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Radial Artery Versus Saphenous Vein Grafts in Coronary Artery Bypass Surgery: A Grade-Assessed Meta-Analysis of Randomized Controlled Trials

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Abstract

Background

This systematic review and meta-analysis compared the long-term efficacy and clinical outcomes of radial artery (RA) versus saphenous vein grafts (SVG) in coronary artery bypass grafting (CABG).

Methods

Following PRISMA guidelines, databases were searched through March 2026 for randomized controlled trials (RCTs) comparing RA and SVG for non-left anterior descending coronary arteries. The primary outcome was graft failure, defined as a composite of complete or functional occlusion (string sign).

Results

Four RCTs assessing 1,219 grafts (621 RA; 598 SVG) were included. No statistically significant differences were found between RA and SVG in overall graft failure (12.4% vs. 14.9%; P = .11) or patency rates (87.6% vs. 85.1%; P = .11). However, RA grafts demonstrated significantly lower odds of complete occlusion (7.1% vs. 13.9%; P = .046) but a 6-fold higher risk of functional occlusion (6.1% vs. 0.8%; P < .001). Leave-one-out sensitivity analysis revealed that omitting one outlier study eliminated heterogeneity and shifted primary outcomes significantly in favor of RA grafts. No significant differences were observed for all-cause mortality (P = .13) or repeat revascularization (P = .37).

Conclusion

Neither conduit is universally superior. RA grafts reduce complete anatomical occlusion but are highly susceptible to competitive flow-induced functional occlusion. Graft selection should be individualized based on patient demographics and target vessel characteristics.

Introduction

Cardiovascular disease (CVD) is the leading cause of death globally. CVDs are estimated to kill 19.8 million people by 2022, accounting for approximately 32% of all deaths globally. Heart attacks or strokes accounted for 85% of these deaths. More than 75% of CVD deaths occur in low- and middle-income nations. CVDs accounted for at least 38% of the 18 million premature deaths (before the age of 70) from noncommunicable diseases in 2021 [1].

Coronary Artery Bypass Grafting (CABG) is a surgical treatment that revascularizes a stenosed coronary artery by constructing new pathways, which improves cardiac perfusion.

Long-term survival and adequate biological and hemodynamic behavior are the most important graft selection criteria. The effectiveness of CABG interventions depends on a number of factors, including the extent of the disease (left ventricular function), coexisting cardiological pathology (e.g., porcelain aorta), patient data (anthropometric-age-sex), coexisting conditions (chronic kidney disease (CKD), diabetes mellitus (DM), chronic obstructive pulmonary disease, peripheral vascular disease) availability of grafts, on-pump/ off-pump techniques, and post-operative medication adherence. The common conduits used in CABG surgery are Internal Thoracic Artery (ITA), Radial Artery (RA), and Saphenous Vein (SV) [2].

The choice of Graft remains the central reason for the short and long term outcomes following Graft placement surgery. On short-term follow-up, some studies found that RA graft patency is lower than that of SV grafts. However, with long-term follow-up, RA grafts improved due to the revival phenomenon (a previously narrowed vascular graft regaining its lumen and blood flow over time), which is not typically seen in SV grafts [3]. Overall, RA Grafts have higher long-term graft patency than SV Grafts, albeit this varies by coronary area [4].

In coronary artery bypass grafting, using RA instead of SV is associated with a statistically significant decrease in the incidence of the composite outcome of death, myocardial infarction, or recurrent revascularization [5]. Several RCTs have shown results inclining in the favour of RA grafts, but still limited by small sample sizes, variable patient populations, insufficient follow-up data, and varied research methodologies.

This leads to a limitation towards generalizability of the available results and need for a systematically synthesized analysis to ensure more precise and robust evaluation of comparative efficacy of both conduits. Therefore, this systematic review and meta analysis aims to provide a more statistically powerful and rigorous synthesis of consistent effects of RA grafts on graft failure, vascular occlusion, and major adverse cardiac events (MACE) by pooling data from all RCTs.

Methods

Search Strategy

We conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) following the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [6]. A systematic search of PubMed, Google Scholar, EMBASE, Cochrane library, Scopus was conducted from inception through March 2026. The search strategy employed a combination of Medical Subject Headings (MeSH) and relevant keywords including 'coronary artery bypass grafting', 'CABG', 'radial artery', 'saphenous vein graft', and 'randomized controlled trial'. To ensure a comprehensive search, we manually reviewed the reference lists of previous meta-analyses and the included trials. No language or geographical restrictions were applied. Detailed search strategy is present in Supplementary Table 1.

Study Selection

Studies were eligible for inclusion if they met the following criteria: (1) randomized clinical trials (RCTs) comparing the use of a radial artery (RA) graft versus a saphenous vein graft (SVG) for the bypass of non-left anterior descending (non-LAD) coronary arteries; (2) included adult patients undergoing primary or repeat CABG; and (3) reported angiographic follow-up data specifically identifying complete occlusion or functional occlusion (string sign). Exclusion criteria included observational studies, studies where RA was compared to conduits other than SVG, and trials without protocol-mandated or clinically indicated angiographic follow-up.

Data Extraction and Management

Data from the four included RCTs were extracted independently into a standardized spreadsheet. For angiographic outcomes (graft failure, complete occlusion, functional occlusion, and patency rate), the denominator was strictly defined as the analysed N (the number of grafts or patients who actually underwent follow-up angiography) rather than the baseline randomized number, ensuring results were not diluted by attrition bias. For clinical outcomes (all-cause mortality and repeat revascularization), an intention-to-treat (ITT) approach was utilized, using the total number of patients randomized at baseline as the denominator. For continuous outcomes where trials reported results as medians with interquartile ranges (IQR) or minimum-maximum ranges, the data were converted to means and standard deviations (SD) using the validated statistical formulas described by Wan et al. (2014) [7] and Luo et al. (2018) [8].

Outcomes and Definitions

The primary outcome was graft failure, defined as a composite of complete occlusion (TIMI flow grade 0) or functional occlusion (the 'string sign', defined as diffuse narrowing of the graft to < 1 mm in diameter). Secondary angiographic outcomes included complete occlusion and functional occlusion analyzed separately, and the overall patency rate. Secondary clinical and continuous outcomes included all-cause mortality, repeat revascularization (percutaneous coronary intervention or repeat bypass grafting), and follow-up duration (years).

Quality and Certainty Assessment

The risk of bias was assessed at the study level using the revised Cochrane risk of bias tool for randomized trials (RoB 2). Two reviewers (W.M. and S.D.) independently judged each trial across the standard RoB 2 domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Discrepancies were resolved by consensus, with input from (M.E.K.) when required. Each outcome within each trial was assigned an overall risk of bias judgment (low risk, some concerns, or high risk). We summarized the

risk-of-bias assessments in traffic-light plots and considered them explicitly in the interpretation of the results and the GRADE certainty ratings (Fig. 2a & 2b).

The overall certainty of the evidence for each key outcome (12-month urinary continence, 12-month erectile function, positive surgical margins, and major complications) was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework. Starting from high certainty for randomized evidence, we considered downgrading for risk of bias, inconsistency (including any unexplained heterogeneity or subgroup effects), indirectness, imprecision (width of confidence intervals and optimal information size), and suspected publication bias. The Summary of Findings tables present pooled effect estimates alongside their corresponding GRADE certainty ratings for the most clinically relevant outcomes.

Statistical Analysis

All statistical analyses were performed using the latest version of RStudio (2026.01.2) and the 'meta' package. A random-effects model was employed for all outcomes to account for potential between-study heterogeneity arising from differences in surgical design (within-patient vs. parallel groups) and follow-up intervals. For dichotomous outcomes, the treatment effect was expressed as an odds ratio (OR) with 95% CIs, calculated using the Mantel-Haenszel (MH) method. For continuous outcomes, the mean difference (MD) with 95% CIs was used. Between-study heterogeneity was assessed using the I^2 statistic and the Chi-square test, where $I^2 > 50\%$ or $P < .10$ was considered indicative of significant heterogeneity. The Restricted Maximum-Likelihood (REML) estimator was used to calculate the between-study variance (tau^2).

Sensitivity Analysis

To evaluate the robustness of the pooled estimates and identify studies exerting a disproportionate influence on the results, a systematic leave-one-out (LOO) sensitivity analysis was performed for all outcomes. In this influence analysis, the meta-analysis was recalculated by iteratively omitting one study at a time to assess the stability of the pooled OR or MD and the impact on statistical heterogeneity. All P values were 2-sided, and statistical significance was defined as $P < .05$.

Results

Study Characteristics

Four randomized clinical trials (RCTs) (Fig. 1) involving a total of 1219 evaluated grafts (621 radial artery [RA] and 598 saphenous vein grafts [SVG]) were included in the analysis. The mean follow-up duration was comparable between the RA and SVG groups (mean difference [MD], − 0.00 years; 95% CI, − 0.05 to 0.04 years; $P = .95$; $I^2 = 0\%$). Baseline characteristics were well-balanced across the included trials (Table 1).

Primary Angiographic Outcome: Graft Failure

Graft failure (defined as the composite of complete occlusion or functional occlusion/string sign) occurred in 77 of 621 RA grafts (12.4%) and 89 of 598 SVGs (14.9%). In the random-effects model, RA grafts were associated with 50% lower odds of failure compared with SVGs, although this did not reach statistical significance (odds ratio [OR], 0.50; 95% CI, 0.22–1.16; *P* = .11; Fig. 1). Moderate heterogeneity was observed among the studies (I^2 = 62.2%; *P* = .05) (Fig. 3).

Secondary Angiographic Outcomes

Complete Occlusion

The odds of complete graft occlusion were significantly lower in the RA group compared with the SVG group. Complete occlusion occurred in 38 of 539 RA grafts (7.1%) and 73 of 524 SVGs (13.9%) (OR, 0.29; 95% CI, 0.08–0.98; *P* = .046; Fig. 2). Moderate heterogeneity was present (I^2 = 48.6%) (Fig. 4a).

Functional Occlusion (String Sign)

The incidence of functional occlusion (string sign) was significantly higher in RA grafts compared with SVGs. Events were identified in 33 of 539 RA grafts (6.1%) and 4 of 524 SVGs (0.8%). RA use was associated with a more than 6-fold increase in the odds of string sign formation (OR, 6.77; 95% CI, 2.61–17.58; *P* < .001; Fig. 3). No heterogeneity was observed for this outcome (I^2 = 0%) (Fig. 4b).

Patency Rate

The overall patency rate was 87.6% (544 of 621) for RA grafts and 85.1% (509 of 598) for SVGs. There was no statistically significant difference in the odds of patency between the two conduits (OR, 1.98; 95% CI, 0.87–4.54; *P* = .11; I^2 = 62.2%;) (Fig. 4c).

Clinical Outcomes

All-Cause Mortality

Data for all-cause mortality were available from 2 trials. Mortality occurred in 34 of 195 patients (17.4%) in the RA group and 44 of 172 patients (25.6%) in the SVG group. The difference in odds of mortality was not statistically significant (OR, 0.66; 95% CI, 0.39–1.12; P = .13; I^2 = 0%; Supp Fig. 1).

Repeat Revascularization

Repeat revascularization was reported in 2 trials. Events occurred in 8 of 674 RA patients (1.2%) and 12 of 672 SVG patients (1.8%). No significant difference was found between groups (OR, 0.65; 95% CI, 0.26–1.66; P = .37; I^2 = 0%; Supp Fig. 2).

Follow-up Duration

Four randomized clinical trials (RCTs) involving a total of 1219 evaluated grafts (621 radial artery [RA] and 598 saphenous vein grafts [SVG]) were included in the analysis. The mean follow-up duration across the included trials ranged from 0.91 years to 6.35 years. The pooled analysis demonstrated that the follow-up duration was comparable between the RA and SVG groups (mean difference [MD], − 0.00 years; 95% CI, − 0.05 to 0.04 years; P = .95; I^2 = 0%; Supp Fig. 3).

Sensitivity and Influence Analysis

Leave-one-out sensitivity analyses revealed that the pooled estimates for graft failure and patency were highly influenced by the inclusion of the study by Desai et al. (RAPS). In the analysis of graft failure, omission of Desai et al. resulted in a statistically significant benefit for the RA group (OR, 0.32; 95% CI, 0.15–0.69; P = .003; Supp Fig. 4) and resolved all observed heterogeneity (I^2 = 0%). Similarly, for the patency rate, omission of Desai et al. led to a significant result favoring RA (OR, 3.13; 95% CI, 1.44–6.78; P = .004; I^2 = 0%; Supp Fig. 7).

The increased odds of string signs in the RA group were also primarily driven by the Desai et al. trial; upon its omission, the association was no longer statistically significant (OR, 2.65; 95% CI, 0.27–25.95; P = .40; Supp Fig. 6). The pooled estimate for complete occlusion remained consistent in direction across all iterations; however, statistical significance was lost upon omission of either Collins et al. (OR, 0.38; 95% CI, 0.10–1.42; P = .15; Supp Fig. 5) or Gaudino et al. (OR, 0.35; 95% CI, 0.08–1.51; P = .16; Supp Fig. 5), reflecting the limited number of contributing studies and the predominant influence of Desai et al. on this outcome. Outcomes for mortality and repeat revascularization remained consistent in both direction and significance across all iterations of the leave-one-out analysis. Outcomes for mortality and repeat revascularization remained consistent in both direction and significance across all iterations of the leave-one-out analysis (Supp Fig. 8,9). Similarly, the sensitivity analysis for follow-up duration demonstrated high stability; the pooled mean difference remained non-significant and near zero across all iterations, with heterogeneity consistently maintained at I^2 = 0% regardless of study omission (Supp Fig. 10).

Discussion

Primary Findings:

The current meta-analysis suggests that the association of RA grafts with numerically reduced Graft Failure didn't reach statistical significance due to moderate heterogeneity and wide confidence interval. Heterogeneity may be due to different study designs, target vessel characteristics and patient populations. The difference between the included studies is not just random but depicts that graft efficacy is inconsistent in various settings and populations.

Our findings are inconsistent with the existing literature which suggested that RA grafts are superior to SV graft in terms of graft failure [9–11]. However, these are just observational studies with different patient baseline characteristics and study designs.

With removal of Desai et al [12] in sensitivity analysis, heterogeneity vanishes (I^2= 0%) and the pooled effect estimates shifted towards RA graft. This interprets that the initial signal towards insignificant results is largely due to this one outlier study. Other studies depict significant differences between the two conduits. This finding underscores the caution for interpreting pooled estimate results and highlights the importance of exploring patient specific factors that influence the observed variability.

Graft failure in RA bypass patients in Desai et al. study may be physiologically influenced by patient characteristics. Graft patency is highly dependent on severity of stenosis in native vessels. Composite arterial grafts provide good patency when grafted to coronary arteries with more than 50% stenosis [13].

Secondary Findings

Our findings conclude that RA Grafts are associated with less events of complete occlusion than SV Grafts which is also statistically significant (p = 0.046). However, moderate heterogeneity is present in these findings as well. After sensitivity analysis, with removal of either Collins et al. [14] or Gaudino et al. [15], these results lost their statistical significance. This just depicts that the number of studies reporting this outcome is very small and by removing just one of them will skew the result to one extreme. Consequently, this finding is so fragile that minute changes in data can reverse the results and cannot lead to definitive clinical implications. This degree of fragility aligns with a methodological research demonstrating that statistically significant results in a meta analysis can be less robust than presumed [16]. It highlights a fundamental limitation which could only be interpreted as hypothesis-generating rather than practice-changing.

This meta analysis found that there is significant association of positive string sign with RA Graft. There is 6 times greater functional occlusion with RA Grafts than with SV ones. This finding is also majorly influenced by Desai et al [12]. Upon its removal, results become insignificant.

Functional occlusion is different from anatomical one. In functional occlusion there is physiologic RA spasm due to mild native vessel stenoses while on the other hand, SV is not much influenced by local blood flow conditions. This functional occlusion is temporary and can become functional due to revival phenomenon [3] or it may require surgical revascularization.

From a patient's perspective, a functionally occluded graft does not cause immediate ischemia because of compensatory supply from native vessels. But it also provides no myocardial protection and can be detrimental over time [17].

Our findings suggest no statistically significant difference between the overall patency of both conduits. SV grafts leading to intimal hyperplasia and increased atherosclerotic potential [18], and RA grafts being sensitive to flow conditions [3] are two opposing biological factors that may have balanced out the results. The initial patency of both conduits are similar with significant deterioration of SV Grafts in further medium or long term follow ups [19]. This suggests that biological vulnerability of both conduits manifest at different postoperative times.

Saphenous graft failure is often caused by four main pathophysiological mechanisms: early acute thrombosis, vascular inflammation, intimal hyperplasia, and late accelerated atherosclerosis [20]. In contrast, RA string sign, a functional occlusion due to competitive flow presents early and is reversed by revival phenomena or progression of native vessel disease.

Hence, only patency does not impart whole clinical selection of graft, rather choice of graft should be individualised by patient's demographic.

There is no significant difference between all-cause mortality of either group($p = 0.13$). After sensitivity analysis, results remain robust and consistent, depicting that the choice of graft should be independent of mortality benefits.

This finding is consistent with previous literature. However, some studies contradict with our finding including Tranbaugh et al, a single-centre observational study [21] and Gaudino et al, a meta-analysis of greater sample size and longer follow up duration [22] due to possible confounders.

Patients requiring revascularization after the first CABG procedure either with RA Graft or with SV Graft were reported in only 2 trials with no significant difference. ($p = 0.37$). Even after sensitivity analysis, findings remain in the same direction and not a single study is driving these results.

The lack of statistical significance, despite RA grafts being associated with better patency, is due to several factors. Firstly, repeat revascularization is not a frequent event in long-term follow up of CABG patients. Secondly, the choice of performing revascularization (either percutaneous or surgical) depends on patients' symptoms, imaging, and intra-operative complications, not merely on the type of conduit used. Additionally, as noted in RADIAL-Extended follow up protocol, studies were focused on protocol-driven revascularization rather than clinically-indicated repeat revascularization. This resulted in overestimation of rate of reintervention in both groups and biasing towards null. [23]

Hence, our findings in terms of revascularization procedures should be considered hypothesis-generating rather than definitive so as to direct future studies to follow a more structured and adequate follow up duration to capture these late events.

This meta-analysis suggests that both venous and arterial graft are clinically acceptable irrespective of mortality and revascularization. Functional occlusion remains the major factor influencing clinical choice of the graft placement solely based on patient specific data and target vessel characteristics i.e. RA Grafts should be used for patients with Quantitative Flow Rate (QFR) of less than 0.57 and SV Grafts for higher QFR [17]. However, the main outcome - Graft Failure is, overall, inclined in the support of RA Graft but due to inconsistent data no definitive conclusion can be drawn from it.

Future Recommendations:

This Meta analysis highlights the need for further randomized studies on Graft failure and Functional occlusion to reduce confounding and selection bias that contributes to the considerable heterogeneity in previous studies. Further studies should follow a generalized reporting of outcomes so as to decrease fragility in analytical results. Future large head-to-head Randomized studies with standardized follow up period should be done to find out durability and survival impacts of both conduits. Standardized definitions and clear cut off values for outcomes along with stratification of population into sub-group based on vessel conditions and co-morbidities should be implicated in future trials. Developing predictive tools for patient-centred choice of conduit with cost-effectiveness and quality of life analysis would prove clinically significant.

Limitations:

This paper has a few limitations. Very few RCTs were found that matched the inclusion criteria and most of them used small sample sizes. Heterogeneity was moderate to high, which is not unexpected. Although we intend to apply a random-effects model to handle heterogeneity, our results may remain vulnerable to variability as a result of residual heterogeneity.

This review incorporates RCTs with diverse age groups, sex distributions, and baseline characteristics, which might restrict the external validity of our results. To overcome this, we used a random-effects model and performed, where applicable, sensitivity analyses to assess whether these elements impacted the overall effect estimate

Since we focused on more impactful findings, it is likely that our research is prone to publication bias. This is likely to have negative impacts on the overall effect. The omission of grey literature alongside unpublished data contributes to this overestimation. While methodologies such as funnel plot analysis and Egger's test have been integrated to check for publication bias, there is always the risk of residual bias. Some of the RCTs that are included in our study showed signs of participant drop-out, which contributes to bias. To manage the missing data of participants who dropped out midway, we applied a last known value approach and regarded their last recorded outcome as the final outcome. To reduce errors, the extraction of data was done independently by several reviewers. Though some degree of error remains possible.

Recent evidence may not be captured in our analysis. This is because our search was limited to studies published by the year 2020.

Strengths:

This Systematic Review and Meta Analysis exclusively includes RCT studies only which decreases the risk of bias and represents the highest level of evidence for the intervention. In clinical research, RCTs are thought to provide the strongest level of evidence for proving causation [24]. A very comprehensive search strategy was employed with data from various reliable databases and screened manually, which reduces the risk of missing any related study.

Appropriate statistical models were used to analyse the data with various sensitivity analyses which ensure the robustness of results. By pooling the data from all the 4 RCTs, our analysis yields an accurate effect size estimate with significantly higher statistical power, which is crucial when the primary study is constrained by a small sample size [25]. Furthermore Risk of bias assessment was done by using a validated tool i.e. Cochrane RoB. depicting the reliability of our outcomes.

Conclusion

In conclusion, this systematic review and meta-analysis comparing two graft placement conduits for the CABG surgery suggests that none of the two conduits is superior to the other universally. However, as far as graft patency and long term efficacy is concerned, RA Graft is favourable but with greater study heterogeneity. Hence, Graft selection should be more based on patient specific outcomes.

Declarations

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

MH and AAK conceptualized the study, conducted the systematic literature search, and drafted both the initial and revised versions of the manuscript. MH and ZS performed data extraction, data analysis, and interpretation of the results. AA, HWS and MA contributed to manuscript writing and refinement of the content. HWS assisted with table preparation and quality assessment. AAK and MA supported manuscript preparation and the compilation of results. AS contributed to reference management and study screening. IUHC provided overall supervision, expert guidance, and final approval of the manuscript. All authors reviewed and approved the final version of the manuscript.

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Tables

Table 1 is available in the Supplementary Files section.

Figures

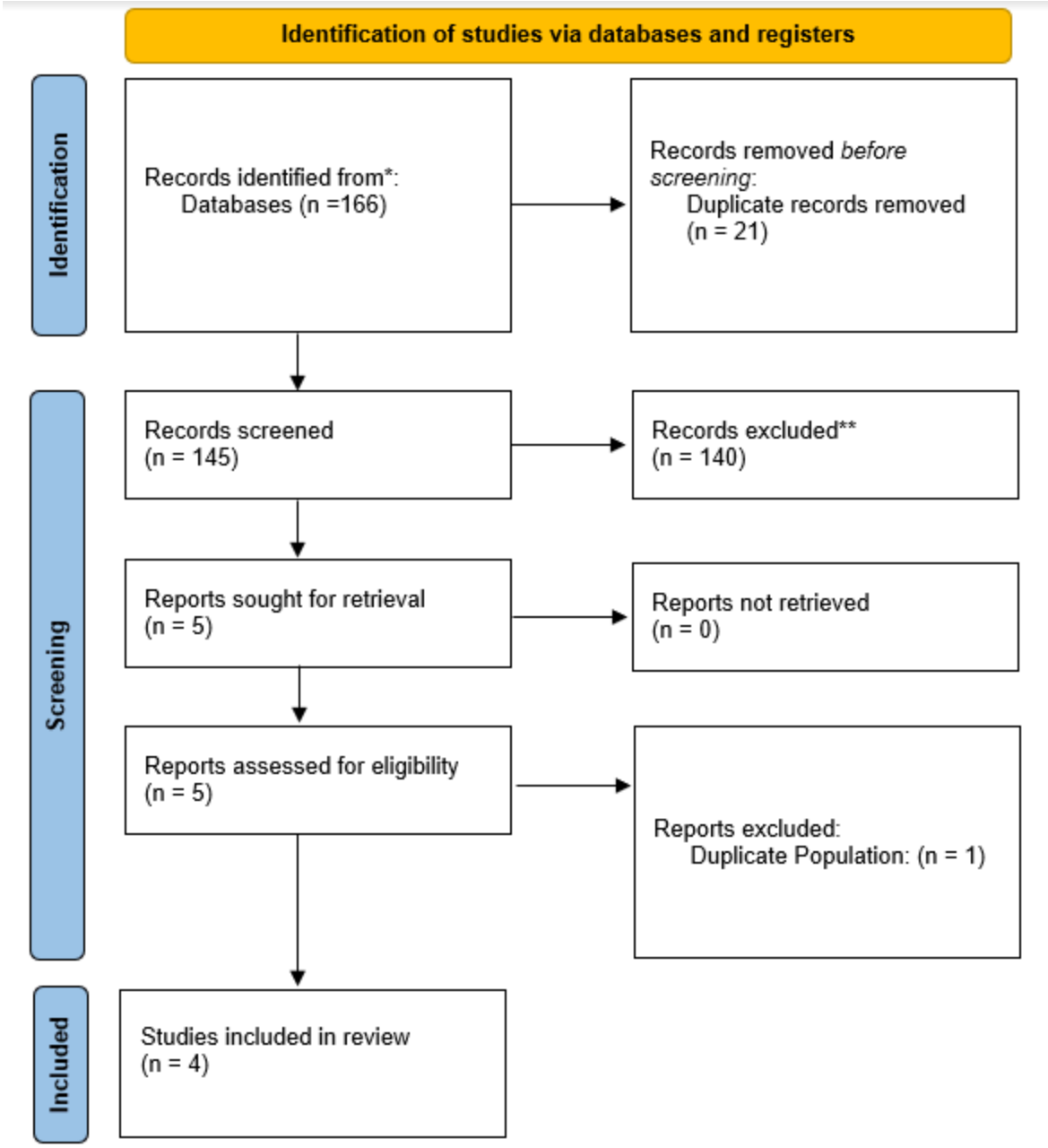


Figure 1

PRISMA Flowchart Summary of Inclusion Process

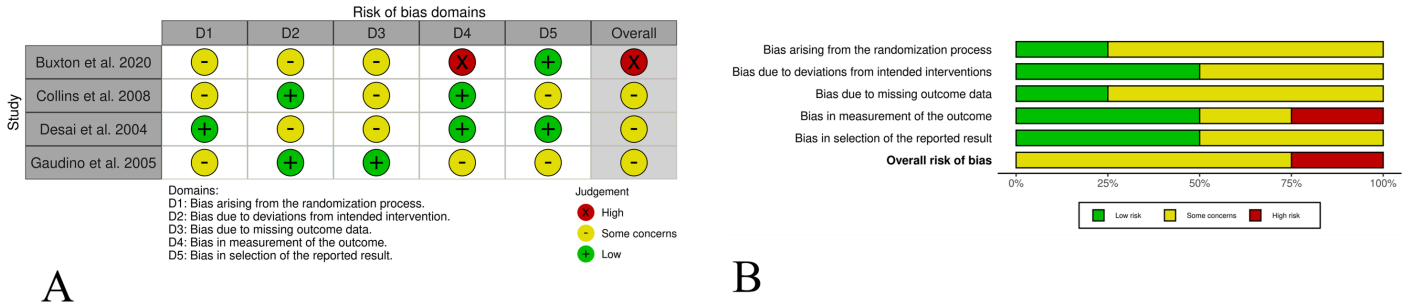


Figure 2

2a: Risk of Bias Assessment via RoB2

2b: Risk of Bias Assessment via RoB2 Traffic Light Plot

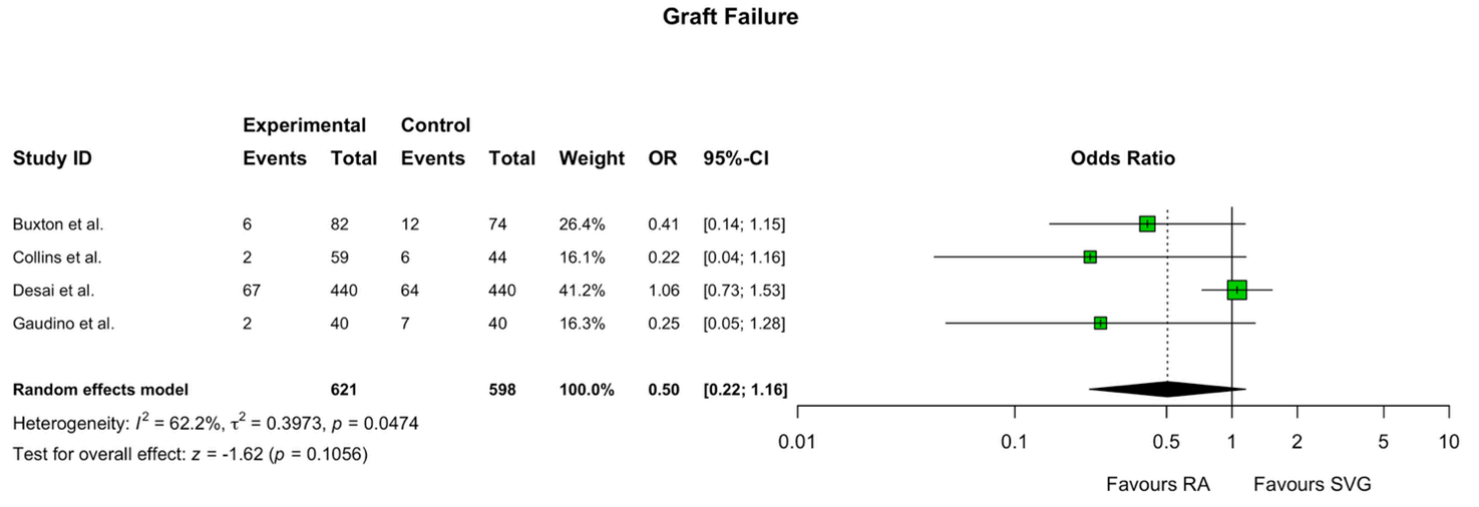


Figure 3

Forest Plot for Primary Outcome Graft Failure

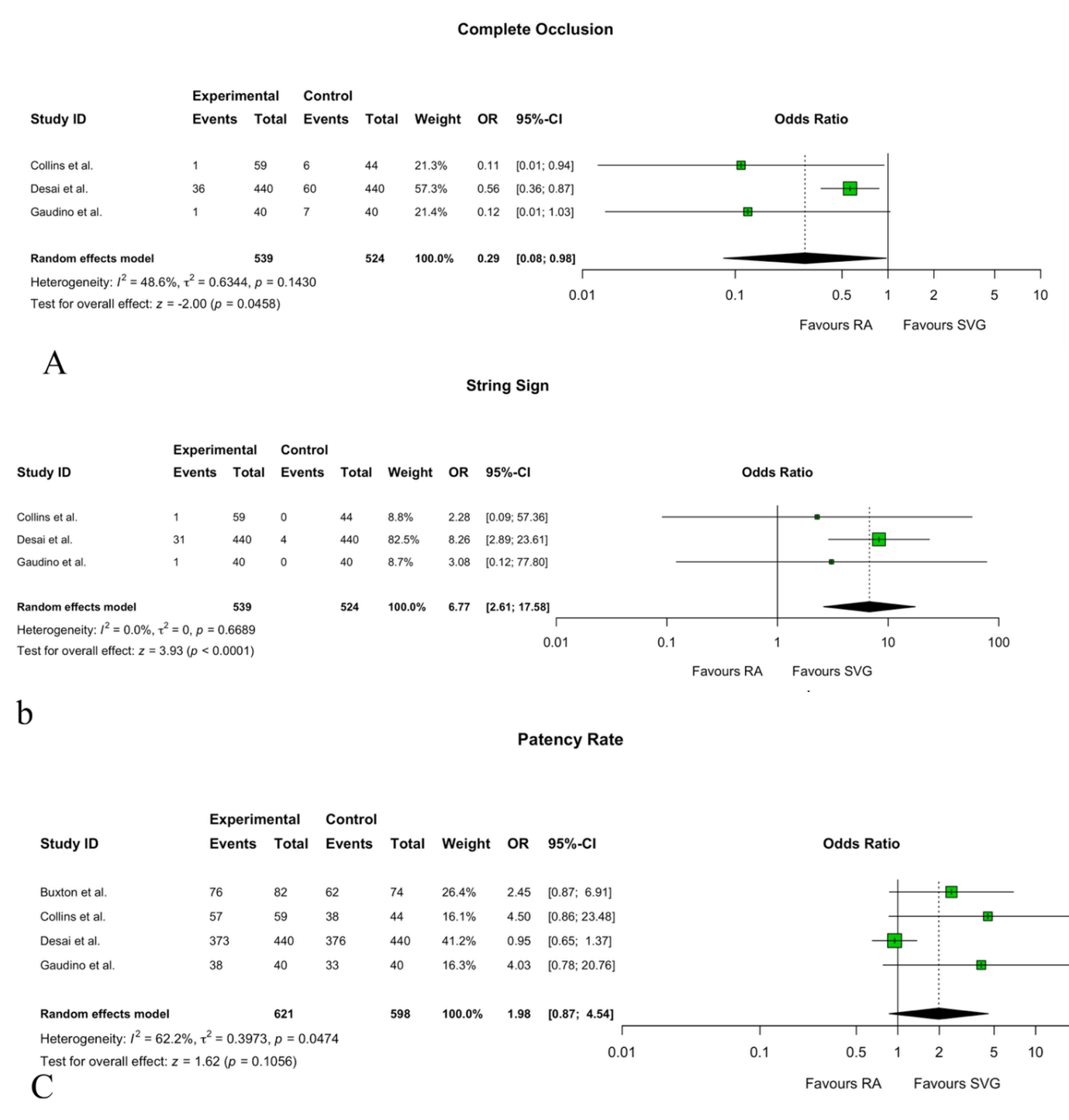


Figure 4

4a: Forest Plot for Secondary Outcome Complete Occlusion

4b: Forest Plot for Secondary Outcome String Sign

4c: Forest Plot for Secondary Outcome Patency Rate

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1BaselineCharacteristics.docx
- Supplementary.docx