

Comparative Functional and Surgical Outcomes Following Autologous and Synthetic Cranioplasty: A Systematic Review and Meta-analysis of 958 patients

Isabel Martin del Campo

isabelmdc.med@gmail.com

Universidad Anáhuac

Montserrat Oria Orozco

Universidad Anáhuac

Pedro Pablo Brol

Universidad Francisco Marroquín

Jimena Gonzalez-Salido

Beth Israel Deaconess Medical Center

Angel F Godina

Universidad de Guadalajara

David Santiago-Dieppa

University of California San Diego

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Abstract

Introduction

Cranioplasty following decompressive craniectomy restores cranial integrity and may promote neurological recovery by restoring cerebral physiology. Although autologous bone and synthetic implants have been widely compared, their relative effects on functional recovery remain unclear.

Objective

To compare functional and surgical outcomes following autologous bone versus synthetic implant-based cranioplasty after decompressive craniectomy.

Methods

A PRISMA-guided systematic review and meta-analysis searched PubMed/MEDLINE, Embase, and the Cochrane Library through April 2026. Comparative studies of autologous bone versus synthetic implant-based cranioplasty were included. The primary outcome was functional improvement. Secondary outcomes included postoperative infection, hematoma or hemorrhage, and revision surgery. Random-effects meta-analyses used odds ratios (ORs) with 95% confidence intervals (CIs).

Results

Five retrospective comparative cohort studies including 958 patients met the inclusion criteria; 701 underwent autologous bone cranioplasty and 257 synthetic reconstruction. Three studies reported functional outcomes suitable for meta-analysis. Functional improvement did not differ between autologous and synthetic cranioplasty (OR 1.01, 95% CI 0.59–1.72; $p = 0.98$; $I^2 = 0\%$). Postoperative infection was also similar (OR 1.00, 95% CI 0.59–1.71; $p = 0.99$; $I^2 = 0\%$). Autologous cranioplasty showed a nonsignificant trend toward lower postoperative hematoma or hemorrhage (OR 0.46, 95% CI 0.14–1.47; $p = 0.12$; $I^2 = 0\%$) and higher revision rates (OR 1.42, 95% CI 0.74–2.73; $p = 0.18$; $I^2 = 0\%$). Neurocognitive and quality-of-life outcomes could not be pooled because of inconsistent reporting.

Conclusions

Current evidence shows no significant differences between autologous bone and synthetic implant-based cranioplasty in functional recovery, postoperative infection, hematoma, or revision surgery. Material selection should be individualized based on patient, surgical, and resource factors. Prospective comparative studies should standardize reporting of functional, neurocognitive, and quality-of-life outcomes to clarify whether reconstructive material influences long-term neurological recovery.

Introduction

Decompressive craniectomy is a potentially life-saving procedure for patients with severe traumatic brain injury, malignant cerebral infarction, aneurysmal subarachnoid hemorrhage, and other causes of refractory intracranial hypertension. By removing a portion of the skull, decompressive craniectomy reduces intracranial pressure and mitigates secondary brain injury; however, it leaves a cranial defect that subsequently requires reconstruction through cranioplasty (1).

Cranioplasty is traditionally performed using either the patient's own bone flap (autologous cranioplasty) or synthetic implants such as titanium, polymethyl methacrylate (PMMA), polyether ether ketone (PEEK), hydroxyapatite, and other alloplastic materials. While often perceived as a reconstructive procedure intended to restore skull contour and cosmesis, cranioplasty has increasingly been recognized as a procedure with important physiological and neurological implications. Restoration of cranial vault integrity has been associated with improvements in cerebral blood flow, cerebrospinal fluid dynamics, cerebral metabolism, and reversal of syndrome of the trephined, potentially contributing to neurological and functional recovery (2–5).

The ideal cranioplasty material remains a subject of ongoing debate. Autologous bone offers several advantages, including excellent anatomical fit, biological compatibility, and lower cost. However, its use is limited by risks of aseptic bone flap resorption, infection, fragmentation, and storage-related complications (6–8). Synthetic implants avoid the risk of bone resorption and permit patient-specific reconstruction with excellent cosmetic results, but they may be associated with implant-related complications, increased costs, and limited availability in certain settings (9). Consequently, both reconstructive strategies remain widely utilized in contemporary neurosurgical practice.

Most comparative studies evaluating cranioplasty materials have focused on surgical outcomes such as infection, bone flap resorption, implant failure, and revision surgery. Although these endpoints are important, they may not fully capture the impact of cranioplasty on patient recovery. Increasing evidence suggests that restoration of cranial integrity may influence neurological recovery, functional independence, cognition, rehabilitation participation, and quality of life. Nevertheless, these patient-centered outcomes have been reported inconsistently across studies, often using heterogeneous assessment tools and variable follow-up periods, limiting meaningful comparison between reconstructive materials (10–12).

As a result, it remains unclear whether the biological advantages of autologous bone or the structural durability of synthetic implants translate into measurable differences in functional recovery following cranioplasty. Addressing this question is essential to move beyond complication-based decision-making and toward a more comprehensive assessment of patient outcomes after decompressive craniectomy.

Therefore, the aim of this systematic review and meta-analysis was to compare functional and surgical outcomes following autologous bone versus synthetic implant-based cranioplasty after decompressive craniectomy.

Methods

Study design and reporting

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The review was designed to compare clinical and surgical outcomes after autologous bone cranioplasty versus synthetic implant-based cranioplasty in patients undergoing cranioplasty after decompressive craniectomy. The protocol was registered in PROSPERO; CRD420261452332

Information sources and search strategy

A systematic literature search was performed in PubMed/MEDLINE, Embase and Cochrane Library to April 2026. Search terms combined controlled vocabulary and free-text terms related to cranioplasty, decompressive craniectomy, autologous bone flap, bone flap replacement, synthetic implants, polymethyl methacrylate, titanium, polyether ether ketone, hydroxyapatite, and postoperative outcomes. The complete search strategy should be provided in the supplementary material.

Reference lists of included studies and relevant reviews were also screened to identify additional eligible studies. Conference abstracts, editorials, letters, narrative reviews, systematic reviews, non-human studies, cadaveric studies, and studies without extractable comparative outcome data were excluded.

Eligibility criteria

Studies were eligible if they met the following criteria: (1) included patients undergoing cranioplasty after decompressive craniectomy; (2) compared autologous bone cranioplasty with synthetic implant-based cranioplasty; (3) reported at least one extractable clinical, functional, or surgical outcome; and (4) used an original comparative clinical study design.

Autologous bone cranioplasty was defined as replacement of the patient's own bone flap after decompressive craniectomy. Synthetic implant-based cranioplasty was defined as reconstruction using any non-autologous material, including but not limited to polymethyl methacrylate, titanium, titanium-reinforced calcium phosphate, polyether ether ketone, porous polyethylene, hydroxyapatite, or bone cement.

Mixed cohorts were eligible only when data for autologous bone and synthetic implant groups could be extracted separately. Studies were excluded if they were noncomparative, lacked separable data for the intervention and comparator groups, reported overlapping cohorts without usable non-overlapping data, or did not provide extractable outcome data.

Study selection

All records were imported into Rayyan for screening. The search identified 1,154 records. After duplicate removal, 840 records remained for title and abstract screening. Potentially eligible articles underwent full-text review according to the predefined eligibility criteria. Overall, five studies met inclusion criteria and were included in the systematic review and quantitative synthesis.

Two reviewers independently screened titles and abstracts, followed by full-text assessment. Disagreements were resolved by consensus or by consultation with a third reviewer. Reasons for exclusion at the full-text stage were recorded and summarized in the PRISMA flow diagram.

Data extraction

Data were extracted using a standardized data extraction form. Extracted variables included first author, publication year, country, study design, study period, indication for decompressive craniectomy, sample size, number of patients in the autologous bone and synthetic implant groups, synthetic implant material, autologous bone storage method, time to cranioplasty, follow-up duration, baseline demographic and clinical characteristics, outcome definitions, event counts, denominators, and effect estimates.

When studies reported outcomes as percentages, event counts were calculated using the reported denominator when possible. Values were not imputed when denominators were unclear. Outcome-specific denominators were used when the number of patients contributing data differed across endpoints. When discrepancies existed between reported enrollment and analyzable denominators, the denominator used for the specific outcome analysis was extracted and prioritized.

Outcomes

The primary effectiveness outcome was study-defined functional improvement, as reported by each included study. Functional improvement included modified Rankin Scale (mRS)-based outcomes, Functional Independence Measure (FIM) change, or study-specific definitions of postoperative functional recovery. Because functional outcome definitions, assessment instruments, and follow-up timepoints varied across studies, outcomes were pooled only when they represented clinically comparable measures of overall functional recovery. Although different instruments were used, all were designed to assess functional status following neurological injury. Outcomes were therefore dichotomized according to each study's definition of favorable functional recovery, and pooling was restricted to clinically comparable endpoints. Under this framework, odds ratios were considered an appropriate common effect measure for quantitative synthesis.

Risk of bias assessment

Risk of bias was assessed at the study level using ROBINS-I for nonrandomized comparative studies. The main domains considered were bias due to confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, outcome measurement, and selection of the reported result.

Each study was assessed independently by two reviewers, with disagreements resolved by consensus. Because all included studies were retrospective observational cohorts and no randomized controlled trials were identified, no RoB 2 assessment was performed.

Statistical analysis

Comparative dichotomous outcomes were synthesized using odds ratios with 95% confidence intervals. For outcomes reported as raw event counts, study-specific odds ratios were calculated from 2×2 tables. For outcomes reported as log odds ratios and standard errors, the generic inverse-variance method was used.

Random-effects models were used because clinical and methodological heterogeneity was expected across studies, including differences in indication for decompressive craniectomy, implant material, timing of cranioplasty, follow-up duration, and outcome definitions. Between-study variance was estimated using restricted maximum likelihood when available in RevMan. Hartung-Knapp-Sidik-Jonkman adjustment was applied for pooled confidence intervals when used by the software for event-count outcomes. Wald-type confidence intervals were used for generic inverse-variance analyses based on log odds ratios and standard errors.

Heterogeneity was assessed using Cochran's Q test, τ^2 , and the I^2 statistic. Statistical significance was defined as a two-sided p value < 0.05 . Quantitative analyses and forest plots were generated using Cochrane Review Manager software.

Additional analyses and publication bias

Subgroup and sensitivity analyses were planned when sufficient studies were available; however, they were not performed because of the small number of studies contributing to each pooled outcome and the limited consistency of outcome definitions across studies.

Publication bias was not formally assessed because fewer than 10 studies were available for each quantitative analysis. Funnel plots and small-study effect tests were therefore not performed.

Results

Study selection

The database search identified 1,154 records. After duplicate removal, 840 records were available for title and abstract screening in Rayyan. Potentially eligible reports underwent full-text assessment according to the predefined eligibility criteria. Overall, five studies met the inclusion criteria and were included in both the systematic review and quantitative synthesis (Fig. 1).

Study characteristics

The included studies were published between 2015 and 2026 and included 958 patients undergoing cranioplasty after decompressive craniectomy. All studies were retrospective comparative cohort studies. Four studies were single-center cohorts, and one was a retrospective multicenter near-nationwide cohort. Studies were conducted in Norway, the Republic of Korea, Sweden, and India.

Overall, 701 patients underwent autologous bone cranioplasty and 257 underwent synthetic implant-based cranioplasty. Synthetic materials included polymethyl methacrylate, porous polyethylene, hydroxyapatite, titanium, titanium-reinforced calcium phosphate, polyether ether ketone, and bone cement. When reported, autologous bone flaps were most commonly cryopreserved. Indications for decompressive craniectomy included traumatic brain injury, middle cerebral artery infarction, aneurysmal subarachnoid hemorrhage, stroke, and other causes. Study characteristics and baseline clinical variables are summarized in Tables 1 and 2.

Table 1
Characteristics of included studies comparing autologous bone and synthetic implant-based cranioplasty following decompressive cr

Study (Author, Year)	Country	Study Design	Study Period	Indication for DC	Total N	n Autologous	n Synthetic	Synthetic Implant Types	Autologous Storage	Time to Craniop
Brommeland, 2015	Norway	Retrospective, single-center	NR	Trauma (85%), Stroke (15%)	87	77	10	PMMA, porous polyethylene, hydroxyapatite	Cryopreservation (– 80°C)	Median days (range) 19–353
Gil, 2025	Republic of Korea	Retrospective, single-center	NR	Aneurysmal SAH	54 a	26 a	28 a	Titanium (Ti-6Al-4V), PEEK	Cryopreservation (– 50°C)	Mean 4.5.2 mon
Holmgren, 2026	Sweden	Retrospective, multicenter (near-nationwide)	2008–2022	TBI (41%), MCA infarction (38%), SAH (13%), Other (8%)	725 (695) b	540 (512) b	185 (183) b	Ti-CAP (9%), PMMA (9%), PEEK (3%), PPE (3%)	Cryopreservation (99%); subcutaneous (1%)	Median months 3–9)
Sharma, 2018	India	Retrospective, single-center	2008–2017	Traumatic brain injury	47	26	21	Dynamic titanium mesh (Stryker, 1 mm)	NR (preserved autologous bone)	6 month 2 weeks
Svedung Wettervik, 2021	Sweden	Retrospective, single-center	2008–2018	Severe traumatic brain injury	45	32	13	Custom-made implant (18%), Porex (7%), bone cement (4%)	Cryopreservation (– 70°C)	Median months 5–10; range 2–19)

Table 2
Baseline patient demographics and clinical characteristics of the included studies

Study	Group / Arm	n	Age (median [IQR] or mean $\pm$ SD)	Male, n (%)	Indication for DC	Defect size (cm ²)	VP shunt pre-CP, n (%)	VP shunt post-CP, n (%)	Pre-CP mRS (median [IQR])	FIM (median [IQR])
Brommeland, 2015	Autologous	77	Median 31 yrs (range 1–65) c	62% (54/87) c	Trauma/Stroke	NR	9% (5/57) c	NR	NR	NR
	Synthetic (PMMA/PPE/HA)	10	— c	— c	Trauma/Stroke	NR	NR	NR	NR	NR
Gil, 2025	Autologous bone (AC)	26 a	Mean 51.7 $\pm$ 12.2 yrs	21% (5/26) a	Aneurysmal SAH	79.5 $\pm$ 31.6 mm ² (calc cm ²) c	72% (36/50) c	NR	NR	NR
	3D-printed synthetic (3-DC)	28 a	Mean 58.4 $\pm$ 10.3 yrs	39% (11/28) a	Aneurysmal SAH	102.8 $\pm$ 27.1 mm ² (calc cm ²) c	72% (36/50) c	NR	NR	NR
Holmgren, 2026	Autologous	540 (512 analyzed) b	Median 49 yrs (IQR 33–59) c	69% (499/725) c	TBI/MCA/SAH/Other (see Table 1)	Median 101 cm ² (IQR 87–115) c	NR	14% shunt (100/725) c	Median 4 (IQR 3–4) c	Median 4 (IQR 3–4) c
	Synthetic (Ti-CAP/PMMA/PEEK/PPE)	185 (183 analyzed) b	— c	— c	TBI/MCA/SAH/Other	— c	— c	— c	— c	—
Sharma, 2018	Autologous bone flap	26	NR (total cohort mean NR)	77% (20/26)	Traumatic brain injury	NR	NR	NR	NR	NR
	Dynamic titanium mesh	21	NR	76% (16/21)	Traumatic brain injury	NR	NR	NR	NR	NR
Svedung Wettervik, 2021	Autologous bone flap	32	Median 42 yrs (IQR 20–53) c	75% (46/61) c	Severe TBI	Median 94 cm ² (IQR 77–110) c	11% (5/45) c	4% (2/45) c	Median 4 (IQR 1–5)	Median 4 (IQR 3–5)
	Synthetic (custom/Porex/bone cement)	13	— c	— c	Severe TBI	— c	— c	— c	— c	—

Abbreviations: CP = cranioplasty; DC = decompressive craniectomy; FIM = Functional Independence Measure; GOS-E = Glasgow Outcome Scale Extended; IQ Scale; NR = not reported; NS = not significant; PEEK = polyether ether ketone; PMMA = polymethyl methacrylate; PPE = porous polyethylene; SAH = subarachnoid hemorrhage; calcium phosphate.

a Gil 2025: denominators in outcome analyses (autologous = 26, synthetic = 28) differ from reported enrollment (AC = 24, 3-DC = 26); see Table 1 footnote.

b Holmgren 2026: enrolled N = 725; analyzed N for complication outcomes = 695 (autologous = 512, synthetic = 183).

Supplementary Fig. 1. Risk of bias assessment using ROBINS-I.

Study	Group / Arm	n	Age (median [IQR] or mean $\pm$ SD)	Male, n (%)	Indication for DC	Defect size (cm ²)	VP shunt pre-CP, n (%)	VP shunt post-CP, n (%)	Pre-CP mRS (median [IQR])	F
c Demographic/clinical variable reported for total cohort; per-arm breakdown not available.										
Supplementary Fig. 1. Risk of bias assessment using ROBINS-I.										

Outcome-specific denominators differed across analyses because not all studies reported extractable data for every endpoint. Therefore, the denominator used for each pooled analysis reflects the number of patients with extractable data for that outcome.

Risk of bias

Risk of bias was assessed using ROBINS-I and is summarized in (Supplementary). All included studies were retrospective observational cohorts, and no randomized controlled trials were identified. The main domains requiring consideration were confounding, selection of participants, outcome measurement, and missing or incomplete outcome data.

Study-defined functional improvement

Three studies provided extractable data for study-defined functional improvement comparing autologous bone cranioplasty with synthetic implant-based cranioplasty. This endpoint included functional outcomes as defined by each study, including modified Rankin Scale-based outcomes, Functional Independence Measure change, or study-specific definitions of postoperative functional improvement.

The pooled random-effects estimate showed no statistically significant difference between autologous bone and synthetic implant-based cranioplasty for study-defined functional improvement (OR 1.01, 95% CI 0.59 to 1.72; $p = 0.98$; $I^2 = 0\%$; Fig. 2).

No quantitative synthesis was performed for neurocognitive recovery or quality of life because comparable instruments, definitions, and follow-up timepoints were not consistently reported across the included studies.

Safety and surgical outcomes

Postoperative infection

Four studies reported postoperative infection. Infection occurred in 74 of 647 patients in the autologous bone group and 26 of 234 patients in the synthetic implant group. The pooled random-effects analysis showed no statistically significant difference between groups (OR 1.00, 95% CI 0.59 to 1.71; $p = 0.99$; $I^2 = 0\%$; Fig. 3).

Postoperative hematoma or hemorrhage

Four studies reported postoperative hematoma or hemorrhage. Hematoma or hemorrhage occurred in 26 of 647 patients treated with autologous bone and 20 of 234 patients treated with synthetic implants. The pooled random-effects estimate was lower in the autologous bone group, but the difference was not statistically significant (OR 0.46, 95% CI 0.14 to 1.47; $p = 0.12$; $I^2 = 0\%$; Fig. 4).

Revision surgery

Four studies reported revision surgery. Revision surgery occurred in 203 of 647 patients in the autologous bone group and 54 of 234 patients in the synthetic implant group. The pooled random-effects estimate was higher in the autologous bone group, but the difference was not statistically significant (OR 1.42, 95% CI 0.74 to 2.73; $p = 0.18$; $I^2 = 0\%$; Fig. 5).

Additional analyses and publication bias

Subgroup and sensitivity analyses were not performed because of the small number of studies contributing to each pooled outcome and the limited consistency of outcome reporting across studies. Publication bias was not formally assessed because fewer than 10 studies were available for each quantitative analysis. Funnel plots and small-study effect tests were therefore not performed.

Across all pooled outcomes, no statistically significant difference was detected between autologous bone cranioplasty and synthetic implant-based cranioplasty.

Discussion

In this systematic review and meta-analysis of 958 patients undergoing cranioplasty after decompressive craniectomy, autologous bone and synthetic implant-based reconstruction demonstrated no statistically significant differences across the outcomes that could be quantitatively synthesized. Study-defined functional improvement, the primary patient-centered endpoint available for meta-analysis, was similar between groups. Likewise, postoperative infection, postoperative hematoma or hemorrhage, and revision surgery did not differ significantly according to reconstructive material. Although postoperative hematoma was numerically less frequent following autologous cranioplasty and revision surgery occurred more often in the autologous group, neither association reached statistical significance.

The interpretation of functional outcomes warrants particular consideration. The available studies used different instruments to assess postoperative recovery, including the modified Rankin Scale (mRS), Functional Independence Measure (FIM), and study-specific definitions of functional improvement. Although these measures are not interchangeable and evaluate different dimensions of recovery, all were designed to assess functional status following neurological injury. To maximize comparability while minimizing inappropriate aggregation, outcomes were dichotomized according to each study's definition of favorable functional recovery and pooled only when they reflected a clinically similar construct of overall postoperative improvement. Under this framework, odds ratios were considered an appropriate common effect measure for synthesis. Consequently, the pooled estimate should be interpreted as a measure of global functional recovery rather than evidence regarding any specific functional assessment instrument.

The absence of a material-specific functional advantage is biologically plausible. The neurological benefits associated with cranioplasty likely depend less on the reconstructive material itself and more on restoration of cranial vault integrity. Large cranial defects may alter cerebral blood flow, cerebrospinal fluid dynamics, atmospheric pressure transmission, cortical compliance, and cerebral autoregulation. Cranioplasty has been associated with improvements in cerebral perfusion, normalization of intracranial pressure gradients, restoration of cerebrospinal fluid circulation, and reversal of sinking skin flap physiology or syndrome of the trephined. These physiological mechanisms may facilitate neurological recovery regardless of whether reconstruction is performed using autologous bone or a synthetic implant. Therefore, it is conceivable that restoration of cranial anatomy rather than material composition represents the principal determinant of functional improvement.

Although functional outcomes appeared similar, differences between materials may still influence long-term surgical durability. Autologous bone remains attractive because of its anatomical fit, biological compatibility, osteoconductive potential, and lower cost. However, it is uniquely susceptible to aseptic bone flap resorption, fragmentation, contamination during storage, and delayed structural failure. Conversely, synthetic implants avoid the risk of bone resorption and allow patient-specific manufacturing with excellent cosmetic reconstruction. Nevertheless, they introduce alternative concerns, including foreign-body reaction, implant exposure, thermal conductivity, cost, and availability. These competing advantages and disadvantages may affect long-term implant survival and revision burden even if early neurological recovery remains comparable.

The pooled analysis demonstrated no significant difference in postoperative infection between autologous and synthetic reconstruction. This finding suggests that infection risk following cranioplasty is unlikely to be determined solely by implant material. Rather, infection probably reflects the interaction of multiple factors, including wound condition, timing of reconstruction, prior contamination, cerebrospinal fluid diversion, operative duration, soft-tissue coverage, and patient comorbidities. While synthetic implants may theoretically increase susceptibility to biofilm formation and foreign-body infection, autologous bone flaps may be vulnerable to contamination or devitalization during storage and reimplantation. The absence of a detectable difference in the current analysis supports the notion that perioperative and patient-related factors likely play a greater role than material choice alone.

Postoperative hematoma or hemorrhage was numerically less common in the autologous group, although the pooled estimate did not reach statistical significance and confidence intervals remained wide. Consequently, this observation should be considered hypothesis-generating rather than conclusive. The development of postoperative bleeding after cranioplasty is influenced by numerous factors, including dural dissection, epidural or subgaleal dead space, coagulation status, drain use, defect size, and fixation technique. Although synthetic implants may differ biomechanically from autologous bone with respect to rigidity and contour matching, the available evidence is insufficient to determine whether these characteristics translate into meaningful differences in hemorrhagic risk.

Revision surgery occurred more frequently in the autologous bone group, although the difference was not statistically significant. The direction of this association is clinically plausible given the well-established risk of bone flap resorption after autologous cranioplasty. Progressive resorption may lead to loss of structural protection, contour deformity, cosmetic dissatisfaction, and eventual reoperation. However, revision surgery represents a composite outcome encompassing multiple failure mechanisms, including infection, hematoma, wound breakdown, implant exposure, fracture, cosmetic failure, and bone resorption. While the pooled estimate provides an overall measure of surgical burden, it does not identify which specific mechanisms are responsible for subsequent intervention. Future studies should report material-specific causes of revision to facilitate a more nuanced understanding of implant performance.

The low statistical heterogeneity observed across pooled outcomes should be interpreted cautiously. With only three to four studies contributing to most analyses, statistical tests have limited power to detect true between-study heterogeneity. Substantial clinical heterogeneity remained present despite low I^2 values. Included studies differed with respect to indications for decompressive craniectomy, timing of cranioplasty, reconstructive material, defect characteristics, follow-up duration, and outcome definitions. Therefore, the absence of statistical heterogeneity should not be interpreted as evidence of clinical equivalence between studies.

Neurocognitive Recovery and Quality of Life

Neurocognitive recovery and quality of life were central to the objectives of this review but could not be quantitatively synthesized because studies did not report comparable outcome measures at consistent follow-up intervals. This represents a major limitation within the existing literature. Cranioplasty is not solely a reconstructive procedure; it may influence cognition, attention, executive function, fatigue, participation in rehabilitation, social reintegration, cosmetic satisfaction, and overall quality of life.

The biological rationale supporting neurocognitive improvement after cranioplasty is compelling. Restoration of cranial contour may improve cerebral perfusion, normalize cerebrospinal fluid dynamics, restore cerebral pulsatility, and reduce abnormal pressure transmission across the cranial defect. These effects may be particularly important in patients with syndrome of the trephined, sinking skin flap physiology, or delayed neurological recovery following decompressive craniectomy. However, the current comparative literature remains insufficient to determine whether autologous bone, titanium, PMMA, PEEK, hydroxyapatite, or other implant materials differentially influence neurocognitive recovery or quality of life.

Future studies should prioritize patient-centered outcomes as core endpoints rather than secondary observations. Standardized reporting of preoperative and postoperative mRS or Glasgow Outcome Scale scores, Functional Independence Measure assessments, validated neuropsychological testing, quality-of-life instruments, and predefined follow-up intervals would substantially improve comparability across studies. Additionally, investigators should distinguish early postoperative complications from delayed material-specific failure mechanisms. Without greater standardization, future meta-analyses will continue to characterize implant-related complications while remaining unable to determine whether one reconstructive strategy leads to superior long-term recovery.

Limitations

Several limitations should be acknowledged. First, all included studies were retrospective observational cohorts, introducing the potential for selection bias, residual confounding, and outcome ascertainment bias. Second, only five comparative studies met inclusion criteria, limiting statistical power and preventing meaningful subgroup or sensitivity analyses. Third, functional outcomes were measured using heterogeneous instruments and definitions, necessitating harmonization into a study-defined functional improvement endpoint. Although pooling was restricted to clinically comparable constructs, some degree of measurement heterogeneity remains unavoidable. Fourth, neurocognitive recovery and quality-of-life outcomes could not be quantitatively synthesized because of inconsistent reporting. Finally, differences in implant type, timing of cranioplasty, patient populations, and follow-up duration may have influenced the observed results.

Overall, both autologous bone and synthetic implant-based cranioplasty remain reasonable reconstructive options following decompressive craniectomy. Based on the currently available evidence, neither strategy demonstrates a clear advantage with respect to functional recovery or major postoperative complications. Consequently, material selection should be individualized according to patient age, defect size, risk of bone resorption, prior infection, soft-tissue condition, cerebrospinal fluid shunt status, implant availability, cost considerations, cosmetic goals, and institutional experience.

Conclusion

In this systematic review and meta-analysis of 958 patients, autologous bone and synthetic implant-based cranioplasty demonstrated no statistically significant difference in the outcomes that could be quantitatively pooled. Functional improvement, the primary patient-centered endpoint available for meta-analysis, did not differ significantly between groups. Similarly, postoperative infection, postoperative hematoma, and revision surgery showed no clear material-related difference. Although postoperative hematoma was numerically lower with autologous bone and revision surgery was numerically higher in the autologous group, these findings did not reach statistical significance and should therefore be interpreted cautiously.

The available evidence does not support the superiority of either autologous bone or synthetic implants for functional recovery after cranioplasty. However, this should not be interpreted as proof of equivalence. The current literature remains limited by inconsistent reporting of functional outcomes, heterogeneous outcome definitions, small numbers of comparative studies, and a continued emphasis on surgical complications rather than patient-centered recovery. Neurocognitive outcomes and quality of life, despite being central to the clinical impact of cranioplasty, were not reported consistently enough to permit quantitative synthesis.

Overall, both autologous and synthetic implant-based cranioplasty remain reasonable reconstructive options after decompressive craniectomy. Material selection should be individualized according to patient characteristics, defect features, risk of bone resorption, infection risk, implant availability, cost, cosmetic goals, and institutional expertise. Future prospective comparative studies should standardize the reporting of preoperative and postoperative functional scales, validated neurocognitive testing, quality-of-life measures, timing of assessment, and material-specific complications to better determine whether reconstructive material influences meaningful neurological recovery.

Declarations

Clinical trial number: not applicable.

Ethics approval: Ethics approval was not required for this study because it is a systematic review and meta-analysis based exclusively on data from previously published studies. No new human participants were enrolled, and no identifiable patient data were collected. Institutional Review Board approval was not required because this study is a systematic review and meta-analysis of previously published studies.

Consent to participate: Not applicable. This study is a systematic review and meta-analysis of previously published studies and did not involve direct participation of human subjects, human tissue, or identifiable personal data.

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Registration: This systematic review was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; Registration No. CRD420261452332, registered on July 21, 2026)

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Figures

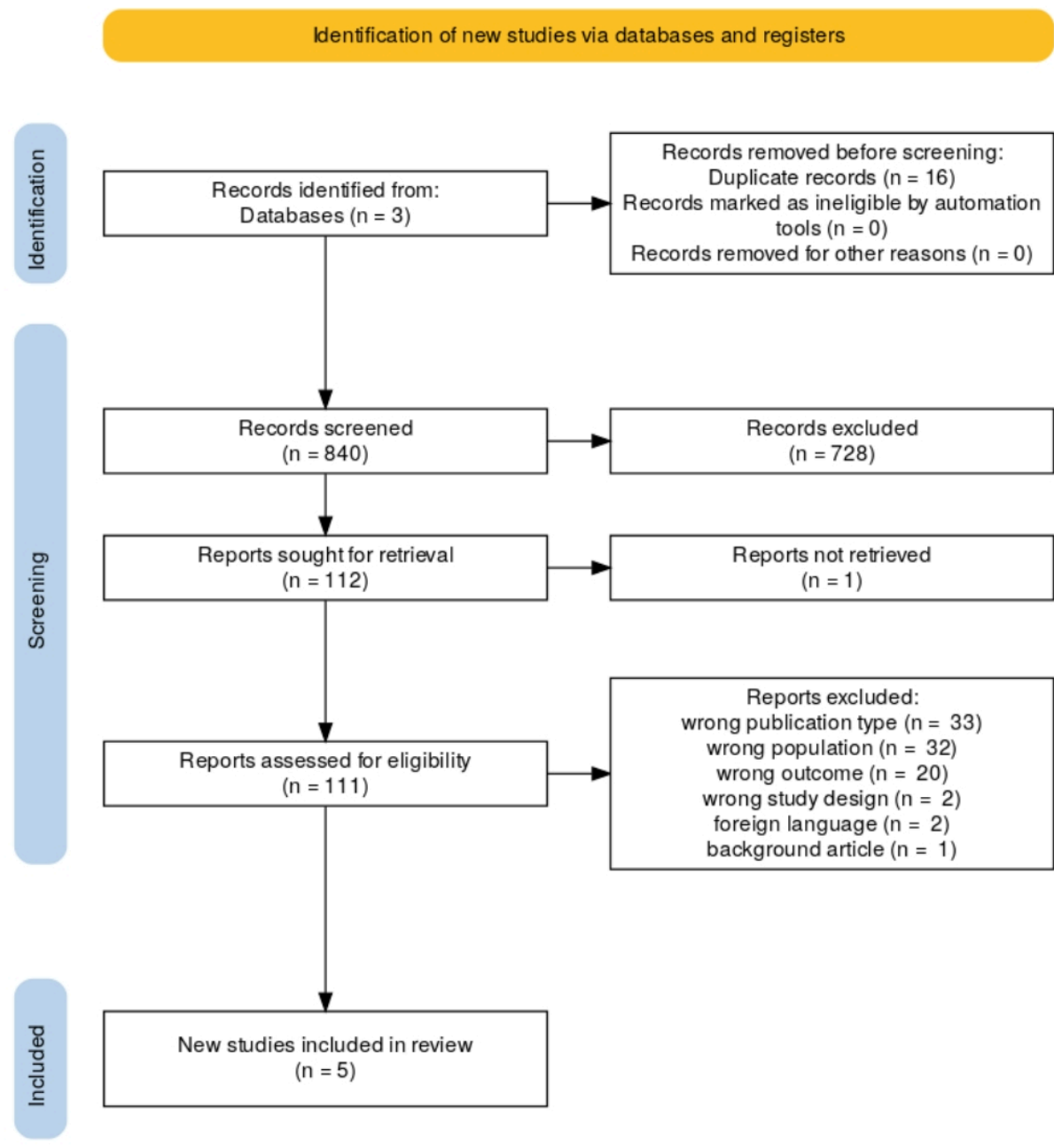
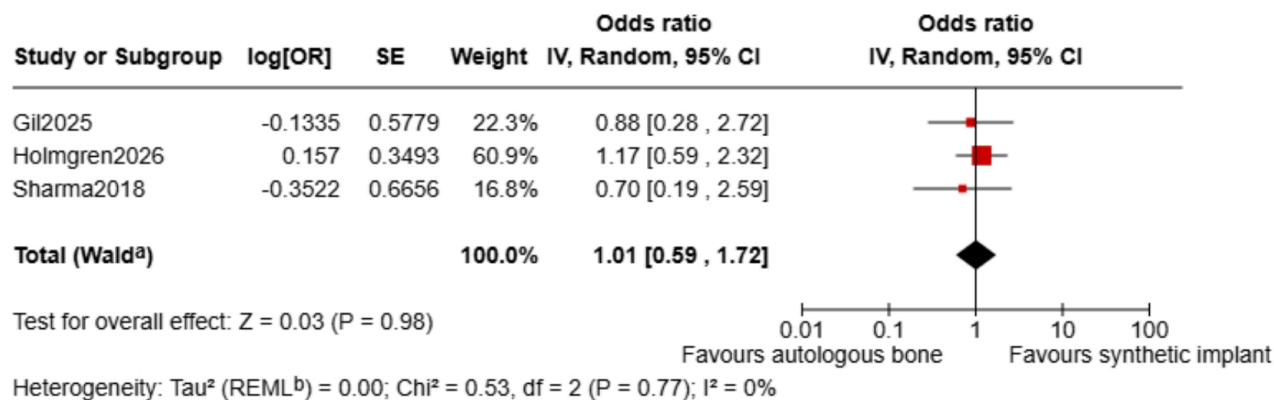


Figure 1

PRISMA flow diagram of study selection.



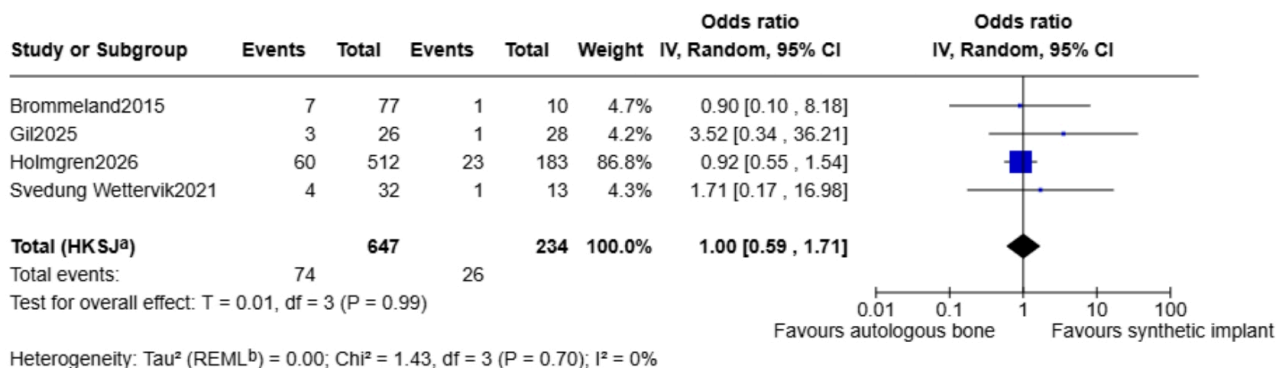
Footnotes

^aCI calculated by Wald-type method.

^b Tau^2 calculated by Restricted Maximum-Likelihood method.

Figure 2

Study-defined functional improvement after autologous bone cranioplasty versus synthetic implant-based cranioplasty.



Footnotes

^aCI calculated by Hartung-Knapp-Sidik-Jonkman method.

^b Tau^2 calculated by Restricted Maximum-Likelihood method.

Figure 3

Postoperative infection after autologous bone cranioplasty versus synthetic implant-based cranioplasty.

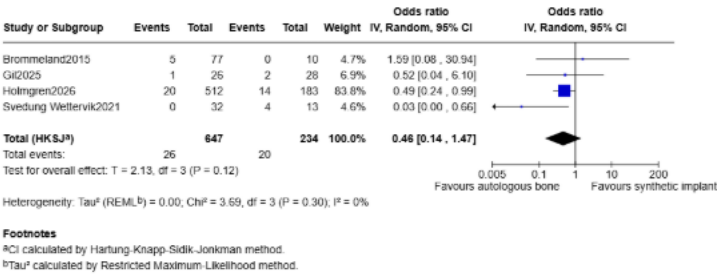


Figure 4

Postoperative hematoma or hemorrhage after autologous bone cranioplasty versus synthetic implant-based cranioplasty.

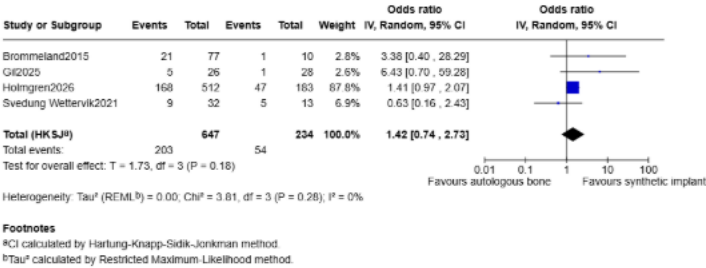


Figure 5

Revision surgery after autologous bone cranioplasty versus synthetic implant-based cranioplasty.

Supplementary Files

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