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High-flow Extracranial-to-Intracranial Bypass for Complex and Giant Cerebral Aneurysms: A Systematic Review and Meta-Analysis

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Abstract

Background

Intracranial aneurysms affect 3–5% of adults, with giant aneurysms posing substantial therapeutic challenges for which high-flow extracranial-to-intracranial (HF EC-IC) revascularization may be required.

Methods

A systematic literature search of PubMed, Embase, the Cochrane Library, and ClinicalTrials.gov was performed following PRISMA guidelines up to July 2025 to identify randomized controlled trials (RCTs), cohort, observational studies about HF EC-IC bypass for complex and giant cerebral aneurysms. Meta-analysis was performed using Review Manager (RevMan 5.4.1) with a random-effects model.

Results

Across 13 studies, patients receiving the intervention three times more likely to achieve favorable functional outcome compared to controls (pooled OR 3.09; 95% CI: 1.91–5.00). The effect was significant ($Z = 4.59$, $p < 0.00001$) despite high heterogeneity ($I^2 = 83\%$, $Chi^2 = 68.69$, $p < 0.00001$), likely due to variability in surgical techniques, patient characteristics, aneurysm complexity, and follow-up durations. Nonetheless, most studies reported ORs above 1.0, suggesting a consistent benefit of the intervention in improving functional outcomes. Among 11 studies, the intervention was associated with over tenfold higher odds of maintaining graft patency (pooled OR 10.56; 95% CI: 5.98–18.64), statistically significant ($Z = 8.13$, $p < 0.00001$) with moderate heterogeneity ($I^2 = 56\%$) attributable to patient populations, surgical techniques, graft types, and follow-up durations. Despite several studies reported high OR with wide confidence intervals, overall evidence demonstrates the intervention markedly improves graft patency.

Conclusions

HF EC-IC revascularization demonstrates consistent functional benefits and substantially enhances graft patency in complex and giant intracranial aneurysms, supporting its role in challenging cerebrovascular cases

1. Introduction

Intracranial aneurysms affect approximately 3–5% of the adult population and remain a significant cause of subarachnoid hemorrhage, rupture leading to subarachnoid hemorrhage, a devastating condition associated with high mortality and long-term neurological disability.[1] Considering that aneurysmal

subarachnoid hemorrhage is a serious complication of intracranial aneurysms, with a mortality rate of 67% and nearly 50% of survivors remaining disabled, clinicians should clarify the risk of rupture.[2]

Aneurysms are categorized clinically based on their maximal diameter: small (< 5 mm), medium (5 mm ≤ diameter < 15 mm), large (15 mm ≤ diameter < 25 mm), and giant (≥ 25 mm).[3] Among intracranial aneurysms, giant aneurysms have always been remain the most difficult cerebrovascular lesions to manage because of their complex morphology and anatomy significantly complicates both microsurgical and endovascular approaches.[4,5] Giant aneurysms also have a much higher 5-year rupture risk than the smaller one due to the substantial correlation between size and rupture risk. [3]

Giant intracranial aneurysms may present with mild progressive clinical symptoms attributable to mass effect on adjacent neurovascular structures, such as slow cranial nerve dysfunction, especially affecting the optic and oculomotor nerves, progressive neurological dysfunction, chronic headache, or slowly advancing dementia.[6]

High flow extracranial to intracranial (HF EC-IC) cerebral revascularisation may be necessary in the management of complex skull base tumours and intracranial aneurysms. EC-IC bypass surgery has two main indications: (1) flow augmentation and (2) flow replacement.[7] Zhang Jibo, et al. 2021 Complex intracranial aneurysms present special and difficult problems for endovascular coiling or surgical clipping. This issue can be effectively resolved by high flow EC-IC bypass grafting.[8] This systematic review aims to assess the effectiveness and safety of high-flow EC-IC bypass in patients with complex and giant cerebral aneurysms.

2. Materials and Methods

2.1 Study Design

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) recommendations. The study protocol was prospectively recorded in the PROSPERO 2025 registry (ID CRD420251173279).

2.2 Research Question

The research question was formulated using the Population, Intervention, Comparison, and Outcomes (PICO) framework. The population comprised patients of any age diagnosed with complex or giant cerebral aneurysms, defined as aneurysms measuring ≥ 25 mm in diameter or those considered unsuitable for direct microsurgical clipping or endovascular coiling, who underwent cerebral revascularization.

The intervention of interest was high-flow EC–IC bypass using interposition grafts, including radial artery grafts, saphenous vein grafts, or synthetic conduits, performed for aneurysm management.

Comparator groups included medical therapy alone, other surgical or endovascular procedures (such as indirect revascularization or endovascular stenting), or preoperative baseline data in single-arm studies.

Primary outcomes were long-term graft patency rate (> 12 months) and long-term neurological functional outcome, commonly assessed using the modified Ranking Scale (mRS 0–2) at the last follow-up.

Secondary outcomes included perioperative stroke or ischemia, 30-day and long-term mortality, perioperative complications (including graft occlusion, infection, and wound-related complications), and postoperative hemodynamic changes assessed by angiographic flow or perfusion imaging.

2.3 Study Eligibility Criteria

A comprehensive literature search was conducted to identify randomized controlled trials (RCTs), cohort, observational studies about high flow EC-IC bypass for complex and giant cerebral aneurysms. Studies were include if they involved patients (any age) diagnosed with complex or giant cerebral aneurysms (≥ 25 mm or unsuitable for direct clipping/coiling); who underwent high flow EC-IC bypass and reported postoperative functional outcomes and graft patency. Studies were excluded if they were that animal and cadaveric studies; do not compare superficial temporal artery to middle cerebral artery (STA-MCA) with other treatment; were non-english article; and focused on moya moya disease.

2.4 Search Strategy and Study Selection Process

A comprehensive literature search was conducted in PubMed, Embase, the Cochrane Library, and Clinicaltrials.gov from database inception to July 2025 to identify randomized controlled trials (RCTs), cohort, observational studies about high-flow EC-IC bypass for complex and giant cerebral aneurysms. The search strategy combined Medical Subject Headings (MeSH) and free-text terms. The PubMed search strategy was as follows (“giant cerebral aneurysm” OR “complex intracranial aneurysm”) AND (“high-flow EC-IC bypass” OR “extracranial to intracranial bypass”) AND (“graft patency” OR “functional outcome”). Only pubslished studies were include.

2.5 Data Extraction

Data from inclusion studies were summarized using table, following information: author’s name, year of publication, sample size, population male and female and clinical characteristics (types of aneurysm, location, treatment type of bypass, number of bypass, mRS preop ≤ 1, mRS post op ≤ 2, estimate p, SE, Bypass patency immediately, Bypass patency 6 months post op, artery/cortical infarction, Regional Angiography, Cerebral Blood Volume, Cerebral Blood Flow, Mean Transit Time,and Time to Peak). Data extraction was performed independently by two reviewers using a standardized data extraction form. Discrepancies were resolved through discussion and consensus. The review followed PRISMA guidelines.

2.6 Quality Assessment

The risk of bias of included studies was independently assessed by at least two reviewers using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool. The following domains were evaluated: bias due to confounding, randomization process, deviations from intended interventions, completeness of outcome data, accuracy of outcome measurement, and any selection of the reported results. Any discrepancies between reviewers were resolved by consensus. Additional information was not sought from study investigators when required data were unclear or unavailable in the published reports.

2.7 Statistical Analysis

Statistical analysis was performed using Review Manager (RevMan version 5.4.1). For each included study, the odds ratio (OR) was log-transformed, and the corresponding standard error was calculated. The combined effect estimate was synthesized using a random effects model considering anticipated clinical and methodological heterogeneity between studies. Statistical heterogeneity was assessed using the I^2 statistic. The overall effect size was reported as a pooled OR with a 95% confidence interval (CI). Odds ratios (ORs) with 95% confidence intervals were used for dichotomous outcomes, including graft patency and favorable functional outcome (mRS 0–2). Continuous outcomes were not pooled and were summarized descriptively.

2.8 Ethical Considerations

As this study is a review of published literature, ethical approval was not required. However, the review adhered with ethical guidelines for systematic reviews and meta-analyses, ensuring transparency, rigor, and ethical reporting finding

3. Results

3.1 Study selection

A total 62 records were identified from PubMed, Embase, and the Cochrane Library. After removing 2 duplicates, 60 titles and abstracts were screened, of which 27 records were excluded for irrelevance. The remaining 33 articles were retrieved for full-text review, and 3 were excluded due to the full texts could not be obtained. Subsequently, 30 full-text articles were assessed for eligibility, and 16 were excluded due to wrong population, wrong intervention, no outcome of interest, and non-RCT. Ultimately, 14 studies met the inclusion criteria and were included in the meta-analysis. The study selection process is summarized in the PRISMA flowchart, as shown in Fig. 1.

3.2 Quality assessment of the included studies

The results of the quality assessment using ROBINS-1 were presented in Fig. 2. Overall all included studies were judged to have a lower risk of bias, indicating a high level of methodological rigor and reliability in the evidence base.

3.3 Functional Outcomes

Across 13 studies, log-transformed odds ratios and standard errors were synthesized using a random-effects model. The overall pooled OR was 3.09 (95% CI: 1.91–5.00), indicating that patients receiving the evaluated intervention were approximately three times more likely to achieve a good functional outcome compared to controls. The effect was statistically significant ($Z = 4.59$, $p < 0.00001$). However, heterogeneity was high ($I^2 = 83\%$, $Chi^2 = 68.69$, $p < 0.00001$), reflecting substantial variability among studies, likely due to differences in surgical techniques, patient characteristics, aneurysm complexity, and follow-up durations. Despite this heterogeneity, most studies reported ORs above 1.0, with several showing strong and significant associations (e.g., Matano 2016, Natarajan 2019, Wang 2023, Zhang 2021), suggesting a consistent benefit of the intervention in improving functional outcomes in complex aneurysm cases.

3.4 Graft Patency

Across 11 included studies, the pooled odds ratio (OR) for graft patency was 10.56 (95% CI: 5.98–18.64), indicating that the intervention was associated with over tenfold higher odds of maintaining graft patency compared to controls. This finding was highly statistically significant ($Z = 8.13$, $p < 0.00001$). Heterogeneity among studies was moderate ($I^2 = 56\%$), suggesting some variability in effect sizes likely attributable to differences in patient populations, surgical techniques, graft types, and follow-up durations. Notably, several studies such as Natarajan 2019, Wang 2023, and Zhang 2023 reported exceptionally high ORs, although their wide confidence intervals reflect limited sample sizes or event numbers.[9,10,11] Despite these variations, the overall evidence consistently supports that the intervention markedly improves graft patency rates in aneurysm surgery.

4. Discussion

The current study's findings demonstrated that RAG size increased over time in patients with complicated ICA aneurysms receiving EC-IC HFB and therapeutic ICA occlusion, and that SVG was correlated with graft occlusion. Giant intracranial aneurysms continue to pose significant challenges in cerebrovascular surgery.[5,12] Although bypass surgery accounts for a small percentage of intracranial aneurysm treatments by volume, it plays a critical and pertinent role in intracranial aneurysm repair in response to the aneurysms' increasing complexity. All patients had a patent bypass, and 87% of patients with both ruptured and unruptured aneurysms had a satisfactory outcome (mRS < 2) at follow-up. There was 0% procedure-related death and 5% permanent morbidity.[23] Several clinical studies have found that high-flow EC-IC bypass provides reliable revascularization in patients with complex and giant cererbral aneurysms. Cerebral bypass is still a superior option for many patients with large and severe aneurysms.[8,11,24] EC-IC bypass can increase the safety of proximal ICA occlusion, according to a 2023 study by Peeters et al. With this procedure, 90.9% of aneurysms are completely occluded, and long-term bypass graft-related problems are uncommon. This is one of the latest major studies validating the

effectiveness of high-flow EC-IC for complex lesions. [22] This study aimed to evaluate functional outcomes and graft patency following high-flow EC–IC bypass surgery in patients with complex and giant intracranial aneurysms

Across 13 included studies, patients treated with high-flow EC–IC bypass were approximately three times more likely to achieve a favorable functional outcome compared with control treatment strategies. Substantial heterogeneity was observed among studies (I^2 = 83%), likely reflecting differences in aneurysm characteristics (giant versus large, fusiform versus saccular, anterior versus posterior circulation), patient presentation (ruptured versus unruptured aneurysms, baseline neurological status), and operative strategies (radial artery versus saphenous vein grafts, donor and recipient vessel selection, adjunctive endovascular procedures). Variations in follow-up duration and the definition of favorable functional outcome (e.g., modified Rankin Scale versus Glasgow Outcome Scale) further contributed to this heterogeneity.

Despite these differences, the effect consistently favored high-flow EC–IC bypass, with most studies reporting odds ratios greater than 1.0, supporting a true clinical benefit. For example, Natarajan et al. (2019) reported that 36 of 42 patients achieved a postoperative mRS of 0–2.[9] Similarly, Zhang et al. (2021) found that 71 of 79 patients had an mRS of 0–3 at six months follow-up.[8] In a recent series, Wang et al. (2023) observed that 9 of 10 patients achieved a GOS of 4–5 at 6–12 months postoperatively.[10] These findings demonstrate that high-flow EC–IC bypass can reliably improve functional outcomes in patients with complex and giant intracranial aneurysms.

The current study's findings by Matsukawa et al. (2017) demonstrated that RAG size increased over time in patients with complicated ICA aneurysms receiving EC-IC HFB and therapeutic ICA occlusion, and that SVG was correlated with graft occlusion.[12] In addition to functional outcomes, this study demonstrated a marked benefit of high-flow EC–IC bypass in terms of graft patency. High flow extracranial to intracranial saphenous vein bypass grafting can safely and effectively treat complex intracranial aneurysms, and the saphenous vein can supply sufficient blood, according to Zhang et al.'s (2021) demonstration of the safety and efficacy of HF EC-IC. A high rate of graft patency and adequate cerebral blood flow are achievable.[8] The safety of extracranial–intracranial (EC–IC) bypass in the treatment of anterior and posterior circulation intracranial aneurysms (IAs) was the subject of a comprehensive review by Brenner et al. (2024) and Chen et al. (2023). For anterior and posterior circulation IAs, EC-IC treatment has an excellent safety record.[20,21] Despite numerous developments, treating big ICA aneurysms is still difficult in neurosurgery. Treatment options include surgery, endovascular procedures, where flow diverters (FD) are the preferred option, or a mix of the two. In this instance, surgery to remove optic nerve compression (with or without EC-IC revascularization) is a suitable course of action, particularly if the patient's visual impairment keeps getting worse. Intracranial bypass surgery is still a highly relevant treatment option for conditions like Moyamoya vasculopathy, as a salvage option in steno-occlusive disease with hemodynamic compromise, and for aneurysms not amenable to microsurgical or endovascular repair, even though its indications have declined.[23,25]

Across 11 studies, the pooled odds ratio for graft patency exceeded 10, indicating that patients undergoing high-flow bypass had substantially higher odds of maintaining graft patency compared with controls. The moderate heterogeneity observed in this analysis ($I^2 = 56\%$) suggests some variability in patency rates, likely influenced by differences in graft type (radial artery versus saphenous vein), surgical expertise, perioperative management, and follow-up duration.

The results of this meta-analysis support high-flow EC–IC bypass as a valuable treatment option for patients with complex and giant intracranial aneurysms. While the procedure remains technically demanding and associated with inherent risks, the demonstrated improvements in functional outcomes and graft patency emphasize the role of high-flow EC–IC bypass.

Limitations

This systematic review has several limitations. Most of the included studies were small observational cohorts or case series, so patient characteristics, aneurysm morphology, and surgical strategies were reported heterogeneously and incompletely. Although a random effects model was applied, the available data did not allow for adjustment for several important confounding factors; therefore, the pooled estimates should be interpreted as exploratory rather than causal. Functional outcomes, graft patency, and hemodynamic parameters were not uniformly defined or consistently reported, and variability in follow-up duration may have led to underestimation of late graft failure or neurological deterioration at a later stage. Furthermore, limitations in published English-language studies and the small number of eligible studies may restrict generalizability and prevent robust subgroup analysis, underscoring the need for future prospective multicenter studies with standardized reporting of outcomes. The certainty of evidence was assessed qualitatively, taking into account study design, risk of bias, and consistency of results, although a formal GRADE approach was not applied.

5. Conclusion

A consistent benefit of the intervention in improving functional outcomes in complex aneurysm cases. The overall evidence consistently supports that the intervention markedly improves graft patency rates in aneurysm surgery.

Declarations

6. Funding

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7. Conflict of Interest

None.

8. Acknowledgements

None.

9. Ethical Approval

This study is a systematic review based exclusively on data from previously published studies. Therefore, ethical approval from an institutional review board or ethics committee was not required.

10. Consent to Participate

Not applicable.

11. Consent for Publication

Not applicable.

12. Clinical Trial Registration Number

Not applicable.

13. Human ethics and consent statement

This systematic review used data derived from previously published studies; therefore, no human participants were directly involved and informed consent was not required

Author Contribution

Annisa Amalina wrote the main manuscript text. All authors reviewed the manuscript

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Figures

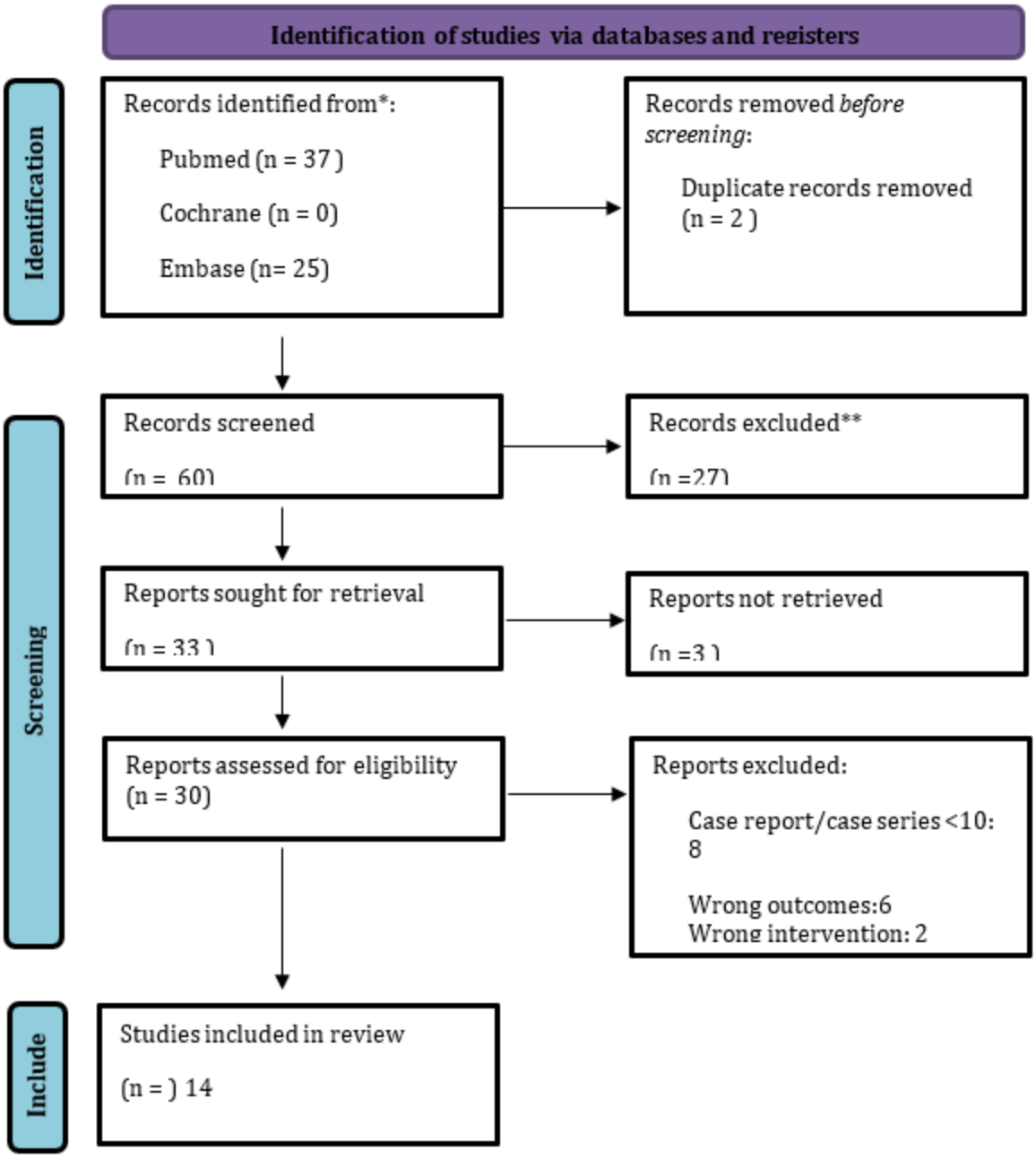


Figure 1

PRISMA Flowchart

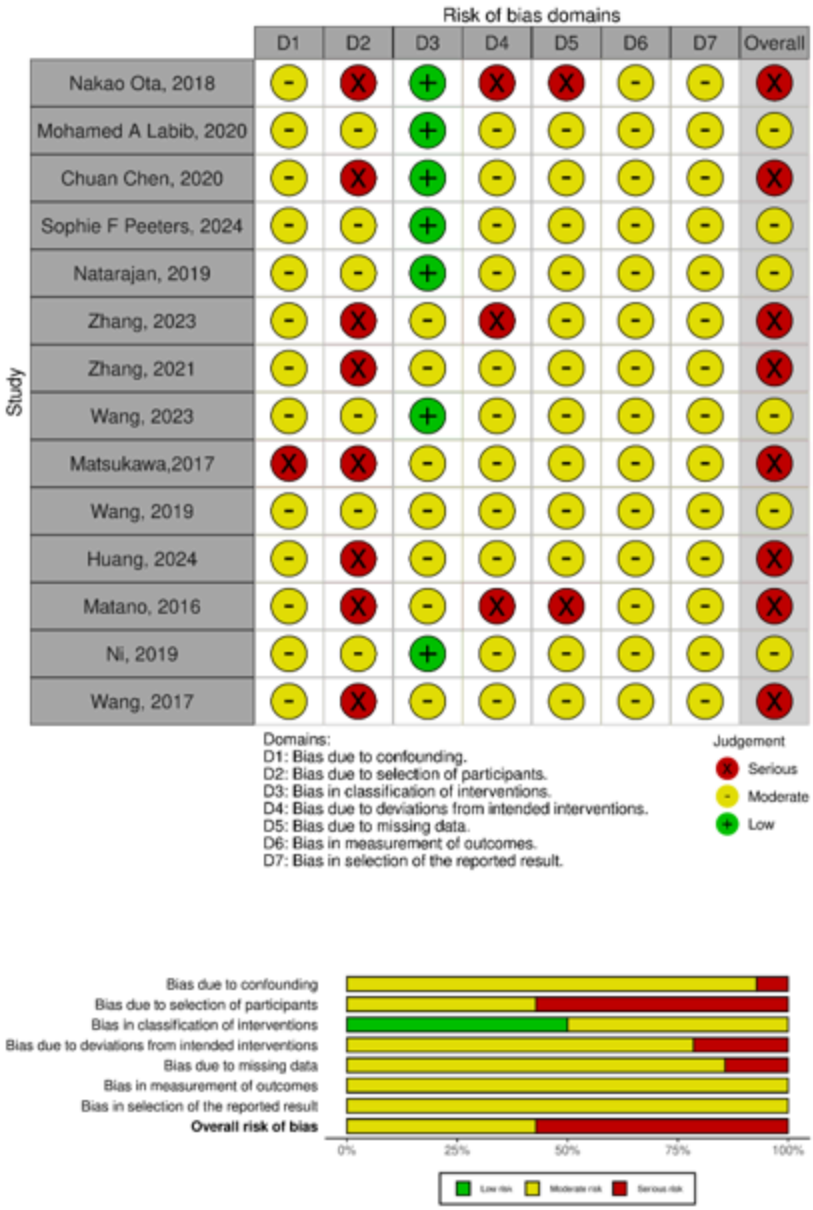


Figure 2

ROBINS-1 assessment of included studies

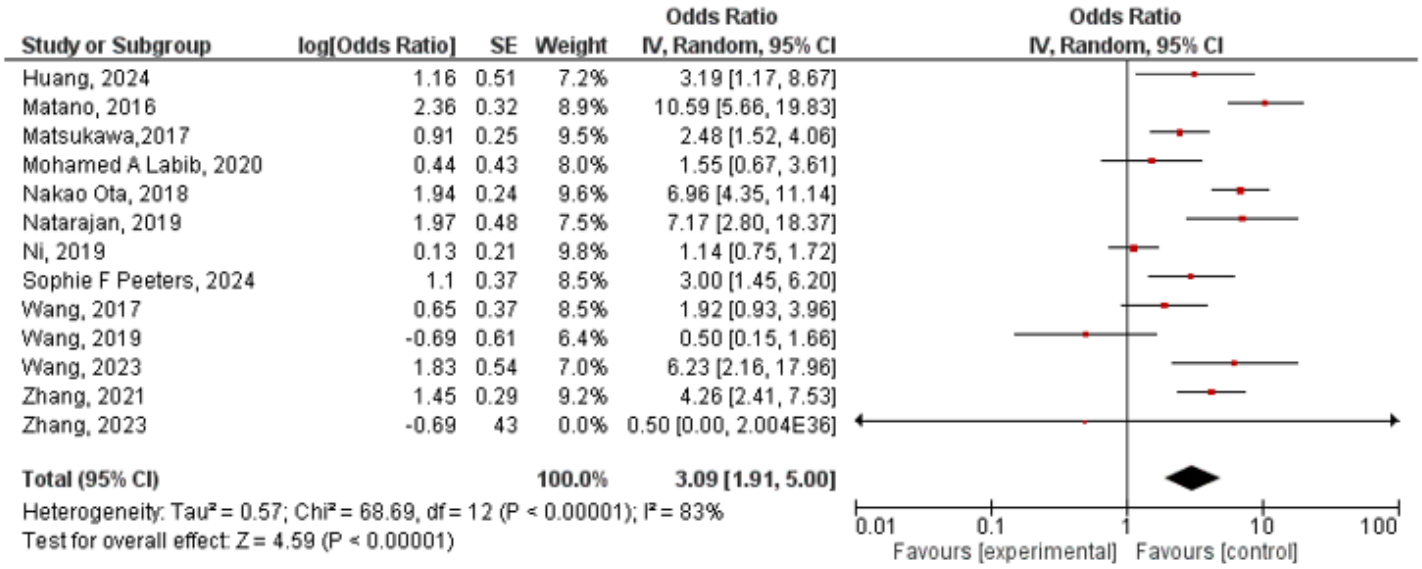


Figure 3

Functional Outcomes

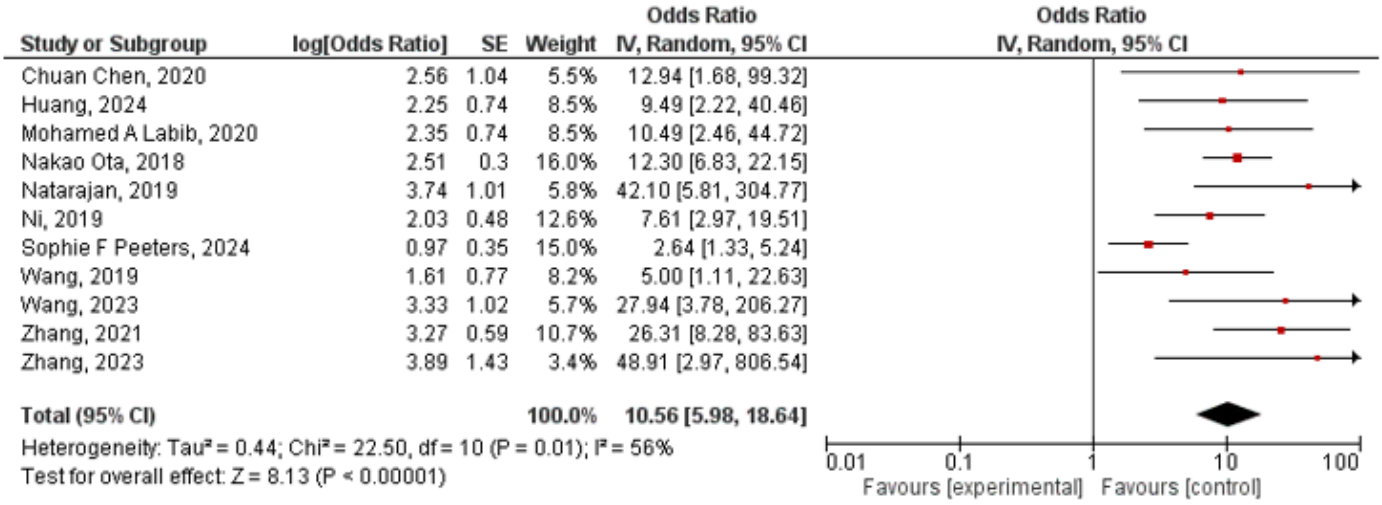


Figure 4

Graft Patency