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Original Article

Bone cement versus bone flap replacement: A comparative meta-analysis of posterior fossa craniotomy complications

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ABSTRACT

Background: Posterior fossa surgeries are often performed to treat infratentorial pathologies, such as tumors that increase intracranial pressure. Posterior fossa craniotomy has been shown to decrease the incidence of postoperative complications and morbidity compared to craniectomy. More recently, the use of bone cement in posterior fossa craniotomies has been implemented, but there is limited comparative postoperative data of this technique to more commonly used bone flap replacement. This study aims to address this information gap through a meta-analysis comparing the incidence of postoperative cerebrospinal fluid leakage and other complications when utilizing bone cement versus bone flap replacement in posterior fossa craniotomies.

Methods: Following a literature review, search parameters for a systematic review were identified and relevant studies were sorted based on selection criteria to be included in the meta-analysis. Data analysis was performed in R studio and Microsoft Excel software. Targeted complications for analysis include cerebrospinal fluid (CSF) leakage, pseudomeningocele formation, and infection. Pooled estimates and odds ratios for dichotomous outcomes were calculated with corresponding 95% confidence intervals, and findings were translated into illustrative tables and figures.

Results: Twenty-one articles were included in a systematic review, nine studies using bone cement and thirteen using bone flap (two studies reported data for both groups). With bone flap replacement, CSF leakage was 8.36% (95% confidence interval [CI] 5.89–10.86%), pseudomeningocele formation was 9.22% (95% CI 4.82–13.62%), and infection was 6.85% (95% CI 4.05–9.65%). With bone cement usage, CSF leakage was 3.47% (95% CI 2.37–4.57%), pseudomeningocele formation was 2.43% (95% CI 1.23–3.63%), and infection was 1.85% (95% CI 0.75–2.95%). The odds ratio of CSF leak, pseudomeningocele formation, and infection was 0.39 (95% CI 0.229–0.559), 0.25 (95% CI 0.137–0.353), and 0.26 (95% CI 0.149–0.363), respectively, with the use of bone cement compared to craniotomy.

Conclusion: Outcomes demonstrated in this meta-analysis revealed an overall decreased incidence of postoperative complications rates of CSF leak, pseudomeningocele formation, and infection when using bone cement compared to bone flap in posterior fossa craniotomies. Our study suggests that bone cement use is safe and effective in posterior fossa surgery. Future studies should further assess the comparative outcomes of these techniques.

Keywords: Bone cement, Bone flap, Meta-analysis, Neurosurgery, Posterior fossa craniotomy

INTRODUCTION

Posterior fossa craniotomies are required for a variety of infratentorial pathologies. Infratentorial mass lesions can impact the posterior fossa by blocking spinal fluid flow, leading to increased intracranial pressure.[5,16] The gravity dependent nature compared to supratentorial craniotomies also leads to increased pressure on the closure.[26] Postcraniotomy incisional complications include pseudomeningocele, infection, and wound breakdown.[34]

There are several approaches to addressing posterior fossa cranial defects. Originally, the bone flap was replaced with titanium plates and screws;[21] this technique is still most commonly employed today. Mesh cranioplasty and craniotomy with skull flap replacement have been evaluated in literature; both approaches are effective, but craniotomy with bone flap replacement has been associated with a lower incidence of postoperative complications and morbidity.[2,9,11,24] However, more recently, the use of bone cement has been integrated as an alternative to bone flap replacement in posterior fossa surgeries, with particular attention to reducing cerebrospinal fluid (CSF) leakage.[1,14,36] This is an important evaluative metric, as CSF leakage and pseudomeningocele are the most common complications from posterior fossa surgeries.[2,8,20]

Bone cement is a biomaterial commonly utilized in orthopedic surgery where a powder phase and liquid phase are mixed and then either injected to harden or molded and implanted into the body.[35] Recent material science advancements have been applied to increase antibacterial activity and decrease biofilm formation, minimizing former complications.[28] There are several materials used in practice with similar effects. Polymethylmethacrylate (PMMA) is the most common bone substitute but has several disadvantages, including being nonbioactive (unable to stimulate bone formation) and nonbiodegradable. Bioceramic material, such as hydroxyapatite bone cement (HBC), has better biological activity compared to PMMA and is biodegradable, making HBC a strong material consideration for biocompatible bone substitutes.[19]

The use of bone cement (frequently HBC) in cranioplasties can integrate an implanted titanium mesh overlay with the HBC prosthesis.[1,6,7] In the application of posterior fossa craniotomies, deciding the specific surgical plan weighs many variables based on operative indications.[4] Deciding between the use of bone cement and bone flap is one consideration in surgical planning that requires postoperative outcome statistics for informed application. As CSF leakage and pseudomeningocele are the most common complications from posterior fossa surgeries,[2,8,20] surgical planning efforts to prevent and reduce CSF leakage are of great importance.[1] By identifying and comparing the statistical outcomes of these two surgical approaches, more informed treatment plans can be applied to reduce complications and improve patient outcomes.

The distinction between complication rates in postoperative outcomes when using a bone flap replacement technique versus bone cement in closing posterior fossa craniotomies is still underreported in the literature. This study aims to address this information gap through a comparative meta-analysis of these two posterior fossa craniotomy surgical approaches by comparing the incidence of postoperative CSF leak and other complications when implementing bone cement versus bone flap replacement.

MATERIALS AND METHODS

A literature review was conducted to assess the current state and gaps of knowledge concerning bone cement utilization versus bone flap replacement in posterior fossa craniotomies. Following Preferred Reporting Items for Systematic Reviews and meta-analysis guidelines, search parameters for the systematic review were identified, and relevant studies were sorted based on selection criteria for the meta-analysis [Figure 1]. Search parameters for identifying relevant studies

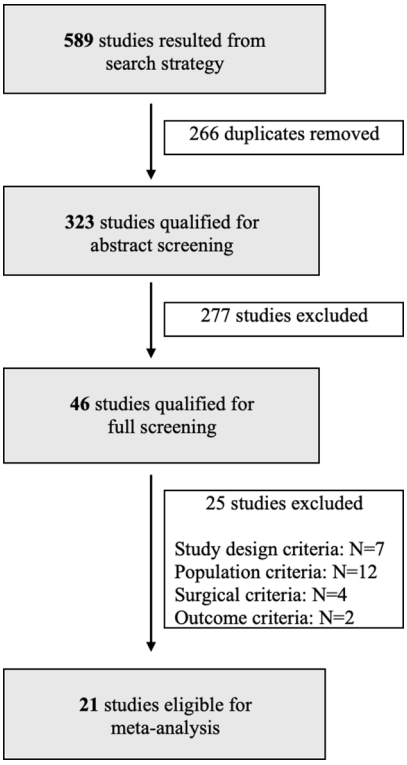

Figure 1: Flowchart schematic of study selection.

began broad, implementing a systematic review with key terminology intersections, including combinations of "bone cement," "bone flap," or "bone replacement" and "posterior fossa craniotomy," "suboccipital craniotomy," "retrosigmoid," "retromastoid," "cerebellar tumor," "posterior fossa surgery," "craniotomy," "cranioplasty," or "posterior fossa." Articles were reviewed and selected for relevance with studies that met the following inclusion criteria: (1) reported outcomes and complication rates for posterior fossa craniotomy utilizing a bone cement and/or bone flap approach; (2) patient outcomes represent primary data (i.e., from an institutional study); and (3) the sample size of patients was larger than 2 and not data from a meta-analysis/systematic review. Exclusion criteria included removing studies that did not isolate outcomes pertaining to the posterior fossa, utilizing other closure techniques besides bone cement or bone flap, and performing an operative approach other than a craniotomy, nonhuman studies, non English language papers, case reports, and low-quality case series. Data analysis was performed using R studio and Microsoft Excel software to compare complication rates following posterior fossa craniectomy with bone cement versus bone flap replacement. Targeted complications for analysis include CSF leakage, pseudomeningocele formation, and infection. Complication incidences reported in each study were recorded and compared in forest plots. Summative analysis was then performed with pooled estimates and odd ratios for dichotomous outcomes were calculated with corresponding 95% confidence intervals (CIs).

RESULTS

A total of 589 studies were initially obtained through the search criteria, and 266 were removed as duplicates. Of the 323 studies screened, 21 proved viable to be included in the meta-analysis. Of those included, 9 studies reported data regarding bone cement[1,12,14,15,18,25,27,28,36] and 13 regarding bone flap utilization;[8-11,13,22-24,27,29,30,32,33] two studies had data for both groups [Table 1]. A total of 3424 cases were statistically analyzed, 1351 cases using bone cement, and 2073 using bone flap.

Table 1: Overview of meta-analysis sample evaluated.

	Number of studies	Number of cases
Bone cement	9	1351
Bone flap	14	2073
Total	21*	3424

*Two studies contained data for both intervention groups

In the bone flap group, the rate of CSF leak, pseudomeningocele formation, and infection were each not reported in one separate instance of the fourteen studies. In the bone cement group, pseudomeningocele formation was not reported in two of the nine studies; CSF leak and infection were reported in all. Corresponding patient cases (n) with unreported data were not included in the corresponding incidence summation total when data were not recorded.

Summative analysis regarding the use of bone flap revealed the following overall incidence rates: CSF leakage was 8.36% (95% CI 5.89–10.86%), pseudomeningocele formation was 9.22% (95% CI 4.82–13.62%), and infection was 6.85% (95% CI 4.05–9.65%). Comparatively, the use of bone cement revealed the following overall incidence rates: CSF leakage was 3.47% (95% CI 2.37–4.57%), pseudomeningocele formation was 2.43% (95% CI 1.23–3.63%), and infection was 1.85% (95% CI 0.75–2.95%) [Table 2 and Figure 2].

The odds ratio (OR) indicates that bone cement usage is 39.41% as likely to experience CSF leak (OR 0.39 with 95% CI 0.165 [0.229–0.559]), 25.52% as likely to experience pseudomeningocele formation (OR 0.25 with 95% CI 0.108 [0.137–0.353]), and 25.59% as likely to experience infection compared to when bone flaps are used (OR 0.26 with 95% CI 0.107 [0.149–0.363]).

The overall incidence of CSF leakage with bone cement was 3.47% and 8.36% with bone flap [Figure 3]. The overall incidence of pseudomeningocele formation with bone cement was 2.43% and 9.22% with bone flap [Figure 4]. The overall incidence of infection with bone cement was 1.85% and 6.85% with bone flap [Figure 5]. Pooled analysis of CSF leakage, pseudomeningocele formation, and infection incidence was all significantly lower with bone cement as

Table 2: Comparative complication rates from bone cement versus bone flap replacement usage in posterior fossa craniotomies.

	CSF leak	Pseudomeningocele formation	Infection
Bone cement			
Incidence (SD)	3.47% (±1.82%)	2.43% (±1.59%)	1.85% (±1.65%)
CI (Min, Max)	±1.1% (2.37%, 4.57%)	±1.2% (1.23%, 3.63%)	±1.1% (0.75%, 2.95%)
Bone flap			
Incidence (SD)	8.36% (±4.67%)	9.22% (±8.43%)	6.85% (±5.28%)
CI (Min, Max)	±2.5% (5.89%, 10.86%)	±4.4% (4.82%, 13.62%)	±2.8% (4.05%, 9.65%)

CI: 95% confidence interval, SD: Standard deviation, CSF: Cerebrospinal fluid

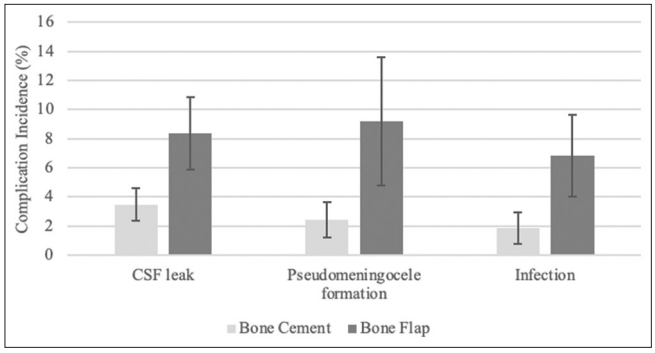

Figure 2: Bar graph illustrating a comparison of complication rate incidence. CSF: Cerebrospinal fluid

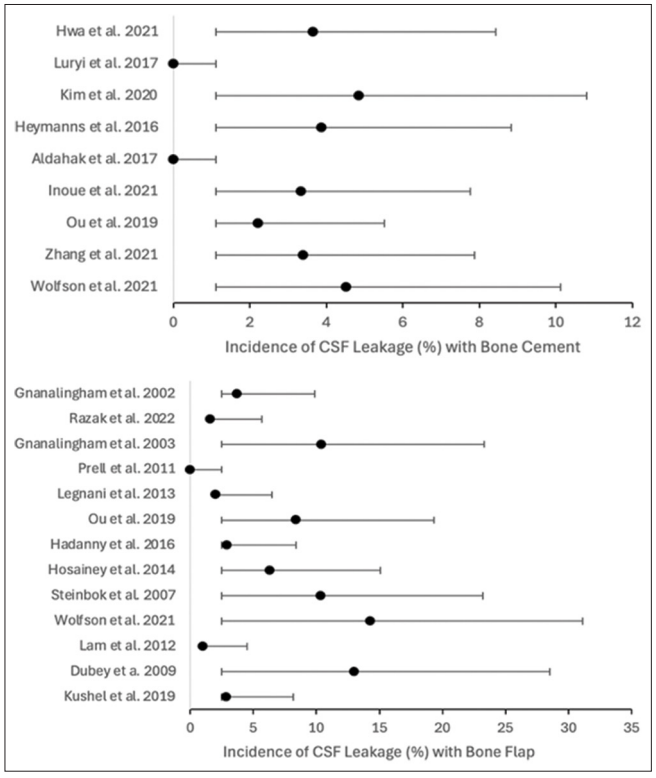

Figure 3: Forest plot incidence of cerebrospinal fluid leakage with bone cement versus bone flap. CSF: Cerebrospinal fluid

compared to bone flap replacement [Figure 6].

DISCUSSION

A total of 3424 cases (1351 using bone cement and 2073 using bone flap techniques) from 21 studies (9 for bone cement and 14 for bone flap; 2 studies provided data for both techniques) were included in the final analysis. Statistical examination in this meta-analysis showed that the overall incidence of CSF leakage in posterior fossa craniotomies was 8.36% with bone flap and 3.47% with bone cement; pseudomeningocele

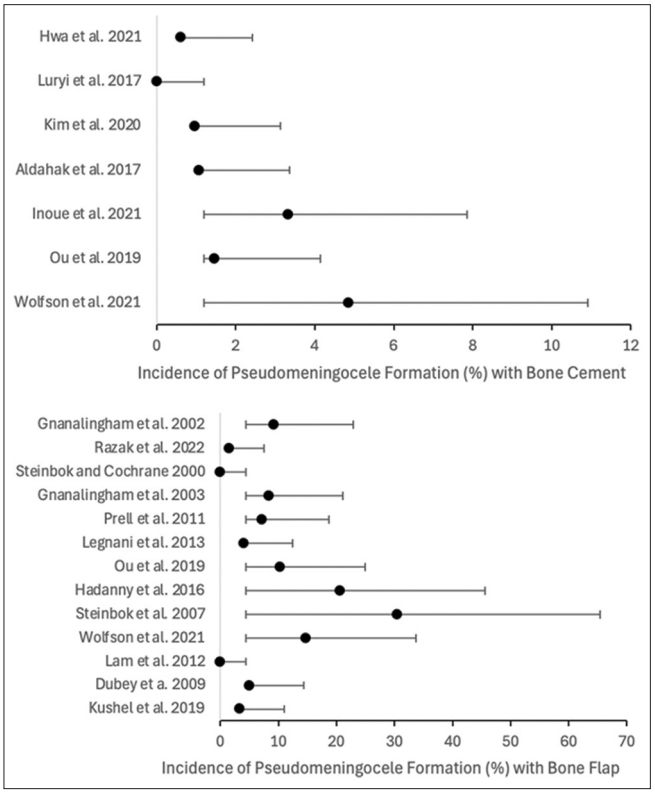

Figure 4: Forest plot incidence of pseudomeningocele formation with bone cement versus bone flap.

formation was 9.22% with bone flap and 2.43% with bone cement; infection was 6.85% with bone flap and 1.85% with bone cement. These results underline the relevance of the craniotomy closure technique in posterior fossa craniotomy complications.

Odds ratio calculations demonstrated that bone cement usage resulted in outcomes 39.41% as likely to experience CSF leak, 25.52% as likely to experience pseudomeningocele formation, and 25.59% as likely to experience infection than when the bone flap is used. The reduced complication rates of CSF leakage and pseudomeningocele formation may be owed to the closer reapproximation of the cranial defect and less dead space for potential fluid to pass through or accumulate.[31] The decreased rate of infection when utilizing bone cement compared to bone flap may be due to the adherence and anti-microbial properties of modern bone cement inhibiting bacterial proliferation compared to organic *in vivo* surfaces;[28] However, further investigation is needed to pinpoint the specific mechanisms.

In addition to increased morbidity and mortality, complications from posterior fossa surgery prolong hospital stay, increase/prolong inpatient and outpatient antibiotic usage, delay treatment of malignancies, increase return to the OR, and increase costs.[3,8,17,37] The clinical motivations

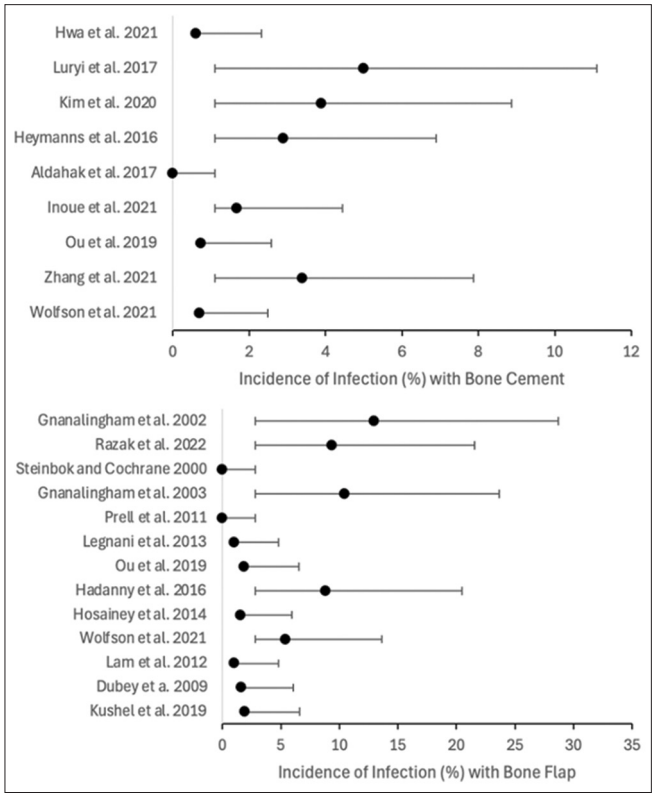

Figure 5: Forest plot incidence of infection with bone cement versus bone flap.

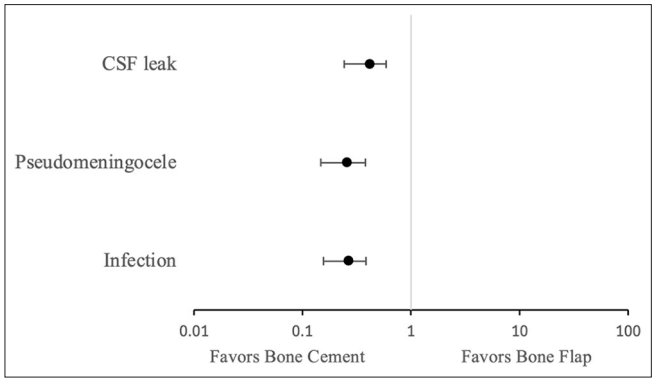

Figure 6: A pooled analysis of risk ratios of measured outcomes. CSF: Cerebrospinal fluid

and focus of the research reported in the literature regarding posterior fossa surgery have been largely characterized by aims to identify and decrease complications,[1,14,36] such as identifying the merits of craniotomy versus craniectomy.[2,11,21,24] Comparatively, as new materials, drugs, and technologies become available, these historic aims are now further directed into determining the risks and complication profiles of various components integrated into surgical planning to improve outcomes. By identifying and characterizing the risks associated with important evaluative metrics, more informed surgical planning can occur. In relevance to this study, CSF leakage and pseudomeningocele are the most common complications from posterior fossa surgeries.[2,8,20] The use of bone cement in posterior fossa craniotomies compared to bone flap replacement demonstrated a decreased incidence of postoperative CSF leak, pseudomeningocele formation, and infection in this meta-analysis, warranting further investigation into its utility.

This meta-analysis is subject to several limitations. Most importantly, the studies included are heterogeneous in the metric; they are primarily evaluating. Relevant data were extracted upstream of the various studies' analyses, but the specific parameters of individual studies may shape the data they present, such as which complications are reported in a specific study and how those complications were defined by those reporting and grouping case values. There may be variability in the degree of complications reported that are grouped, along with the potential for cofounders in the type of posterior fossa craniotomy and comorbidities. These confounders were considered in the study design and mitigated in selection criteria primarily by removing low-quality case series (i.e., noninstitutional reports, comorbid cases, surgical approach variability). The calculated heterogeneity index (I^2) in this meta-analysis is 24.54%. In addition, more studies have been published regarding bone flap than bone cement due to the time course and other factors, generating greater sample sizes for bone flap data and posing the potential of selection bias due to data availability. In addition to limited data, continuous advancements in operative care outside of the specific interventions analyzed in this study may have impacted reported complication rates. Samples utilizing cement may be less impacted by complications due to other confounding considerations of care advancements unrelated to the surgical technique, such as various technological instruments and pharmacologic agents. These factors, coupled with potential selection bias regarding what clinical data are published, present a variety of limitations that require further study to validate the findings in this meta-analysis. A funnel plot comparing the studies included in this meta-analysis demonstrates reasonable distribution [Figure 7]. Future studies should utilize a comparative approach to outcomes using bone flap versus bone cement techniques within a single institution to limit potential noise and confounding factors.

In summary, this meta-analysis reports an overall incidence of CSF leakage in posterior fossa craniotomies as 8.36% with bone flap and 3.47% with bone cement (39.41% as likely with bone cement), pseudomeningocele formation 9.22% with bone flap and 2.43% with bone cement (25.52% as likely with bone cement), and infection 6.85% with bone flap and 1.85% with bone cement (25.59% as likely with bone cement),

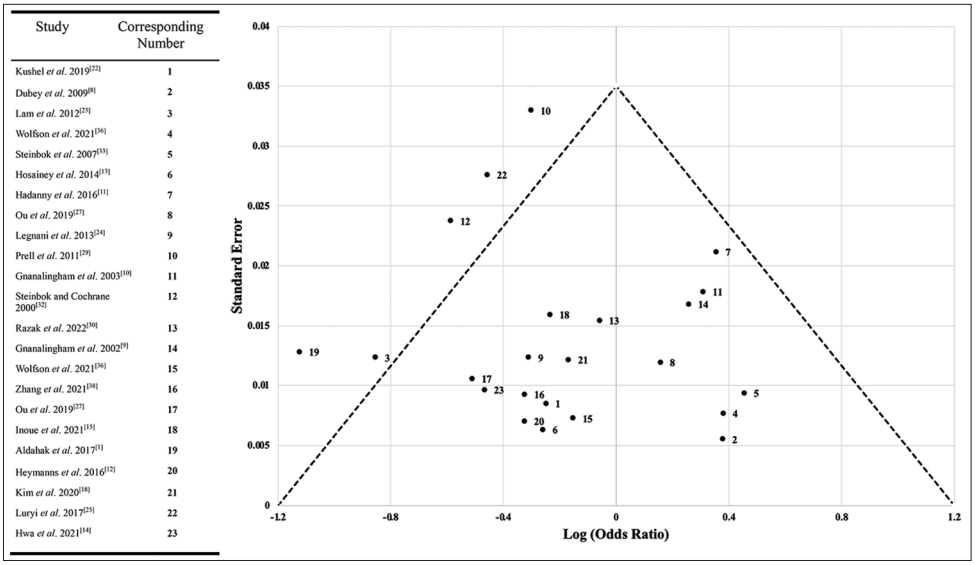

Figure 7: Funnel plot of studies included in the meta-analysis.

underlining the relevance of craniotomy closure technique for complications.

CONCLUSION

The use of bone cement cranioplasty compared to bone flap replacement in posterior fossa craniotomies demonstrated a significantly decreased incidence of postoperative CSF leak, pseudomeningocele formation, and infection. Future prospective studies are needed to assess potential mechanisms for the improved outcomes further, provide direct comparative outcomes of these techniques, and limit intrinsic confounding factors within a meta-analysis to validate the findings of bone cement cranioplasty superiority in this meta-analysis.

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Disclosures

The authors have no personal, financial, or institutional interests in any of the drugs, materials, or devices described in this manuscript.

Ethical approval

Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent is not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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