization; FOAR: frontal orbital advancement and remodeling

Inclusion and exclusion criteria

The inclusion criteria focused on studies that investigate the strategies used in minimizing blood loss during craniosynostosis surgeries. These interventions included: first-pass fluid outflow drainage optimization (1pFODO), second-pass fluid outflow drainage optimization (2pFODO), cranial vault remodeling (CVR), endoscopic strip craniectomy (ES), strip craniectomy (SC), and frontal orbital advancement and remodeling (FOAR). Eligible studies must reported outcomes related to blood loss, including rates of blood transfusion, volume of intraoperative blood loss, and postoperative complications related to hemorrhage. Accepted study designs included randomized controlled trials (RCTs), cohort studies, case-control studies, and cross-sectional studies that provide primary data relevant to these outcomes, with a focus on peer-reviewed articles published in English. Conversely, studies that did not involve surgical interventions for craniosynostosis, lack comparative analysis of surgical techniques, or did not provide adequate data regarding blood loss outcomes will be excluded. Additionally, case series or reports lacking systematic outcome reporting and non-English publications were also omitted. The evaluation of each study's eligibility was conducted independently by two authors, with any discrepancies resolved through discussion and consensus among the review team.

Screening and selection

Two reviewers (GM and LTA-G) conducted each stage, resolving disagreements through consensus using EndNote for reference management. Disagreement was resolved through consensus or by involving a third reviewer (RNR) if necessary. For unclear or missing outcome data, the corresponding authors were contacted. Additionally, the reference lists of included studies and prior reviews were examined for additional relevant research.

Critical appraisal

Two independent reviewers (GM and LTA-G) evaluated the quality of the included studies. The Newcastle-Ottawa Scale (NOS) was employed for the critical appraisal of observational studies, with a detailed description of this tool provided earlier [11]. Any discrepancies were addressed through consensus or by consulting a third reviewer (RNR).

Data extraction

Following the identification and screening of relevant studies based on the established inclusion and exclusion criteria, two independent reviewers undertook the data extraction. The essential data from each included study were extracted such as the first author's name, year publication, country, study design, and sample size. In addition, this process also involved gathering information related to the study characteristics and outcomes, including the type of surgical techniques employed to minimize blood loss, the volume of blood loss during procedures, and the rates of blood transfusion required. Demographic data of the research subjects was extracted, including age and sex, as well as clinical characteristics pertinent to craniosynostosis surgeries. Specific surgical techniques, 1pFODO, 2pFODO, CVR, ES, SC, and FOAR, were documented. Additionally, data on blood loss outcomes were extracted, which included metrics like intraoperative blood loss volume and postoperative transfusion rates. To ensure the reliability of the extracted data, the information gathered by the primary reviewer (GM) was subsequently verified by a second reviewer (LTA-G). Any discrepancies identified during this process were resolved through discussion and consensus.

Statistical analysis

Network meta-analysis based on Bayesian statistics was performed to compare all identified surgical techniques using GeMTC package on R studio (Rstudio, Boston, USA). The random-effects model was chosen where the pooled size effect was calculated using standard mean difference (SMD) and its 95% confidence interval (95%CI). The primary outcome of interest was the volume of blood loss during surgical procedures. High heterogeneity was indicated by an I^2 value greater than 50% or a p-value less than 0.1 based on I^2 statistics. Following the guideline from previous reports [12,13], funnel plot was anticipated for the number of included studies exceeding ten.

Results

Searching results

A total of 1473 records were retrieved from applying the search strategies on four different databases (**Figure 1**). Thereafter, 904 duplicates were identified and removed. The abstract and title screening resulted in the reduction of 569 records to 102, which were sought for full-text retrieval. Three full articles were unable to be retrieved, so the selection based on eligibility criteria was applied only to 99 articles. Eighty-two articles were considered not eligible because they had inappropriate study design, no outcome of interest, unsuitable document type, were duplicates or had no comparison group. Ten studies were excluded because they only reported the prevalence of blood transfusion, without reporting the amount of blood loss [14-23]. One study did not report the standard deviation; therefore, it was excluded from the review due to data incompleteness [24]. From this process, five studies were considered eligible for inclusion in the network meta-analysis [17,25-28].

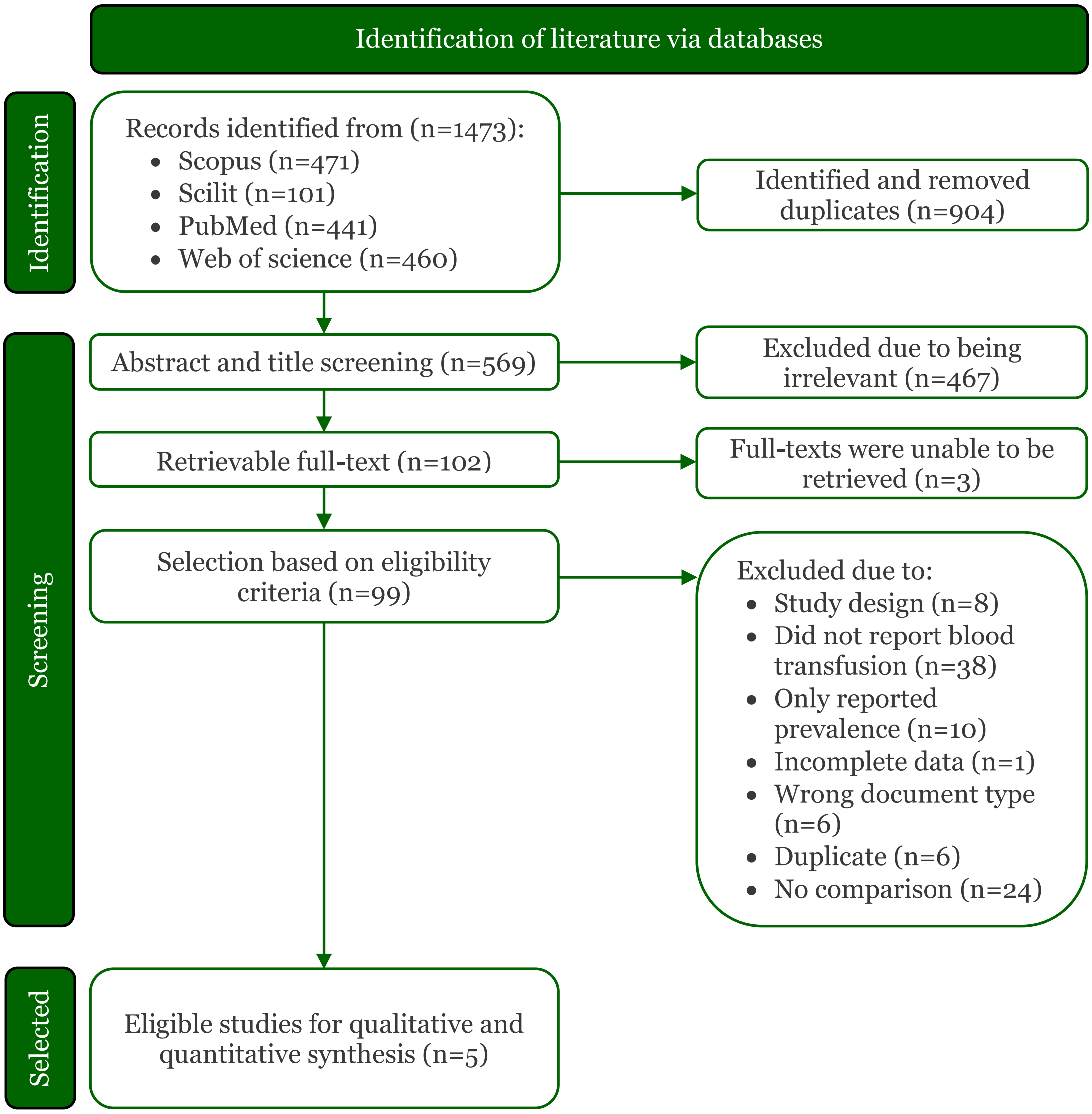


Figure 1. Flowchart depicting the selection process of eligible studies.

Characteristics of included studies

The characteristics of the included studies are summarized in **Table 2**. Across all studies, the number of female patients consistently exceeded that of male patients [17,25-28], with participant ages spanning from 3.1 to 96 months [17,25]. The studies were conducted in diverse geographic locations, including South Korea [25], the United States [26,28], Türkiye [27], and the United Kingdom [17]. Most of the studies focused exclusively on patients with non-syndromic craniosynostosis [17,26-28]. The reported volume of blood loss varied significantly across studies, ranging from 1.4±4.5 to 151.3±51.2 mL [25,26].

Table 2. Characteristics and outcome of interest of the included studies

Author, year [ref]	Country	Study design	Syndromic	Approach	Characteristics [a]			Blood loss (mL)
					n	Age (months) [a]	M/F	
Park *et al.*, 2022 [25]	South Korea	Cross-sectional	Mix	1pFODO	11	31.1±13.1	4/7	1.4±4.5
				2pFODO	9	37.1±16.5	3/6	1.8±0.4
Villavisanis *et al.*, 2022 [26]	United States	Cross-sectional	No	1pFODO	20	6.45±0.2	4/16	30.6±19.7
				CVR	20	9.4±1.88	6/14	58.7±30.4
Albuz *et al.*, 2024 [27]	Türkiye	Cross-sectional	No	CVR	24	11±NR	NR	69.3±24
				ES	61	96±NR	NR	4±61
Jivraj *et al.*, 2019 [17]	United Kingdom	Cohort	No	CVR	23	17.37 (13.2–29.53) [b]	10/13	213.99±59.11
				SC	115	3.1 (0–10) [b]	10/65	80±78.5
Benkler *et al.*, 2021 [28]	United States	Cohort	No	SC	6	3.1±1.0	NR	92.5±49.9
				FOAR	7	17.5±8.5	NR	151.3±51.2

1pFODO: first-pass fluid outflow drainage optimization; 2pFODO: second-pass fluid outflow drainage optimization; CVR: cranial vault remodeling; ES: endoscopic strip craniectomy; FOAR: frontal orbital advancement and remodeling; M/F: male to female ratio; NR: not reported; SC: strip craniectomy

[a] Otherwise stated, the data are presented as mean ± standard deviation

[b] Presented as median (min-max)

Appraisal results on the included studies

The results of the quality appraisal for all included studies are presented in **Table 3**. All cross-sectional studies were graded as moderate in quality due to lack of comparability [25,27] and minimum number of participants recruited [26]. One study enrolled the control participants from a different population than its cohort, but no more concerns were found in the report [17]. A cohort study only received a score of 7 due to the lack of cohort selection and unclear reporting on the follow-up period [28].

Table 3. Quality of the included studies according to Newcastle-Ottawa Scale (NOS) assessment

Author, year (ref)	Study design	Selection	Comparability	Outcome	Total	Remark [a]
Park *et al.*, 2022 [25]	Cross-sectional	★★	★	★★★	6	Moderate
Villavisanis *et al.*, 2022 [26]	Cross-sectional	★	★★	★★★	6	Moderate
Albuz *et al.*, 2024 [27]	Cross-sectional	★★	★	★★★	6	Moderate
Jivraj *et al.*, 2019 [17]	Cohort	★★★	★★	★★★	8	Good
Benkler *et al.*, 2021 [28]	Cohort	★★★	★★	★★	7	Moderate

[a] Cut-off for being good in reporting quality is 7 and 8 for cross-sectional and cohort studies, respectively

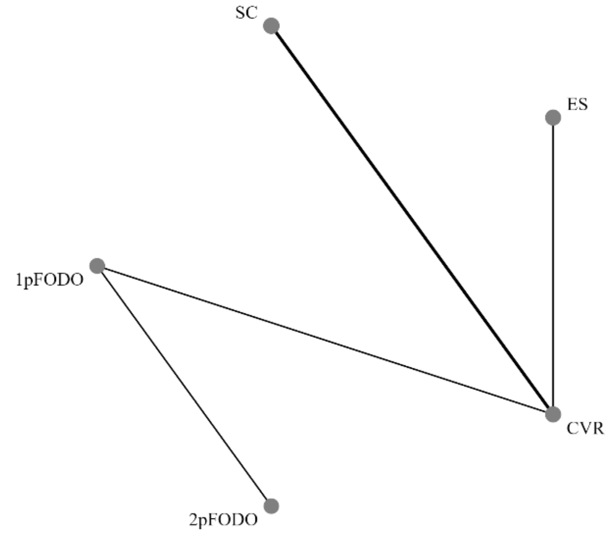
Network meta-analysis among a mixed pool of syndromic and non-syndromic cases

Five approaches were identified used to minimize blood loss during craniosynostosis surgeries. The network model comparing each approach is presented in **Figure 2A**, with direct comparisons established between CVR and IpFODO, CVR and SC, CVR and ES, as well as IpFODO and 2pFODO. The results of these comparisons, derived from the network meta-analysis, are presented in **Figure 2B**. When CVR was chosen as the control, the highest SMD was found in 2pFODO (SMD: -0.99; 95%CI: -140 to 120), followed by 1pFODO (SMD: -1.1;

Windiana et al. Narra Review 2025; 1 (1): e1 - http://doi.org/10.52225/narrarev.v1i1.1

95%CI: -91 to 83). Other techniques such as SC and ES had SMDs of -1.5 (95%CI: -66 to 61) and -2.8 (95%CI: -91 to 83), respectively.

A



B

1pFODO	0.13 (-90.27 to 87.71)	1.11 (-82.10 to 91.16)	-1.70 (-126.31 to 122.98)	-0.39 (-105.70 to 112.01)
	2pFODO	0.99 (-118.48 to 137.09)	-1.83 (-162.38 to 158.03)	-0.50 (-135.61 to 143.907)
		CVR	-2.82 (-91.16 to 83.16)	-1.55 (-66.17 to 60.87)
			ES	1.30 (-107.61 to 111.38)
				SC

Figure 2. Network meta-analysis among a mixed pool of craniosynostosis surgeries of syndromic and non-syndromic cases. (A) Network graph for the comparison of craniosynostosis surgeries. (B) Comparisons of the craniosynostosis surgeries estimated through Bayesian network meta-analysis. The data are presented as SMD (95%CI). Each cell gives the effect of the column-defining intervention relative to the row-defining intervention. 1pFODO: one-point frontal orbital distraction osteogenesis; 2pFODO: two-point frontal orbital distraction osteogenesis; CVR: open total cranial vault reconstruction; ES: endoscopic strip craniectomy; SC: strip craniectomy with helmet.

Forest plot depicting the total effect of each technique when CVR was chosen as the comparator is presented in **Figure 3**. The highest SMD was found in 2pFODO (SMD: -0.99; 95%CI: -140 to 120), followed by 1pFODO (SMD: -1.1; 95%CI: -91 to 83). Other techniques, such as SC and ES, had SMDs of -1.5 (95%CI: -66 to 61) and -2.8 (95%CI: -91 to 83), respectively.

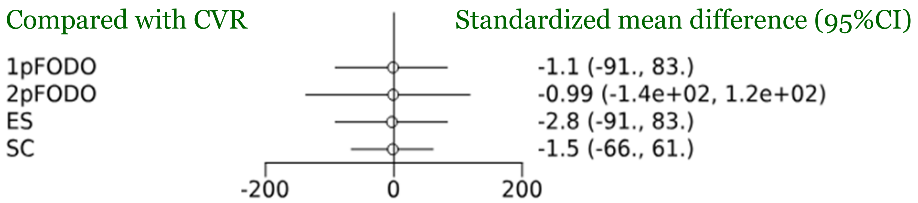


Figure 3. Forest plot for network pooled estimates of craniosynostosis as compared with cranial vault remodeling (CVR). 1pFODO: one-point frontal orbital distraction osteogenesis; 2pFODO: two-point frontal orbital distraction osteogenesis; CVR: open total cranial vault reconstruction; ES: endoscopic strip craniectomy; SC: strip craniectomy with helmet.

Rank probabilities

The rank probabilities of each approach for minimizing blood loss during craniosynostosis surgery, as estimated using a Bayesian method, are presented in **Table 4** and illustrated in **Figure 4**. ES has the highest probability (0.464) of achieving the top rank, while SC holds the highest probability (0.305) for the second rank. For the third and fourth ranks, the approach with the highest scores is 1pFODO, with a probability of 0.264.

Table 4. Rank probabilities of craniosynostosis surgeries based on network Bayesian meta-analysis

Surgical techniques	Probability value				
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
1pFODO	0.117	0.236	0.264	0.264	0.120
2pFODO	0.216	0.168	0.161	0.203	0.252
Cranial vault reconstruction (CVR)	0.040	0.144	0.235	0.249	0.332
Endoscopic strip craniectomy (ES)	0.464	0.147	0.134	0.100	0.156
Strip craniectomy (SC)	0.164	0.305	0.207	0.184	0.140

1pFODO: one-point frontal orbital distraction osteogenesis; 2pFODO: two-point frontal orbital distraction osteogenesis

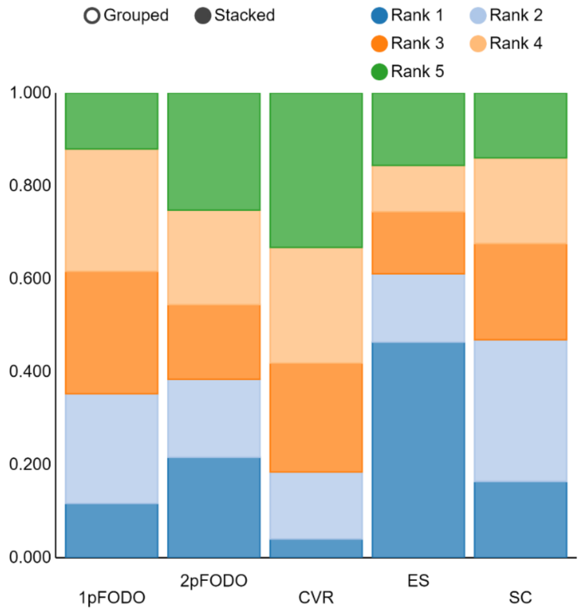


Figure 4. Rank probabilities of surgical techniques for minimizing blood loss in craniosynostosis surgeries. The stacked bar plot displays the probability distribution across five ranking positions for each surgical technique.

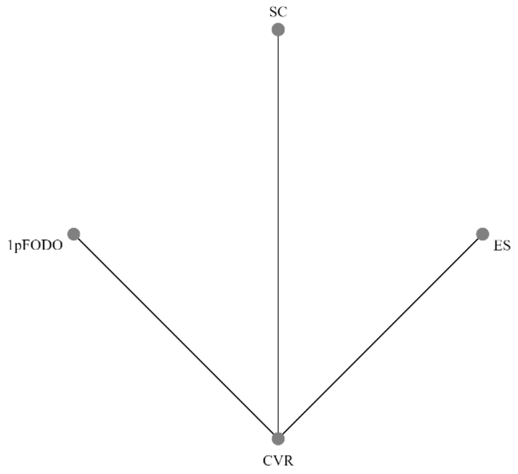
Network meta-analysis among a mixed pool of non-syndromic cases

Four approaches were identified for non-syndromic cases. The network model comparing each approach is presented in **Figure 5A**, with direct comparisons established between CVR and IpFODO, CVR and SC, as well as CVR and ES. The results of these comparisons, derived from the network meta-analysis, are presented in **Figure 5B**. When CVR was chosen as the control, the highest SMD was found in 1pFODO (SMD:1.4; 95%CI: -168.8 to 172.8), followed by other techniques such as SC and ES with SMDs of 0.6 (95%CI: -234.4 to 240.9) and -2.8 (95%CI: -174.5 to 163.4), respectively. Comparison of the included interventions: mean difference (95%CI).

Rank probabilities

The rank probabilities of each approach for minimizing blood loss during craniosynostosis surgery, as estimated using a Bayesian method, are presented in **Table 5** and illustrated in **Figure 6**. ES has the highest probability (0.315) of achieving the top rank, while CVR holds the highest probability (0.356) for the second rank. For the third and fourth ranks, the approach with the highest scores is 1pFODO, with a probability of 0.212.

A



B

1pFODO	1.370 (-168.781, 172.774)	-1.298 (-236.106, 241.215)	-0.463 (-238.630, 249.246)
	CVR	-2.784 (-174.530, 163.365)	-1.837 (-164.110, 166.796)
		ES	0.571 (-234.356, 240.933)
			SC

Figure 5. Network meta-analysis among a mixed pool of craniosynostosis surgeries of non-syndromic cases. (A) Network graph for the comparison of non-syndromic cases approaches. (B) Comparisons of the craniosynostosis surgeries estimated through Bayesian network meta-analysis. The data are presented as SMD (95%CI). Each cell gives the effect of the column-defining intervention relative to the row-defining intervention. 1pFODO: one-point frontal orbital distraction osteogenesis; CVR: open total cranial vault reconstruction; ES: endoscopic strip craniectomy; SC: strip craniectomy with helmet.

Table 5. Rank probabilities of craniosynostosis surgeries based on network Bayesian meta-analysis

Surgical techniques	Probability value			
	Rank 1	Rank 2	Rank 3	Rank 4
one-point frontal orbital distraction osteogenesis (1pFODO)	0.286	0.216	0.212	0.287
Cranial vault reconstruction (CVR)	0.104	0.356	0.387	0.153
Endoscopic strip craniectomy (ES)	0.315	0.208	0.200	0.278
Strip craniectomy (SC)	0.296	0.221	0.201	0.282

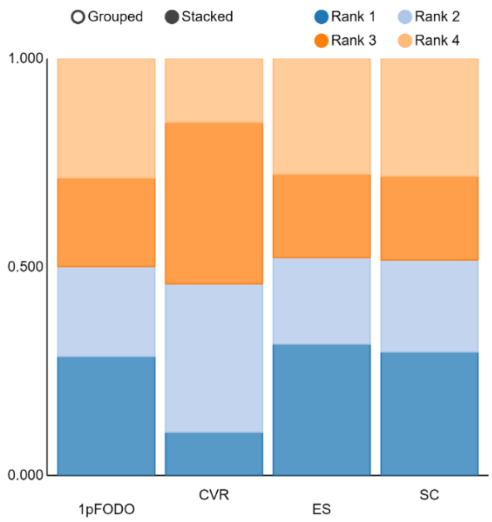


Figure 6. Rank probabilities of surgical techniques for minimizing blood loss in craniosynostosis surgeries. The stacked bar chart presents the distribution of probabilities across four ranking positions (Rank 1 to Rank 4) for each surgical technique.

Discussion

Data from the present meta-analysis indicated that the prevalence of blood loss varied significantly among studies, ranging from 1.4±4.5 to 151.3±51.2 mL. ES had the highest probability (0.464) of achieving the top rank as the surgical technique that allows the least blood loss, while SC had the highest probability (0.305) of being ranked second. For the third with the highest score was 1pFODO, with a probability of 0.264. All interventions resulted in lower blood loss compared to CVR. According to the SMD score, both ES and SC showed lower SMD compared to 1pFODO, indicating a better approach to minimize blood loss.

Blood loss during craniosynostosis surgery is estimated at 60–100% of the total blood volume [29]. The surgical technique used plays an important role in controlling the total volume of blood loss [30]. This study showed that CVR had more SMD than 1pFODO, indicating more blood loss occurred. Open surgery with CVR method was reported to require more blood transfusion compared to endoscopic method. Patients will need transfusion within 24 hours after surgery, longer hospitalization duration, and higher complication rate. A study stated the highest average blood loss of 240 mL and this result was then compared with endoscopic method, which only reported blood loss of 15 mL [31]. As for 1pFODO, minimal dissection of the dura and bone segments results in less blood loss and shorter operative time. This approach also has the potential to reduce complication rates by preserving vascularization. Although there is no statistically significant difference, 1pFODO technique is reported to require a smaller transfusion volume and shorter operating time compared to the 2pFODO technique, which involves separating the dura from the bone [32].

1pFODO and 2pFODO have a more even distribution across ranks, with no extreme probabilities in Rank 1 or Rank 5, indicating a more average performance. 2pFODO is a hybrid of FOAR and 1pFODO because it combines the advantages of both surgical procedures. 2pFODO is performed to overcome the limitations of classic FODO, such as difficulty in bone contouring and orbital roof osteotomy, and FOAR, such as dead space between the bone and dura, increased risk of infection, and higher incidence of deformity recurrence. However, because 2pFODO separates the dura-bone attachment, it results in reduced bone vascularity, which may affect surgical outcomes, such as deformity recurrence and osteogenesis disruption. As for FOAR, although recent studies have shown that this method causes long-term ocular dysfunction and aesthetic problems, it remains an alternative treatment for unicoronal craniosynostosis. FODO is associated with significantly less surgical time than FOAR. This shorter operating time is beneficial because it can reduce the patient's exposure to anesthesia and the tendency to use lower blood transfusion products. Moreover, reconstruction with FODO allows surgery to be performed at an earlier age, which can reduce the possibility of postoperative ophthalmologic complications [33].

ES has the highest probability of being ranked 1, indicating the best performance of all approaches. Patients who underwent surgery with this method were reported to have no significant blood loss during surgery. This was decided because the blood loss was only <15% of the total blood volume and the hematocrit decrease was <25% [31]. This method also reported a shorter hospital stay, lesser volume of blood loss, shorter operative time [31]. Like ES, SC had lower SMD compared to 1pFODO. SC is associated with lower costs and better perioperative outcomes [34]. A previous study showed significant differences in operative time, estimated blood loss, and shorter hospital stay and intensive care unit stay in SC compared to CVR [35]. The study also showed no complications in the SC method and no further reconstruction was required [35].

The above results suggested that ES is effective in minimizing blood loss among patients with craniotomies. This is because the smaller incisions in endoscopic surgery reduce exposure and minimize the number of blood vessels disrupted during surgery. Endoscopic procedures are generally faster than open surgery, which reduces the duration of blood vessels being exposed and susceptible to bleeding [36]. In ES, only a small portion of bone is removed, specifically targeting the affected suture rather than a larger area of the skull. This selective approach reduces the chance of encountering larger blood vessels. On the other hand, CVR involves more blood loss because of the extensive procedure that involves reshaping a large portion of the skull. This procedure requires more extensive dissection and larger incision to access the cranial vault, which increases blood vessel exposure and results in more blood loss.

Conclusion

There is a significant difference in volumes of blood loss between minimally invasive surgery (MIS) and open surgery. Specific procedures, such as ES technique, are a preferable option with the least blood loss when compared to other techniques. MIS offers advantages in terms of minimal blood loss when compared to open surgery due to smaller incision and less extensive dissection. While there is some variability among studies, these results indicate that MIS may improve patient outcomes and make better use of healthcare resources. Considerations of the feasibility of both MIS and open surgery should also be performed, such as the cephalic index, length of stay, and neurodevelopmental growth. Improved blood loss can lead to improved surgical outcomes and reduced transfusion-related complications, serving as a foundation for establishing best-practice guidelines and enhancing the safety and efficacy of craniosynostosis management.

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Competing interests

The authors declare no conflicts of interest.

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Underlying data

All underlying data have been presented in this article.

Declaration of artificial intelligence use

We hereby confirm that no artificial intelligence (AI) tools or methodologies were utilized at any stage of this study, including during data collection, analysis, visualization, or manuscript preparation. All work presented in this study was conducted manually by the authors without the assistance of AI-based tools or systems.

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