Systematic Review

The outcomes of robotic-assisted coronary artery bypass grafting surgery in the Atlantic demographic—a systematic review and meta-analysis of the literature

Ashley R. Wilson-Smith[1,2], Christian J. Wilson-Smith[3], Jemilla Strode Smith[3], Rowen Osborn[3], Winky Lo[3], Dominic Ng[1], Bridget Hwang[1], Justin Shaw[1], Benjamin T. Muston[1], Michael L. Williams[4], Aditya Eranki[5], Aashray Gupta[6], Lucy Manuel[6], Malgorzata Szpytma[1], Luca Borruso[7], Advait Pandya[1], David Downes[1]

[1]Department of Cardiothoracic Surgery, The Royal Prince Alfred Hospital, Sydney, Australia; [2]The University of Sydney, Sydney, Australia; [3]The University of New South Wales, Sydney, Australia; [4]St. Vincent's Hospital, Sydney, Australia; [5]The Austin Hospital, Melbourne, Australia; [6]The Royal North Shore Hospital, Sydney, Australia; [7]Department of Vascular Surgery, The Royal Prince Alfred Hospital, Sydney, Australia

Correspondence to: Dr. Ashley R. Wilson-Smith, BMED, MD, M TRAUMA, G Dip Clin US, M SURGERY, PhD Candidate. The Collaborative Research Group (CORE), Sydney, Australia; The University of Sydney, Sydney, Australia; The Royal Prince Alfred Hospital, Sydney, Australia. Email: wilsonsmithash597@gmail.com.

Background: Coronary artery bypass grafting (CABG) has significantly reduced the morbidity and mortality of patients suffering from ischemic heart disease over its six decades of practice. In recent years, minimally invasive techniques have been increasingly described and utilized, with the promise of providing patients with the same standard of care without the need for the traditional full sternotomy, and in select cases without cardiopulmonary bypass, and thus providing improved recovery metrics. The present systematic review and meta-analysis sought to determine the outcomes of all patients receiving robotic-assisted CABG in an Atlantic patient demographic.

Methods: The methods for this systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement. Four databases were searched, using appropriate search terminology. Meta-analysis using proportions or means, as appropriate, were applied, and were presented as per routine practice. Kaplan-Meier curves were digitized and aggregated using previously reported, validated techniques. Quality assessment and risk of bias of each study were assessed systematically. Patient populations were subcategorized as per established technical definitions.

Results: Thirty-five studies were identified through the literature search, with three studies having subgroupings appropriate for separate analysis (yielding 42 data points maximally). A total of 9,078 patients (69% male), with a mean age of 62.3 years, were identified across the study period. On actuarial assessment, survival at yearly assessment from 1-, 2-, 3-, 4- and 5-yearly intervals was determined to be 95%, 94%, 92%, 90%, and 88%, respectively.

Conclusions: The present systematic review and meta-analysis demonstrated that short-term mortality, operative time, and admission [intensive care unit (ICU) and overall length of stay] outcomes were encouraging in the Atlantic demographic. Freedom from long-term mortality assessment of a smaller cohort showed encouraging results. A major caveat to the present analysis is the high degree of heterogeneity in the reporting of data. Analysis of future randomized controlled trials will be vital in establishing these procedures as commonplace.

Keywords: Robotic surgery; coronary grafting; meta-analysis

Submitted Jun 09, 2024. Accepted for publication Sep 10, 2024. Published online Sep 24, 2024.
doi: 10.21037/acs-2024-rcabg-15
View this article at: https://dx.doi.org/10.21037/acs-2024-rcabg-15

Introduction

Coronary artery bypass grafting (CABG) or coronary artery graft surgery (CAGS) has now saved the lives of innumerable patients with ischemic heart disease over its six decades of practice, and exists as one of the most heavily performed and researched operations in the modern era (1). Whilst CABG remains an excellent operation with proven long-term durability of revascularization, particularly with respect to the robustness of the left internal mammary artery (LIMA)-left anterior descending (LAD) graft, it remains an operation that, for the most part, imparts non-inconsequential short-term morbidity in the way of a sternotomy, with all of the associated downstream effects on recovery, quality of life, and delayed return to active society (2,3). Minimally invasive direct coronary artery bypass grafting (MIDCAB grafting—typically through an anterior thoracotomy) and totally endoscopic coronary artery bypass grafting (TECAB grafting—purely through thoracoscopic or robotic suite use) are increasingly being utilized, providing patients with equivalent revascularization outcomes in appropriate cases without the aforementioned deficits. As the patient population becomes increasingly older, frailer, and more medically comorbid, minimal access procedures like robotic coronary grafting are attractive for a number of stakeholders and may indeed form an essential tool in the future cardiothoracic surgeon's armamentarium (4). Whilst that being the case, such strategies are as of yet not widely adopted, and have proven difficult to reproduce generally. Detailed work on this topic has been published by our group intermittently since 2013, though no other research summarizes the up-to-date outcomes in a purely Atlantic (i.e., North America and European) cohort (5,6). This systematic review and meta-analysis sought to determine the outcomes of patients in the Atlantic demographic undergoing all forms of robotically assisted CABG.

Methods

Literature search strategy

The methods for this systematic review adhered to the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) updated statement (7). Four electronic databases were used to perform the literature searches, encompassing Embase, Ovid MEDLINE, PubMed, and Scopus. These databases were searched from the date of database inception through to February 2024. For the examination of the outcomes of robotic CABG in the Atlantic demographic, a search strategy using the combination of keywords and Medical Subject Headings (MeSH) including (coronary artery bypass grafting OR CABG OR CAGS OR CAG) AND (robotic OR robotic-assisted OR robotic assisted OR minimally invasive OR endoscopic) was utilized and is visually presented by the PRISMA flow diagram (see Figure S1). Predefined selection criteria were applied to assess for inclusion or exclusion (see "Inclusion and exclusion criteria"). Studies were individually assessed for location *post-hoc* and were included or excluded accordingly.

Each study was screened independently by three co-authors (A.R.W.S., C.J.W.S., J.S.S.), with any conflicts resolved prior to progression through mutual agreement. Where the title and/or abstract provided insufficient detail in the determination of relevance for additional screening, a full-text review of the record was carried out in the first instance. The reference lists of included studies were manually assessed to identify any missed papers from the literature search that were also eligible for assessment. In the instance of multiple studies produced by the same author with the same cohort, the most recent paper was included. In the instance where concern regarding duplication existed but was not clear in the manuscript, the authors were contacted to clarify if the cohorts were distinct.

Inclusion and exclusion criteria

Studies were included in the review if: (I) they examined the perioperative and postoperative outcomes of interest in patients undergoing robotic CABG through any means (e.g., MIDCAB, TECAB, open/mix, on- and off-pump) (see "Primary and secondary endpoints"). Series remained eligible for inclusion in the instance of 'hybrid'/mixed approaches, as in the case of a median sternotomy with robotic coronary artery harvesting. Studies were excluded for: (I) non-English reporting; (II) narrative reports; (III) studies without clear recruiting details; (IV) no mention of perioperative and postoperative patient outcomes; (V) redo coronary revascularization procedures in the emergent setting; (VI) no specification as to which cardiac procedure was performed; (VII) nil reporting of postoperative outcomes; (VIII) non-adult patients, or those with congenital disorders; (IX) less than 10 patients in their sample sizes.

Primary and secondary endpoints

The primary endpoints of analysis were operation time, hospital and intensive care unit (ICU) length of stay (hLOS/iLOS), and 30-day mortality. Secondary endpoints included baseline demographic data (i.e., age, sex, cross-clamp and cardiopulmonary bypass time if appropriate), post-operative atrial fibrillation (POAF), preoperative left ventricular ejection fraction (LVEF), long-term mortality (as represented through Kaplan-Meier graphs).

Data extraction, critical appraisal, and quality assessment

Two independent reviewers extracted data directly from publication texts, tables, and figures (J.S.S., W.L.). A third reviewer independently reviewed and confirmed all extracted data (A.R.W.S.). Differing opinions between the two main reviewers were resolved through discussion led by the primary investigator (A.R.W.S.). Attempts were made to clarify insufficient/indistinct data from authors of included studies, as required. Data was extracted in a way that each study was effectively treated as a case series, irrespective of underlying design. The Canadian Institute of Health Economics Quality Appraisal score was used as the quality assessment tool (8). Studies were defined as low quality with scores ≤11/18, moderate quality ≥12–14/18, and high quality ≥15/18.

Statistics

A meta-analysis of proportions or means were performed for categorical and continuous variables, as appropriate, by an independent reviewer. A random effects model was used in the first instance to account for differing regions, surgeon experience, surgical technique and equipment, and management protocols across the included studies; in subgroups with insufficient samples, a common effects model was utilized. Means and standard deviations (SDs) were calculated from the median, where reported, using the methods described by Wan and colleagues (9). Pooled data and SDs or standard error (SE) are presented as N (%) ± SD or SE with 95% confidence intervals (CIs). For outcome data, heterogeneity amongst studies was assessed using the I^2 statistic. Thresholds for these values were considered as low, moderate, and high heterogeneity as 0–49%, 50–75% and >75%, respectively. Meta-analysis of proportions or means were performed using Stata (version 17.0, StataCorp, Texas, USA). Risk of bias was assessed using the "Risk of Bias in Non-randomized Studies - of Interventions" (ROBINS-I) tool and has been visually presented (see Figure S2, risk of bias assessment) (10). Reporting of individual variables is also noted. Funnel plots were generated using R {R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. R Studio [RStudio Team (2020)] in the R Studio environment (RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA, USA)}, with Egger's tests were applied for assessment of small-study effects and publication bias. Cohorts underwent sub-group analysis based on their index operation, into the following cohorts: (I) all patients undergoing robotic CABG; (II) those undergoing off-pump coronary grafting; (III) those undergoing on-pump coronary grafting; (IV) those undergoing TECAB; (V) those undergoing MIDCAB; (VI) those undergoing open-access with robotic conduit harvesting; and (VII) mixed (i.e., mini-sternotomy with thoracoscopic harvesting). These subgroups were decided prior to statistical analysis. Forest plots of covariates are presented in Figure S3-S22.

Results

Baseline demographic, perioperative, and postoperative data of all-patient cohort

Total patient cohort

On application of the search terms, a total of 2,362 studies were identified. Following use of the inclusion and exclusion criteria, 35 studies were identified for inclusion, with detailed study characteristics provided in Tables S1-S4. Three papers reported clinical data with appropriate subgroup data splitting, so were considered as "separate" for the purposes of data analysis. Detailed demographic and post-operative outcomes for each cohort are reported in *Table 1*. A total of 9,078 patients were identified, of which 75% (95% CI: 72.3–77.3%) were male with a mean age of 62.3 years (95% CI: 60.8–63.9). A significant difference between on-pump and off-pump patients was demonstrated for age ($P<0.01$; $I^2=93.5\%$) and across the access types ($P=0.01$; $I^2=93.5\%$). The mean preoperative LVEF was 55% (95% CI: 52.4–57.7%). Thirty-one percent of the cohort was diabetic, 9% had a diagnosis of peripheral arterial disease of any severity, 11.5% had chronic obstructive pulmonary disease (COPD), and 80.9% had hypertension on medical therapy of any type and grade. Study variables

Table 1 Demographic characteristics and post-operative outcomes

Surgical cohort by procedure type	All-patient/total	Off-pump	On-pump	TECAB	MIDCAB	Open
Cohort (N)	9,078	7,684	328	5,847	3,087	88
Cohort age, years, N [95% CI]	62.3 [60.8–63.9]	64.9 [63.4–66.4]	59.4 [56.7–62.1]	61.6 [59.5–63.7]	63.9 [60.9–66.9]	63.9 [57.1–70.7]
Cohort male, % [95% CI]	74 [72–77]	71 [65–77]	83 [75–90]	73 [67–79]	74 [68–81]	83 [71–95]
Pre-op LV, % [95% CI]	55 [53–57]	53 [53–54]	56 [55–57]	55 [54–56]	55 [54–56]	54 [53–55]
Cohort comorbidities						
T2DM	3,218/8,422, 38%	3,032/7,544, 37%	43/296, 14.5%	1,866/5,223, 35.7%	1,329/3,087, 43%	9/56, 16%
PVD	718/7,140, 10%	647/5,778, 11%	6/296, 2%	512/5,247, 9.8%	204/1,837, 11%	2/56, 3.6%
COPD	605/5,488, 11%	520/4,777, 10.9%	30/211, 14%	528/4,890, 10.8%	70/542, 12.9%	7/56, 12.5%
HTN	5,704/6,842, 83%	5,078/6,046, 83.8%	220/296, 74%	4,189/5,131, 81.6%	1,442/1,599, 90%	41/56, 73%
Op time, N [95% CI]	288 [269–308]	276 [254–299]	327 [262–392]	291 [268–313]	308 [307–311]	NR
POAF, % [95% CI]	15 [13–17]	15 [13–17]	8 [5–14]	15 [13–17]	12 [6–23]	NR
hLOS day, N [95% CI]	4.5 [3.8–5.2]	3.8 [3.3–4.3]	7.3 [3.9–10.8]	4.3 [3.7–5]	4.1 [3.7–4.6]	6.6 [5.7–7.5]
iLOS day, N [95% CI]	1.4 [1.3–1.6]	1.5 [1.3–1.7]	1.4 [1.2–1.5]	1.4 [1.3–1.5]	1.6 [1.4–1.7]	1.4 [0.6–2.2]
30-d morality [%]	1 [0.8–1.4]	0.6 [0.4–0.8]	0 [0–1.1]	0.7 [0.5–1]	0.4 [0.2–0.7]	0 [0–2]

Comorbidities presented as aggregate mean (overall sampled cohort) + percentage of cohort. TECAB, totally endoscopic coronary artery bypass; MIDCAB, minimally invasive direct coronary artery bypass; N, number; CI, confidence interval; Pre-op, preoperative; LV, left ventricular; T2DM, type 2 diabetes; PVD, peripheral vascular disease; COPD, chronic obstructive pulmonary disease; HTN, hypertension; Op, operative; POAF, post-operative atrial fibrillation; hLOS, hospital length of stay; iLOS, intensive care unit length of stay; 30-d, thirty-day.

reported too infrequently for analysis included: number of cases proceeding to reoperation/reintervention, number of cases receiving repeated revascularization (of any time course), freedom from angina, freedom from major adverse cardiac events (MACEs), flow rates (i.e., via coronary ultrasound)/pulse index, body mass index and body mass index >30 kg/m^2, previous arrhythmia history (of any diagnosis), LVEF <40%, previous cardiac surgery (any operation), concomitant procedures. Eighty percent of included studies were single-institutional studies. Of these studies, 50% were retrospective cohort studies.

Sub-grouped cohorts—off-pump, on-pump, TECAB, and MIDCAB

In the off-pump, on-pump, TECAB, and MIDCAB cohorts, 7,684, 328, 5,847, and 3,087 patients were identified. The majority of reported studies (27/35) were from North American centers. The preoperative LVEFs across these cohorts were 52% (95% CI: 48.6–55.3%), 60.2% (95% CI: 57–63.4%), 55.4 (95% CI: 51.6–59%) and 53.9% (95% CI: 52–55.7%), respectively. A significant difference was identified was identified between the off-pump and on-pump groups with respect to preoperative LVEF, though this difference was marginal and unlikely to be clinically relevant ($P \leq 0.01$; $I^2=98\%$). Type 2 diabetes mellitus across the examined cohorts represented approximately 36%, 15%, 28%, and 41% of patients, respectively. Peripheral arterial disease of any severity was demonstrated in 12%, 3%, 9%, and 12% of patients in the off-pump, on-pump, TECAB, and MIDCAB cohorts, respectively. COPD of any degree of clinical severity was demonstrated in 11%, 15%, 11%, and 13% of patients in the off-pump, on-pump, TECAB, and MIDCAB cohorts, respectively. Hypertension was demonstrated in 81%, 79%, 80% and 89% of the

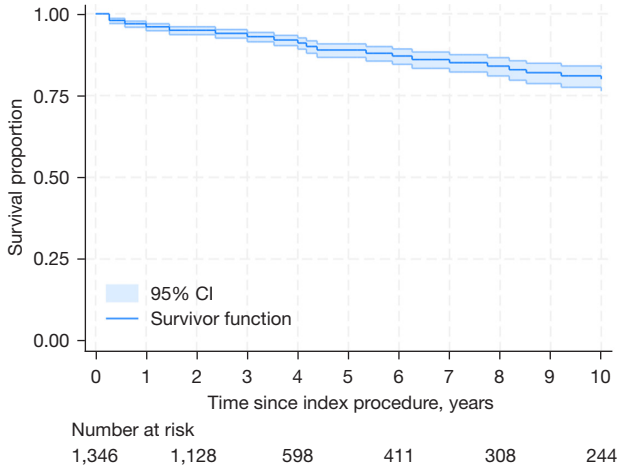

Figure 1 Kaplan-Meier survival assessment—robotic coronary artery bypass grafting. CI, confidence interval.

patient cohorts examined. Mean operative times were found to be 276 minutes (95% CI: 254–299), 327 minutes (95% CI: 262–392), 291 minutes (95% CI: 268–313), and 308 minutes (95% CI: 307–311), respectively. No significant difference was found between pump groups with respect to operation times (P=0.62; I^2=98%).

Postoperative rates of atrial fibrillation were 15.2% (95% CI: 13.1–17.5%), 8.1% (95% CI: 4.7–13.5%), 15% (95% CI: 13.3–16.9%), and 11.7% (95% CI: 5.7–22.8%), respectively. No significant difference between off-pump and on-pump cohorts was identified (P=0.06; I^2=69.4%), or access groups (P=0.54; I^2=69.4%). Mean hLOS was 3.8 days (95% CI: 3.3–4.3), 7.3 days (95% CI: 3.9–10.7), 4.3 days (95% CI: 3.7–5), and 4.1 days (95% CI: 3.7–4.6), respectively. A significant difference was found between off-pump and on-pump cohorts with respect to hLOS (P<0.01; I^2=99%). A significant difference was identified between access approaches (P≤0.01; I^2=99%). Mean iLOS across the cohorts was demonstrated to be 1.5 days (95% CI: 1.3–1.6), 1.4 days (95% CI: 1.2–1.5), 1.4 days (95% CI: 1.3–1.5), and 1.6 days (95% CI: 1.4–1.7), respectively. No significant difference between pump cohorts was identified (P=0.12; I^2=86%). A difference between access approaches was identified (P≤0.01; I^2=86%). Thirty-day mortality rates across the cohorts was found to be 0.6% (95% CI: 0.4–0.8%), 0% (95% CI: 0–1%), 0.7% (95% CI: 0.5–1%), and 0.4% (95% CI: 0.2–0.7%), respectively. No difference across pump cohorts or access approaches (P=0.5; I^2=0%) was identified.

Egger's test of small-study effects and publication bias

On assessment of small-study effects and publication bias for 30-day mortality, Egger's test (t=–0.59; P=0.56; bias estimate =–0.18; SE =0.30) indicated no significant plot asymmetry. Similarly, the meta-analysis of operative time (t=–1.57; P=0.13; bias estimate =–3.58; SE =2.29), was not significant for plot asymmetry, and indicated no strong evidence of publication bias. For the meta-analysis of length of stay (LOS), Egger's test (t=–0.31; P=0.76; bias estimate =–0.85; SE =2.77) no significant plot asymmetry was demonstrated, and no subsequent evidence of publication bias. The meta-analysis of ICU stay did not reveal a significant result, indicating no evidence of publication bias (t=2.04; P=0.052; bias estimate =1.37; SE =0.67).

Quality and risk of bias assessment

Four studies were deemed to be low quality (11-14). Twenty-three studies were deemed to be of moderate quality (15-37). Eight studies were deemed to be of high quality (38-45). Inter-rater reliability between authors assessing study quality was high, with concordance of rating of 95%. Twenty-one studies were deemed to be of low risk of bias, with the remaining fourteen studies deemed as moderate (11,12,14,17,18,20,27,28,31,34,35,37,45,46) (see Figure S2).

Kaplan-Meier assessment of robotic CABG freedom from mortality

All-patient freedom from mortality as derived from aggregated Kaplan-Meier curves from reporting studies (16,17,21,27,28,30,33,36,39,47) is illustrated by *Figure 1*.

Kaplan-Meier survival assessment—robotic CABG

Actuarial survival at yearly assessment from 12- to 60-month intervals was determined to be 95%, 94%, 92%, 90%, and 88%, respectively.

Discussion

CABG has significantly reduced the morbidity and mortality of patients suffering from ischemic heart disease and appears to have a secure future with an ever-increasingly comorbid, frailer patient population. Ongoing refinements

in mini-access techniques and technologies has led to safe, effective revascularization options in the MIDCAB and TECAB strategies, without the need for a full sternotomy. Indeed, however, in amongst a discussion of the utility of any mini-access therapy should be the acknowledgment that the primary aim is to achieve robust revascularization, long-term freedom from secondary major cardiac adverse events, to enhance quality of life, and to return patients to a high level of pre-morbid functionality. So, if required, a full sternotomy with a traditional approach—if that is what is clinically mandated—should be undertaken accepting the short- to intermediate-term morbidity. The present systematic review and meta-analysis demonstrates in the appropriately selected patient, they can indeed benefit from lower morality, shorter operations, and reduced admission periods with robotically assisted coronary grafting.

In recent decades, beating-heart, off-pump, and minimally invasive access surgery have become increasingly considered in the tailored, individualized management of patients in order to spare them from any unnecessary trauma/physiologic disturbance of cardiopulmonary bypass and open-heart surgery. Some of these techniques, such as off-pump surgery, have seen tempered utilization, and minimally invasive surgery has largely been constrained by the ability of the operator to graft lateral and inferior lesions, and thus only indicated in select pathologies such as single to double vessel disease (48,49). That being said, bilateral mammary harvesting is quite feasible for proximal lateral and inferior lesions, as is previously reported (18). Indeed, Cerny *et al.* in their European status report illustrate exceptionally low rates of conversion, low rates of major complications, and that the majority of procedures are performed beating-heart (50). The majority of the included studies in the present systematic review performed totally endoscopic, off-pump surgery, with an average of 1.1 grafts for the all-patient cohort. Robotic coronary grafting clearly has a number of benefits for these patients; easier harvest for the operator with improved dexterity and vessel visibility—and thereby lower risk of inadvertent conduit trauma and minimized handling—faster recovery times in ICU and in hospital overall, and in the instance of purely endoscopic robotic therapy, less pain and subsequent analgesic uptake compared to a traditional, full sternotomy. Especially in cases where only 1–2 vessels require grafting, the avoidance of a full sternotomy is a major benefit.

The results of the present meta-analysis demonstrate a mean length of hospital stay of 4.5 and 4.3 days, in the all-patient and TECAB cohorts, respectively. These results are even more favorable than previously reported meta-analytical data for TECAB cohorts, where data had demonstrated superior results when compared to conventional CABG in a meta-analysis by Cao *et al.* (6,17,37,51). While presumably mediated by surgeon skill in high-volume centers, recent reports have also demonstrated that carefully selected, robotic-coronary bypass patients can be discharged the day following operation with no significant risk of readmission, though far more data are needed to solidify this metric (28). While the widespread adoption of robotic coronary surgery is limited outside of major centers of excellence—as denoted by the overwhelming majority of studies coming from the same, expected institutions—TECAB may actually be cost-effective across the long term and in institutions where there are protocols designed to rapidly recover patients post-operatively (29). Additional cost-effectiveness analyses are currently underway in this respect, the results of which will be critical in guiding practice as the obvious drawback in the initial establishment of robotic programs is the cost of the suites, the proctoring/subspeciality training required, and the ongoing upkeep in the way of maintenance.

Limitations

There are a number of limitations of the present meta-analysis. Firstly, the majority of studies incorporated were of a non-randomized, observational nature. As these procedures are increasingly utilized, both in the North American/European demographics and worldwide, adequately powered, randomized controlled trials are required for confirming the utility of this approach compared to conventional coronary artery bypass surgery. Additionally, desired pre-, peri-, and postoperative variables were not wholistically reported. Mortality assessment was constrained by all-cause assessment, as opposed to cardiac-specific mortality events. Key reporting variables, such as number of grafts performed, were poorly reported overall, and typically reported without variance or SD, or in a non-numeric format. This hampered the ability to perform meta-analysis stratified by number of targeted vessels, despite this being a fundamental and presumably commonsense datapoint of consideration. Furthermore, rates of conversion to open CAGS were also not universally reported, with many studies excluding these patients from analysis. This introduces an inherent risk of both selection and reporting bias, as many of these studies were retrospective in nature. Despite the risk of bias assessment

in this study illustrating an overall low risk of bias, having access to conversion rate data would be beneficial for future studies. Assessment of post-operative pain and subsequent analgesic uptake was not possible quantitatively, as these metrics are very poorly reported on, if at all—despite this being a key selling factor.

Conclusions

The present systematic review and meta-analysis demonstrated through all-patient and subgroup analysis that short-term mortality, operative time, and admission (ICU and overall length of stay) outcomes were encouraging in the Atlantic demographic. Freedom from long-term mortality Kaplan-Meier assessment of a smaller cohort showed similarly encouraging results. Analysis of future randomized controlled trials will be vital in establishing these procedures as commonplace in the future of cardiothoracic surgery.

Acknowledgments

Funding: This research is supported by an Australian Government Research Training Program (RTP) scholarship (A.R.W.S.).

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Melly L, Torregrossa G, Lee T, et al. Fifty years of coronary artery bypass grafting. J Thorac Dis 2018;10:1960-7.
2. Kirov H, Caldonazo T, Riedel LL, et al. Comparing outcomes between coronary artery bypass grafting and percutaneous coronary intervention in octogenarians with left main or multivessel disease. Sci Rep 2023;13:22323.
3. Cao C, Manganas C, Bannon P, et al. Drug-eluting stents versus coronary artery bypass graft surgery in left main coronary artery disease: a meta-analysis of early outcomes from randomized and nonrandomized studies. J Thorac Cardiovasc Surg 2013;145:738-47.
4. Al-Mulla AW, Sarhan HHT, Abdalghafoor T, et al. Robotic Coronary Revascularization is Feasible and Safe: 10-year Single-Center Experience. Heart Views 2022;23:195-200.
5. Seco M, Edelman JJ, Yan TD, et al. Systematic review of robotic-assisted, totally endo-scopic coronary artery bypass grafting. Ann Cardiothorac Surg 2013;2:408-18.
6. Cao C, Indraratna P, Doyle M, et al. A systematic review on robotic coronary artery bypass graft surgery. Ann Cardiothorac Surg 2016;5:530-43.
7. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
8. Institute of Health Economics. Quality Appraisal of Case Series Study Tool. Institute of Health Economics, Edmonton; 2016.
9. Wan X, Wang W, Liu J, et al. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 2014;14:135.
10. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919.
11. Balkhy HH, Nathan S, Arnsdorf SE, et al. Right Internal Mammary Artery Use in 140 Robotic Totally Endoscopic Coronary Bypass Cases: Toward Multiarterial Grafting. Innova-tions (Phila) 2017;12:9-14.
12. Bonaros N, Schachner T, Lehr E, et al. Five hundred cases of robotic totally endoscopic coronary artery bypass grafting: predictors of success and safety. Ann Thorac Surg 2013;95:803-12.
13. Casula R, Khoshbin E, Athanasiou T. The midterm outcome and MACE of robotically enhanced grafting of left anterior descending artery with left internal mammary artery. J Cardiothorac Surg 2014;9:19.
14. Currie ME, Romsa J, Fox SA, et al. Long-term angiographic follow-up of robot-ic-assisted coronary artery revascularization. Ann Thorac Surg 2012;93:1426-31.
15. Balkhy HH, Kitahara H, Mitzman B, et al. Robotic totally endoscopic beating-heart bypass to the right coronary artery: first worldwide experience. Eur J Cardiothorac

Surg 2020;57:529-34.
16. Balkhy HH, Nisivaco S, Kitahara H, et al. Robotic Beating Heart Totally Endoscopic Coronary Artery Bypass in Higher-Risk Patients: Can It be Done Safely? Innovations (Phila) 2018;13:108-13.
17. Balkhy HH, Nisivaco S, Kitahara H, et al. Robotic off-pump totally endoscopic coronary artery bypass in the current era: report of 544 patients. Eur J Cardiothorac Surg 2022;61:439-46.
18. Balkhy HH, Wann LS, Krienbring D, et al. Integrating coronary anastomotic connectors and robotics toward a totally endoscopic beating heart approach: review of 120 cases. Ann Thorac Surg 2011;92:821-7.
19. Bolton JW, Connally JE. Results of a Phase One study on robotically assisted myocardial revascularization on the beating heart. Ann Thorac Surg 2004;78:154-8; discussion 154-8.
20. Bonaros N, Schachner T, Wiedemann D, et al. Quality of life improvement after robot-ically assisted coronary artery bypass grafting. Cardiology 2009;114:59-66.
21. Bonatti J, Schachner T, Bonaros N, et al. Effectiveness and safety of total endoscopic left internal mammary artery bypass graft to the left anterior descending artery. Am J Cardiol 2009;104:1684-8.
22. Damiano RJ Jr, Ducko CT, Stephenson ER Jr, et al. Robotically assisted coronary artery bypass grafting: a prospective single center clinical trial. J Card Surg 2000;15:256-65.
23. Folliguet TA, Dibie A, Philippe F, et al. Robotically-assisted coronary artery bypass grafting. Cardiol Res Pract 2010;2010:175450.
24. Kitahara H, McCrorey M, Patel B, et al. Does Robotic Beating Heart Connector Totally Endoscopic Coronary Artery Bypass Bridge the Gender Gap in Coronary Bypass Surgery? Innovations (Phila) 2018;13:35-9.
25. Kitahara H, McCrorey M, Patel B, et al. Benefit of Robotic Beating-Heart Totally Endo-scopic Coronary Artery Bypass in Octogenarians. Innovations (Phila) 2019;14:531-6.
26. Kitahara H, Patel B, McCrorey M, et al. Is robotic beating heart totally endoscopic coronary artery bypass feasible for BMI > 35 morbidly obese patients? Int J Med Robot 2018;14:e1911.
27. Nisivaco S, Kitahara H, Abutaleb A, et al. Robotic Totally Endoscopic Coronary Bypass to the Left Anterior Descending Artery: Left Versus Right Internal Thoracic Artery Grafts. J Surg Res 2023;291:139-50.
28. Nisivaco S, Patel B, Coleman C, et al. Postoperative Day 1 Discharge After Robotic To-tally Endoscopic Coronary Bypass: The Ultimate in Enhanced Recovery After Surgery. In-novations (Phila) 2023;18:159-66.
29. Pasrija C, Kon ZN, Ghoreishi M, et al. Cost and Outcome of Minimally Invasive Tech-niques for Coronary Surgery Using Robotic Technology. Innovations (Phila) 2018;13:282-6.
30. Patel NC, Hemli JM, Seetharam K, et al. Minimally invasive coronary bypass versus percutaneous coronary intervention for isolated complex stenosis of the left anterior de-scending coronary artery. J Thorac Cardiovasc Surg 2022;163:1839-1846.e1.
31. Peev MP, Nisivaco S, Torregrossa G, et al. Robotic Off-Pump Totally Endoscopic Cor-onary Artery Bypass in Patients With Low Ejection Fraction. Innovations (Phila) 2022;17:50-5.
32. Raad WN, Forest S, Follis M, et al. The Impact of Robotic Versus Conventional Coronary Artery Bypass Grafting on In-Hospital Narcotic Use: A Propensity-Matched Analysis. In-novations (Phila) 2016;11:112-5.
33. Srivastava S, Barrera R, Quismundo S. One hundred sixty-four consecutive beating heart totally endoscopic coronary artery bypass cases without intraoperative conversion. Ann Thorac Surg 2012;94:1463-8.
34. Srivastava S, Gadasalli S, Agusala M, et al. Robotically Assisted Beating Heart Totally Endoscopic Coronary Artery Bypass (TECAB). Is There a Future? Innovations (Phila) 2008;3:52-8.
35. Srivastava S, Gadasalli S, Agusala M, et al. Use of bilateral internal thoracic arteries in CABG through lateral thoracotomy with robotic assistance in 150 patients. Ann Thorac Surg 2006;81:800-6; discussion 806.
36. Torregrossa G, Sá MP, Van den Eynde J, et al. Robotic-assisted versus conventional off-pump coronary surgery in women: A propensity-matched study. J Card Surg 2022;37:3525-35.
37. Zaouter C, Imbault J, Labrousse L, et al. Association of Robotic Totally Endoscopic Coronary Artery Bypass Graft Surgery Associated With a Preliminary Cardiac Enhanced Recovery After Surgery Program: A Retrospective Analysis. J Cardiothorac Vasc Anesth 2015;29:1489-97.
38. Argenziano M, Katz M, Bonatti J, et al. Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. Ann Thorac Surg 2006;81:1666-74; discussion 1674-5.
39. Bonatti J, Lehr EJ, Schachner T, et al. Robotic total endoscopic double-vessel coronary artery bypass grafting--state of procedure development. J Thorac Cardiovasc Surg

2012;144:1061-6.
40. Dhawan R, Roberts JD, Wroblewski K, et al. Multivessel beating heart robotic myocardial revascularization increases morbidity and mortality. J Thorac Cardiovasc Surg 2012;143:1056-61.
41. Halkos ME, Liberman HA, Devireddy C, et al. Early clinical and angiographic outcomes after robotic-assisted coronary artery bypass surgery. J Thorac Cardiovasc Surg 2014;147:179-85.
42. Jonsson A, Binongo J, Patel P, et al. Mastering the Learning Curve for Robotic-Assisted Coronary Artery Bypass Surgery. Ann Thorac Surg 2023;115:1118-25.
43. Leyvi G, Forest SJ, Srinivas VS, et al. Robotic coronary artery bypass grafting decreases 30-day complication rate, length of stay, and acute care facility discharge rate compared with conventional surgery. Innovations (Phila) 2014;9:361-7; discussion 367.
44. Spanjersberg A, Hoek L, Ottervanger JP, et al. Early home discharge after robot-assisted coronary artery bypass grafting. Interact Cardiovasc Thorac Surg 2022;35:ivac134.
45. Varrone M, Sarmiento IC, Pirelli L, et al. Minimally Invasive Direct Coronary Artery By-pass: An Evolving Paradigm Over the Past 25 Years. Innovations (Phila) 2022;17:521-7.
46. Damiano RJ Jr, Tabaie HA, Mack MJ, et al. Initial prospective multicenter clinical trial of robotically-assisted coronary artery bypass grafting. Ann Thorac Surg 2001;72:1263-8; discussion 1268-9.
47. de Cannière D, Wimmer-Greinecker G, Cichon R, et al. Feasibility, safety, and efficacy of totally endoscopic coronary artery bypass grafting: multicenter European experience. J Thorac Cardiovasc Surg 2007;134:710-6.
48. Bakaeen FG, Shroyer AL, Gammie JS, et al. Trends in use of off-pump coronary artery bypass grafting: Results from the Society of Thoracic Surgeons Adult Cardiac Surgery Da-tabase. J Thorac Cardiovasc Surg 2014;148:856-3, 864.e1; discussion 863-4.
49. Bonatti J, Wallner S, Crailsheim I, et al. Minimally invasive and robotic coronary artery bypass grafting-a 25-year review. J Thorac Dis 2021;13:1922-44.
50. Cerny S, Oosterlinck W, Onan B, et al. Robotic Cardiac Surgery in Europe: Status 2020. Front Cardiovasc Med 2021;8:827515.
51. Göbölös L, Ramahi J, Obeso A, et al. Robotic Totally Endoscopic Coronary Artery Bypass Grafting: Systematic Review of Clinical Outcomes from the Past two Decades. Innovations (Phila) 2019;14:5-16.

Cite this article as: Wilson-Smith AR, Wilson-Smith CJ, Smith JS, Osborn R, Lo W, Ng D, Hwang B, Shaw J, Muston BT, Williams ML, Eranki A, Gupta A, Manuel L, Szpytma M, Borruso L, Pandya A, Downes D. The outcomes of robotic-assisted coronary artery bypass grafting surgery in the Atlantic demographic—a systematic review and meta-analysis of the literature. Ann Cardiothorac Surg 2024;13(5):388-396. doi: 10.21037/acs-2024-rcabg-15

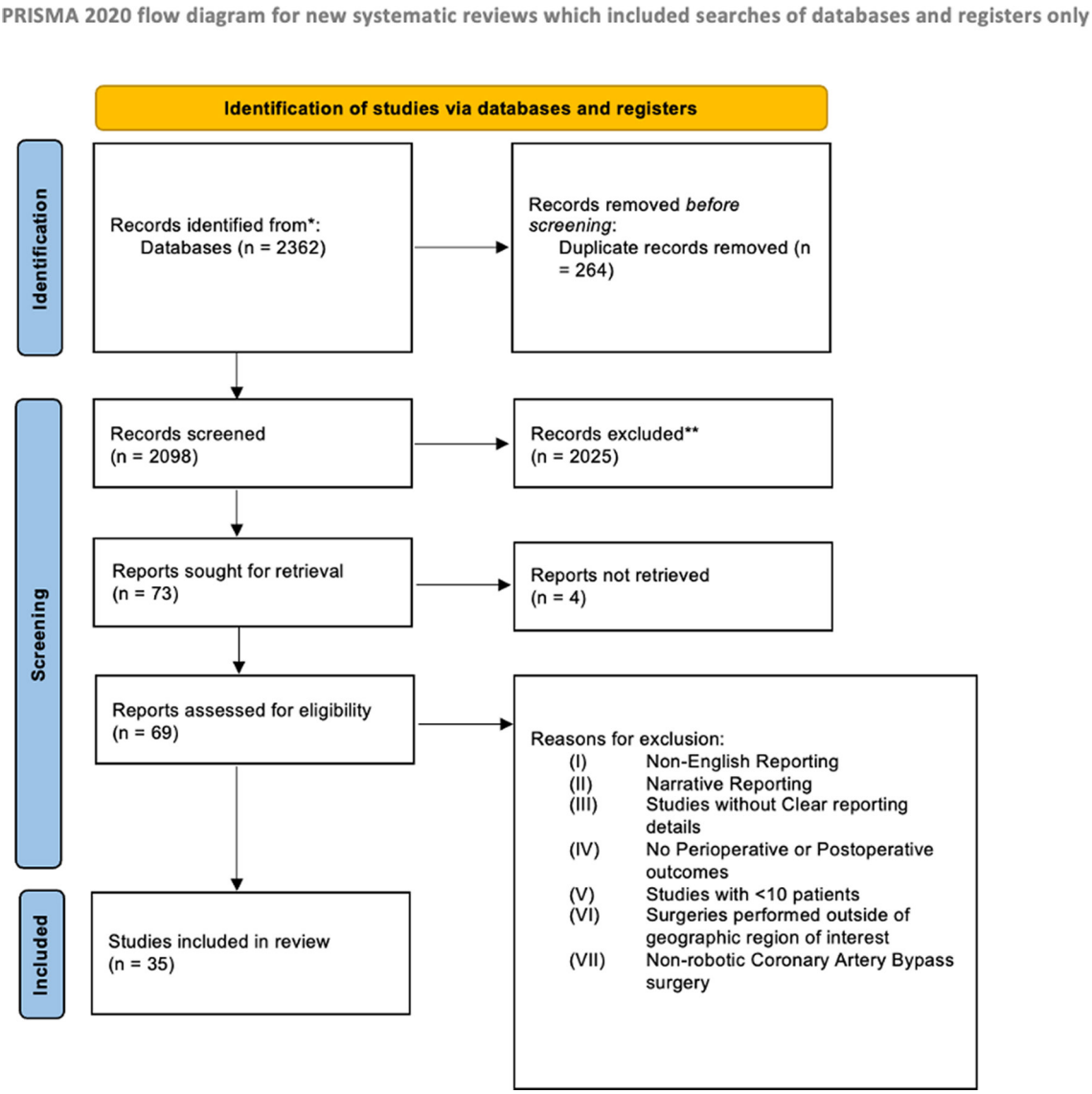

Figure S1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMSA) flowchart.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

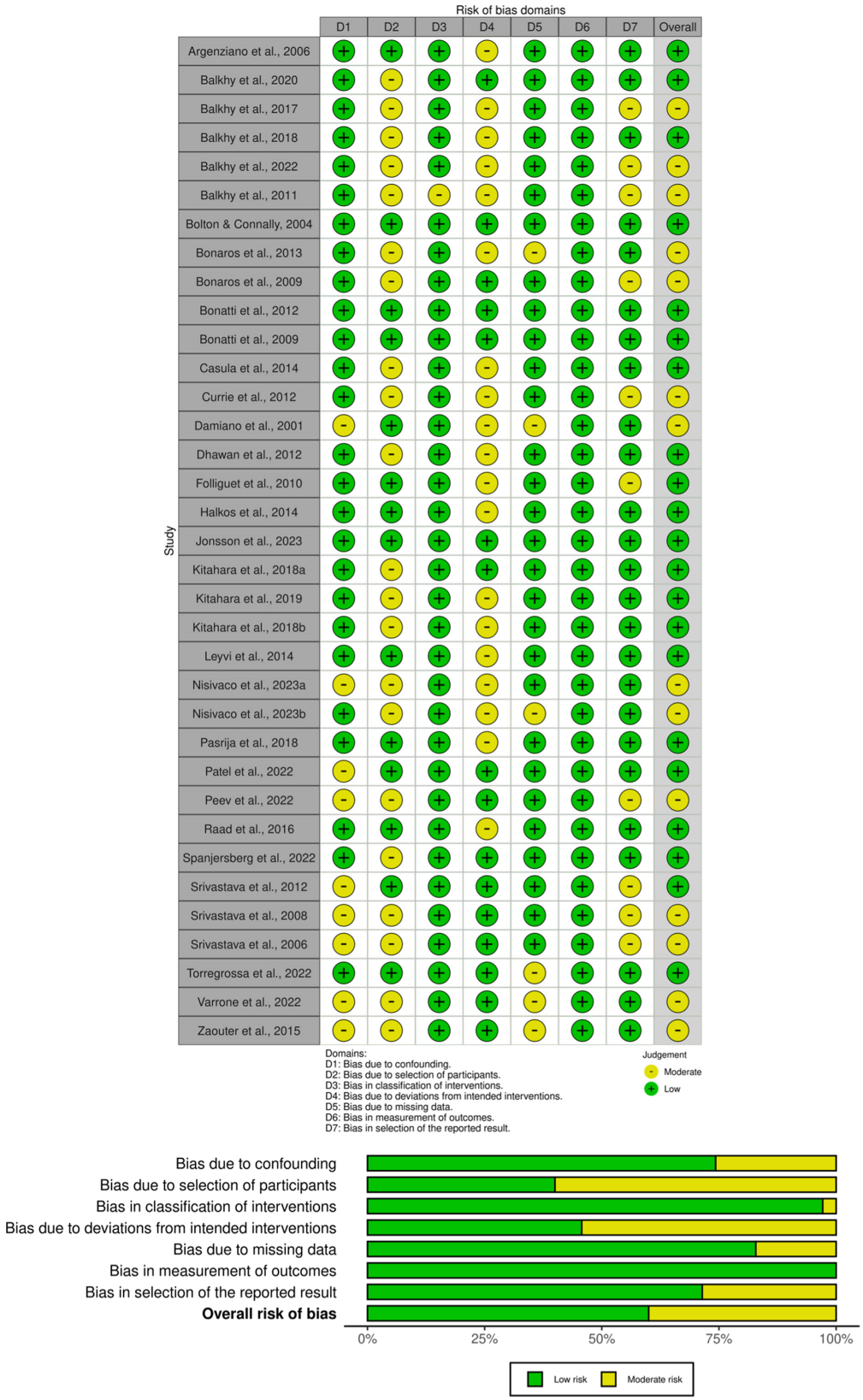

Figure S2 Risk of bias assessment (ROBINS-I Tool).

https://dx.doi.org/10.21037/acs-2024-rcabg-15

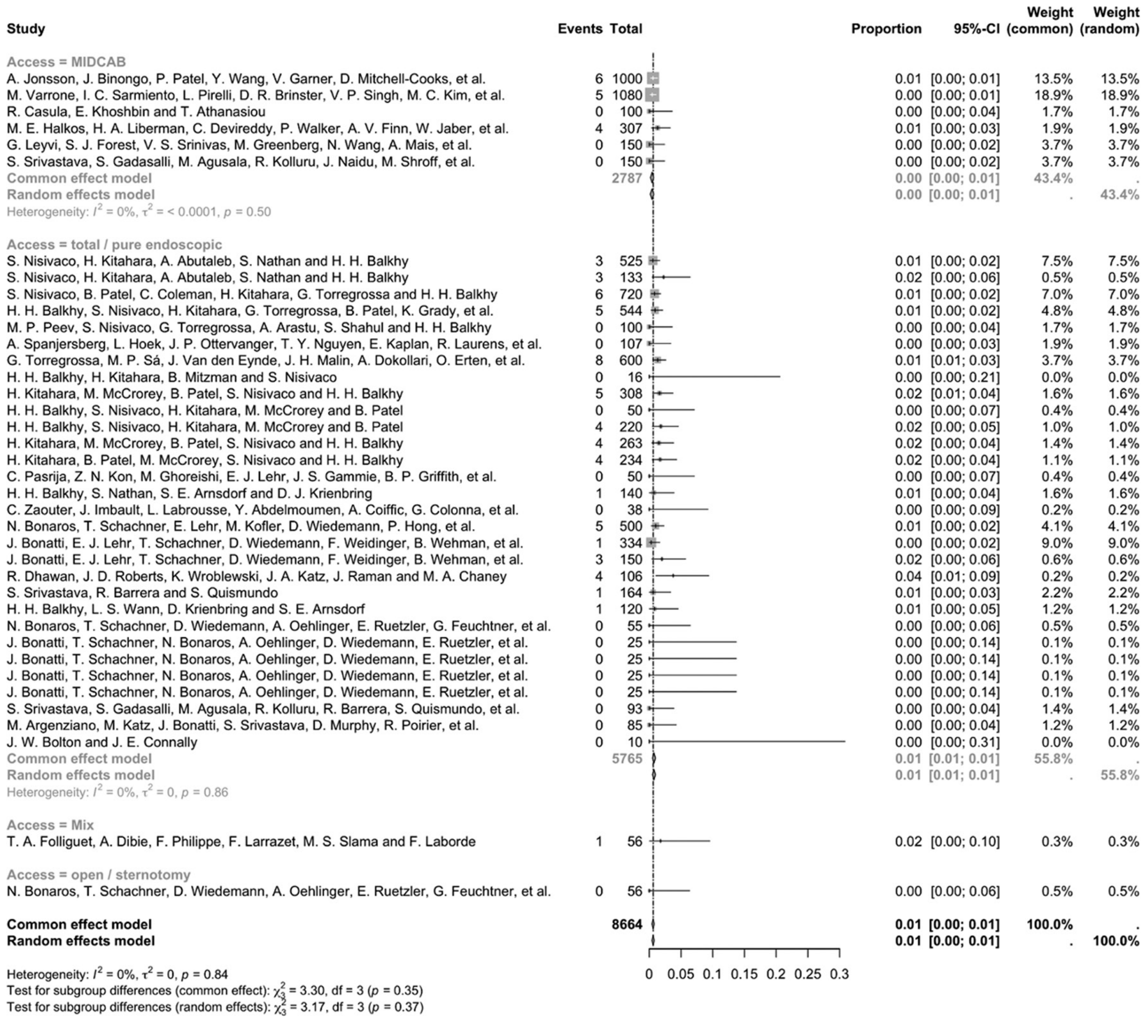

Figure S3 Forest plot for 30-day mortality via access approach.

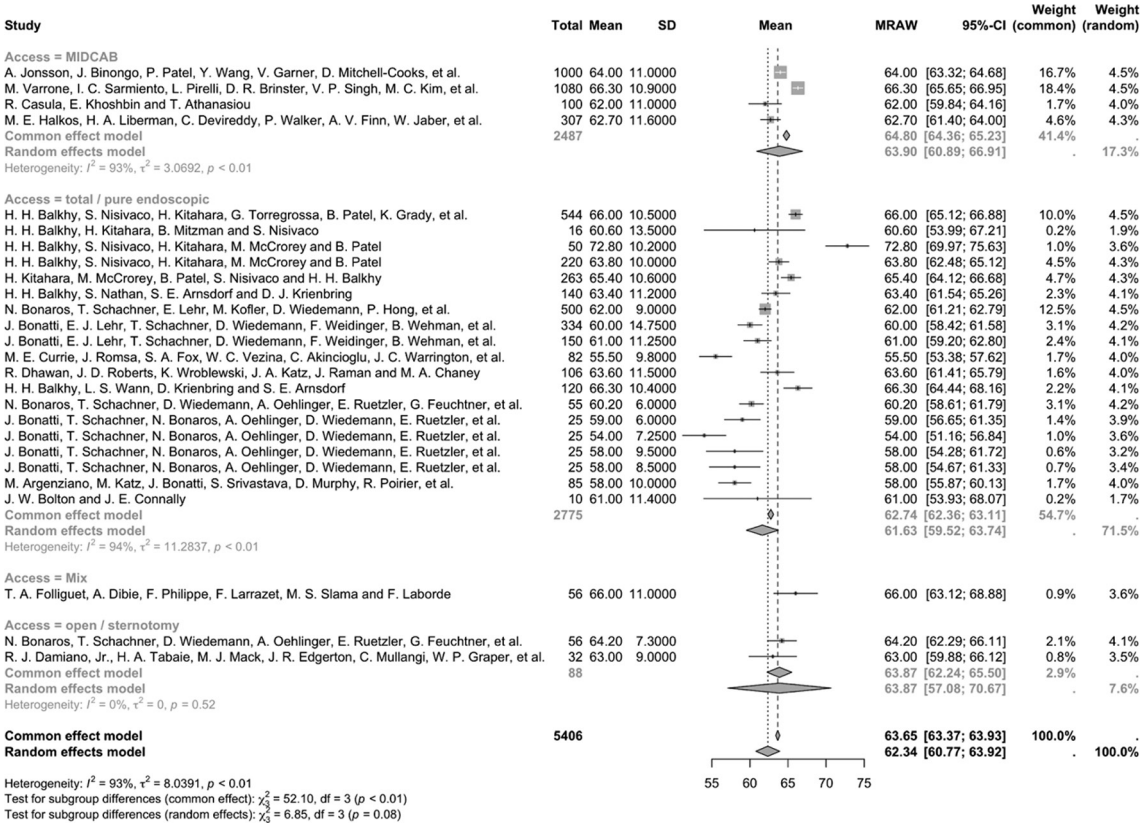

Figure S4 Forest plot for age stratified data via access approach.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

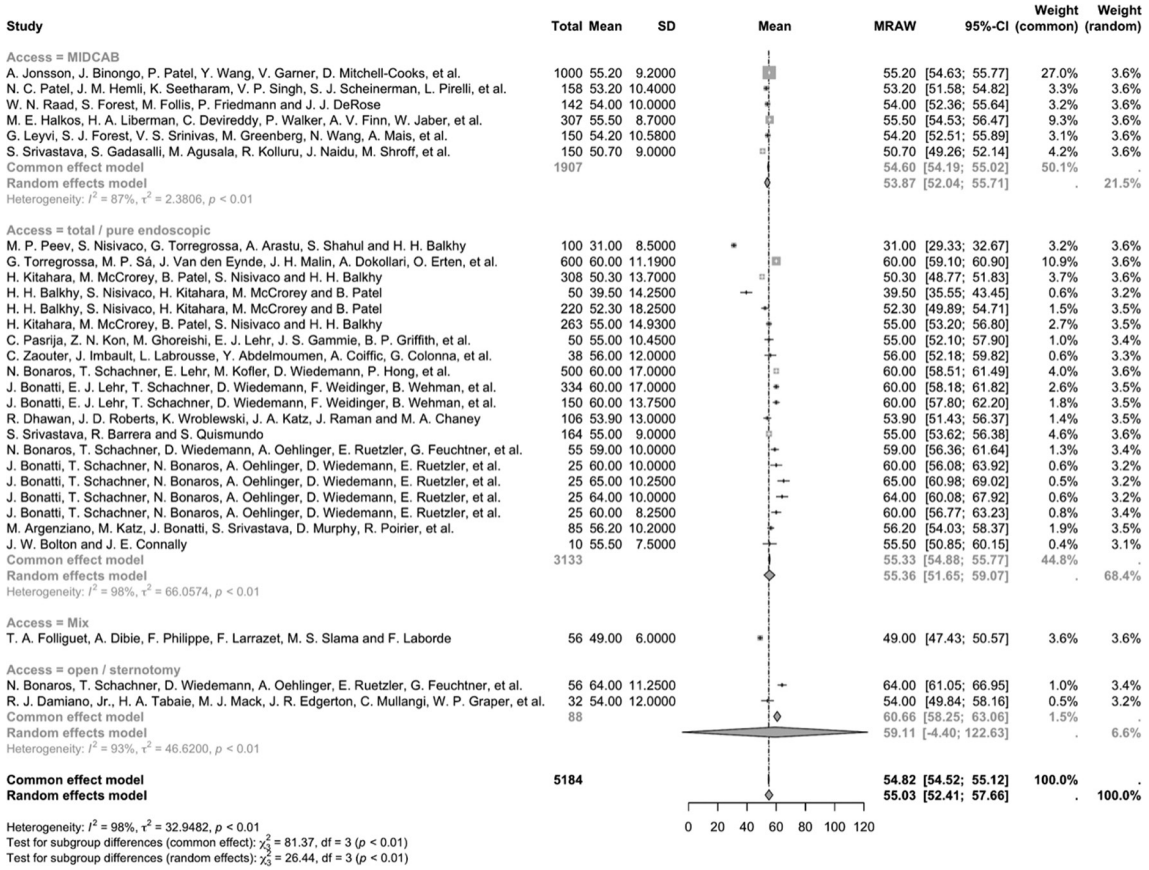

Figure S5 Forest plot for access approach stratified for preoperative ejection fraction.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

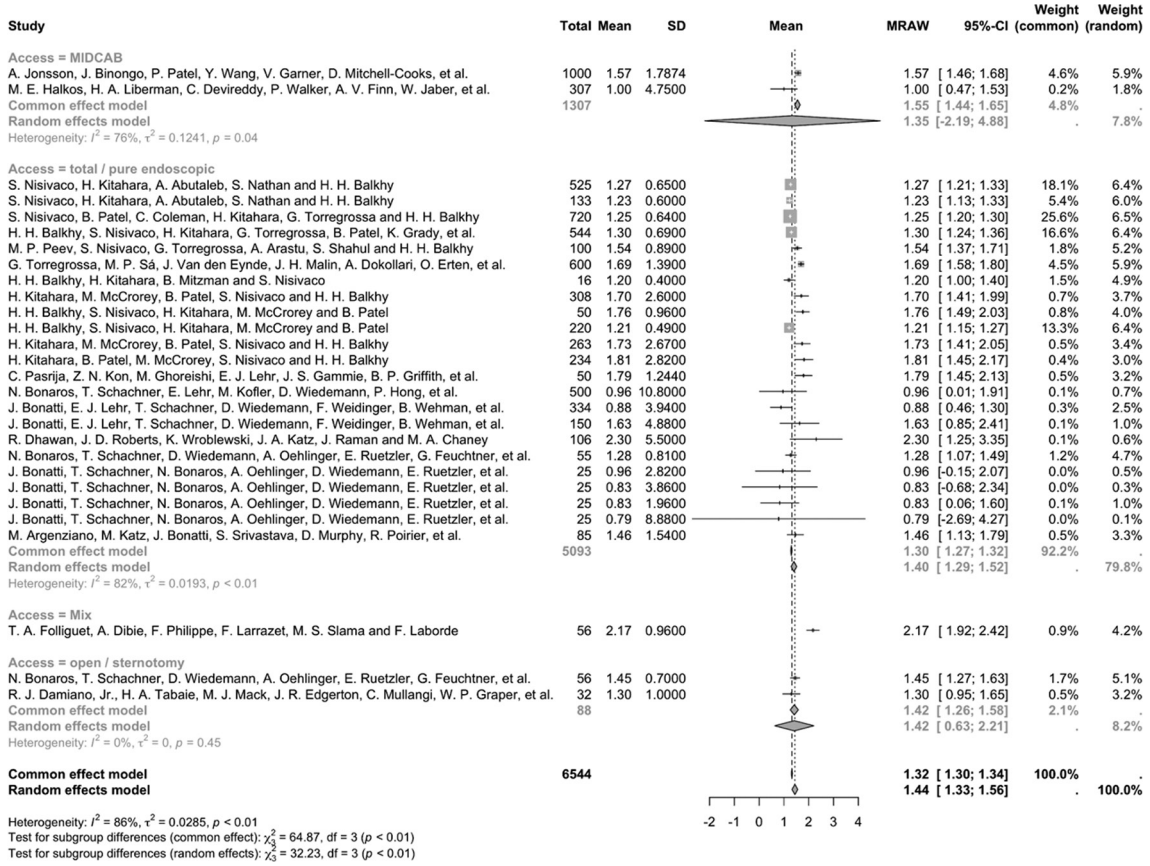

Figure S6 Forest plot for access approach stratified for ICU length of stay.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

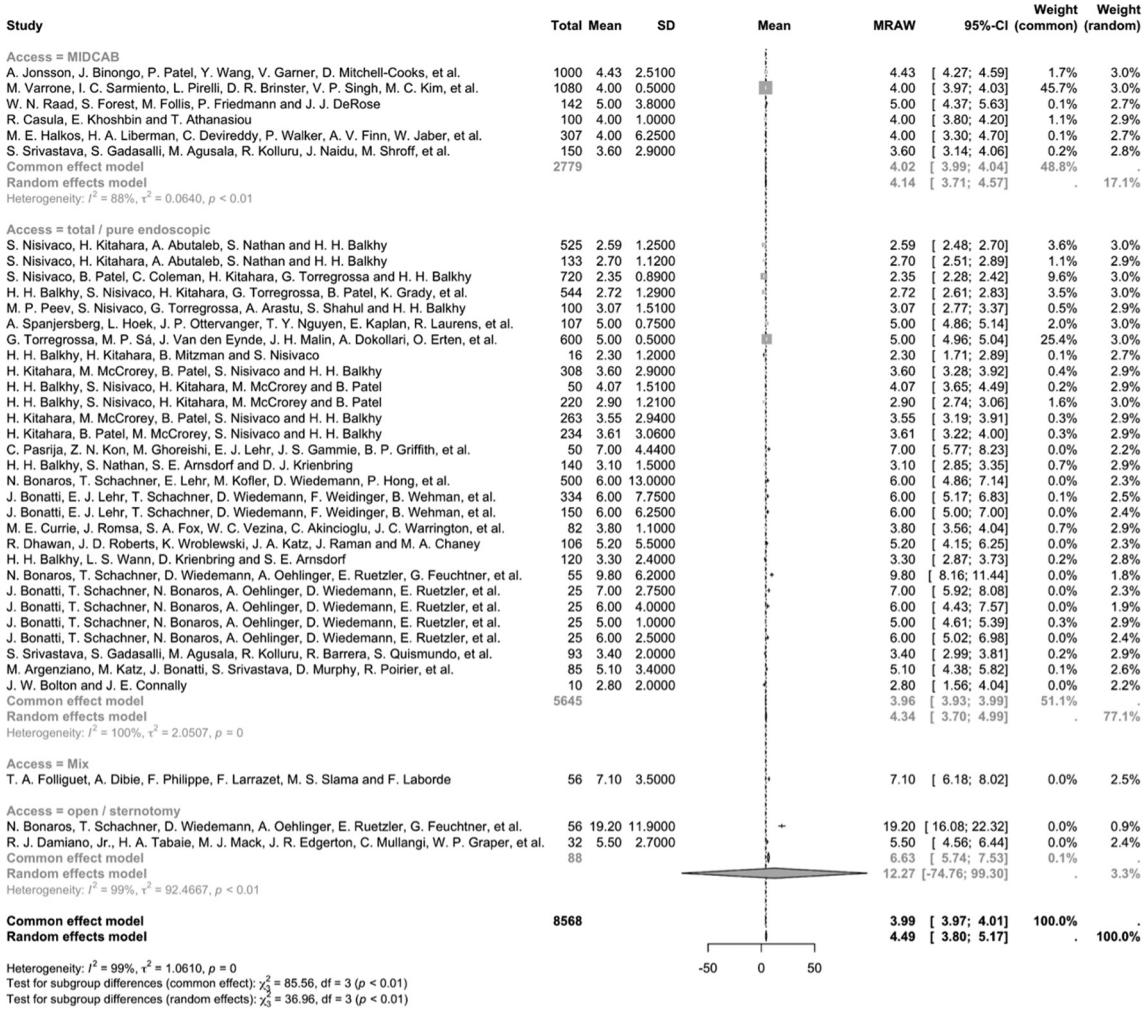

Figure S7 Forest plot for access approach stratified for hospital LOS.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

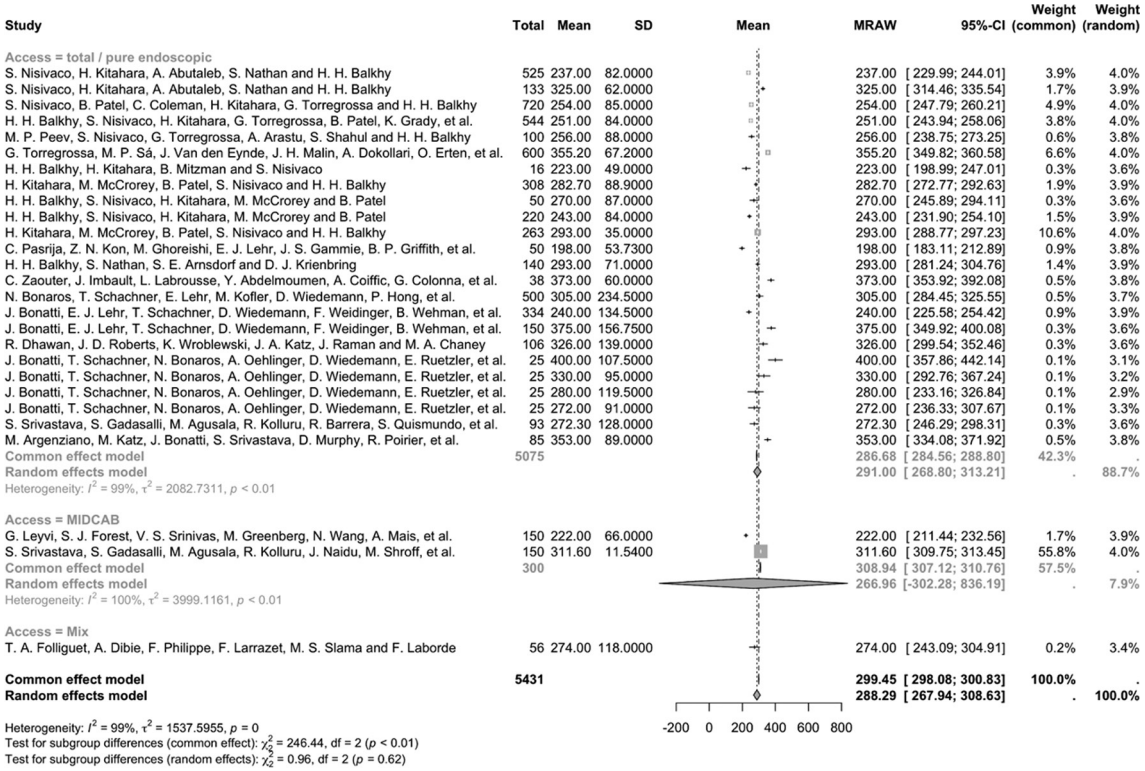

Figure S8 Forest plot for access approach stratified for operation time.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

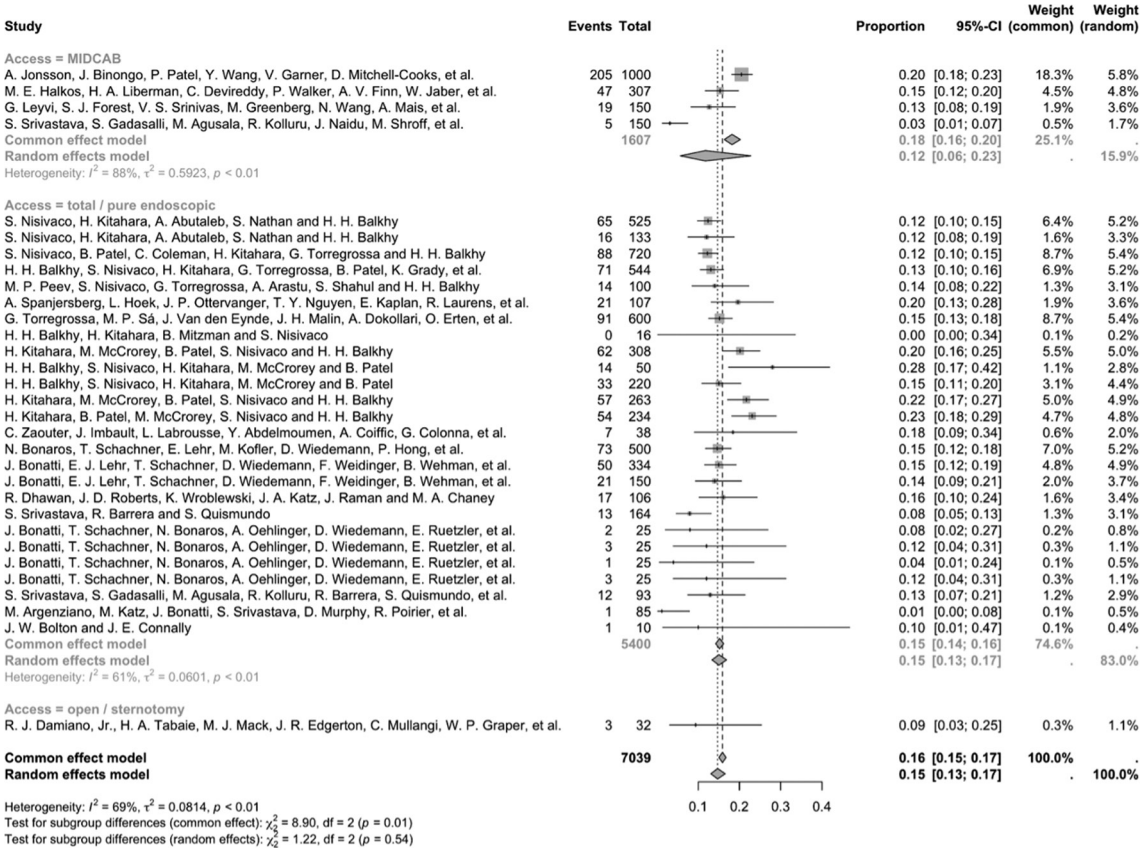

Figure S9 Forest plot for access approach stratified for post-operative atrial fibrillation.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

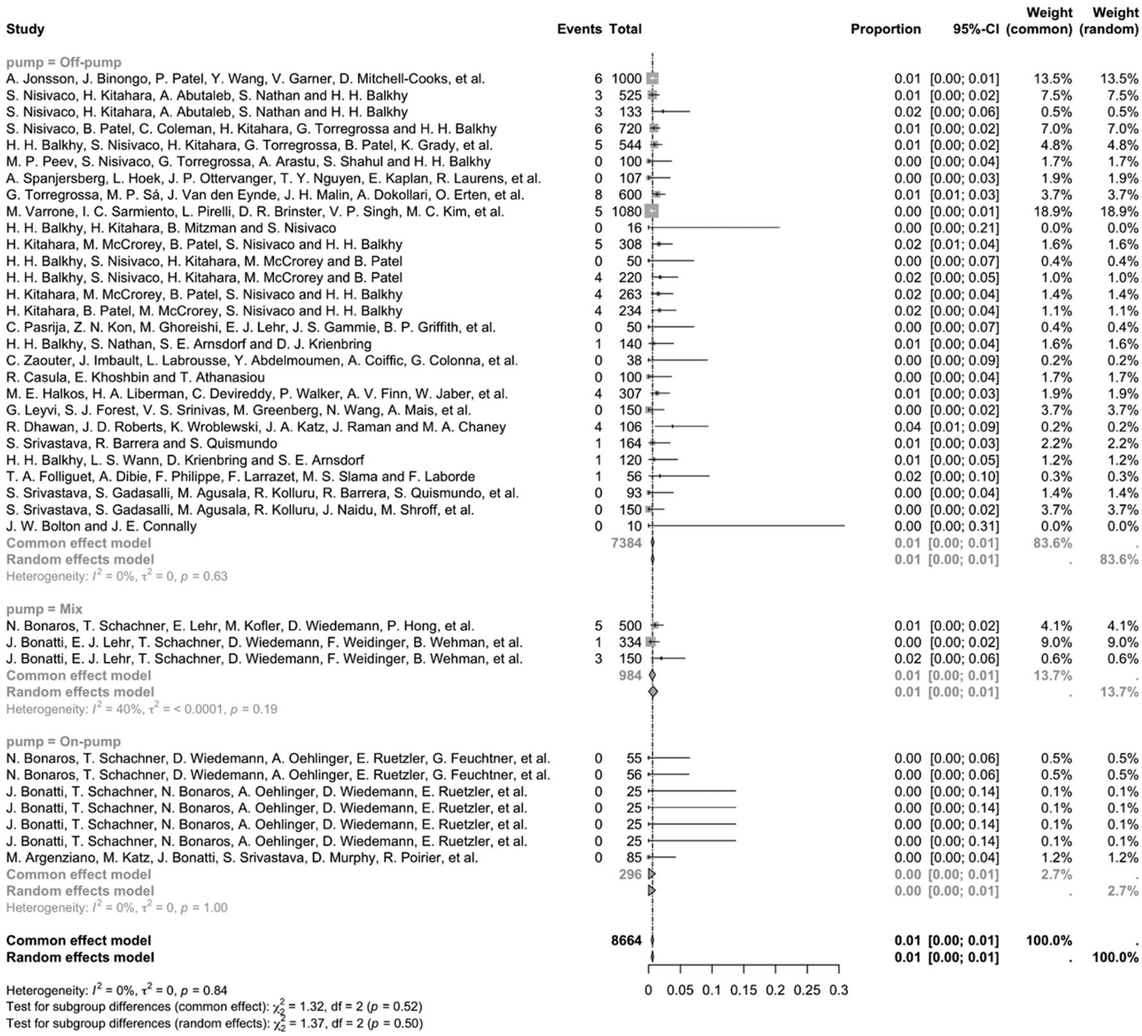

Figure S10 Forest plot for pump-stratified 30-day mortality.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

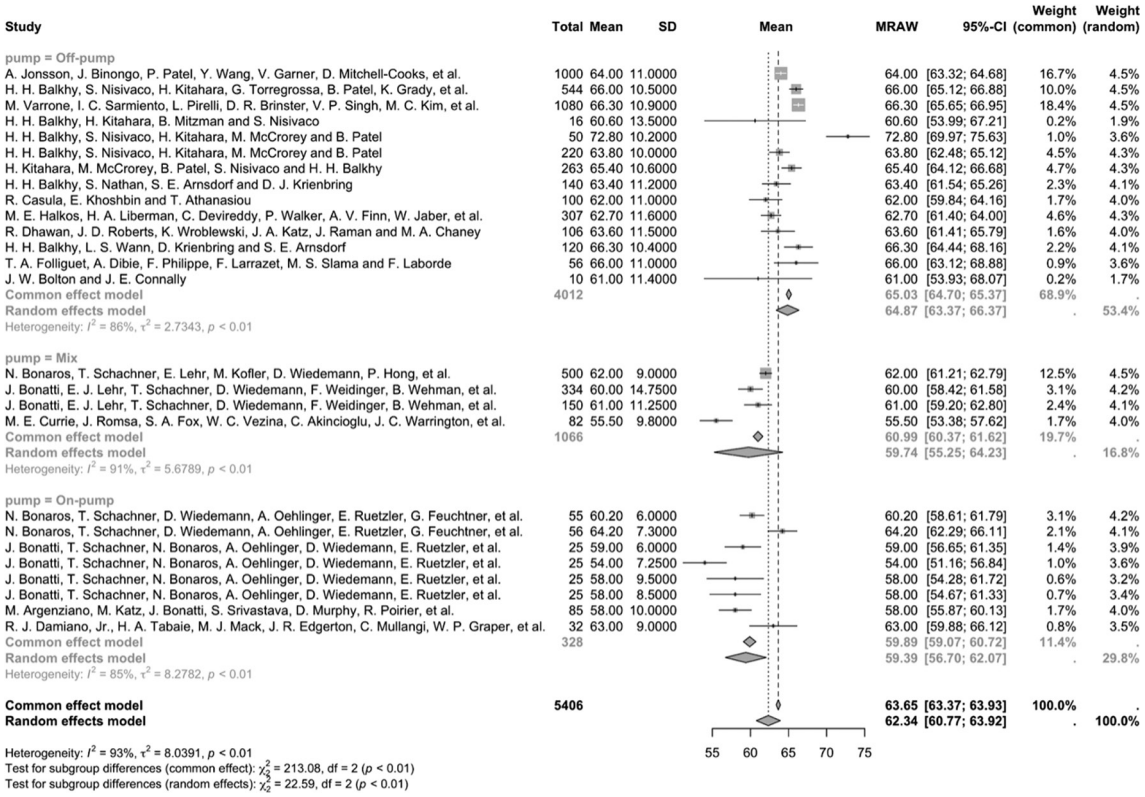

Figure S11 Forest plot for pump-stratified age.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

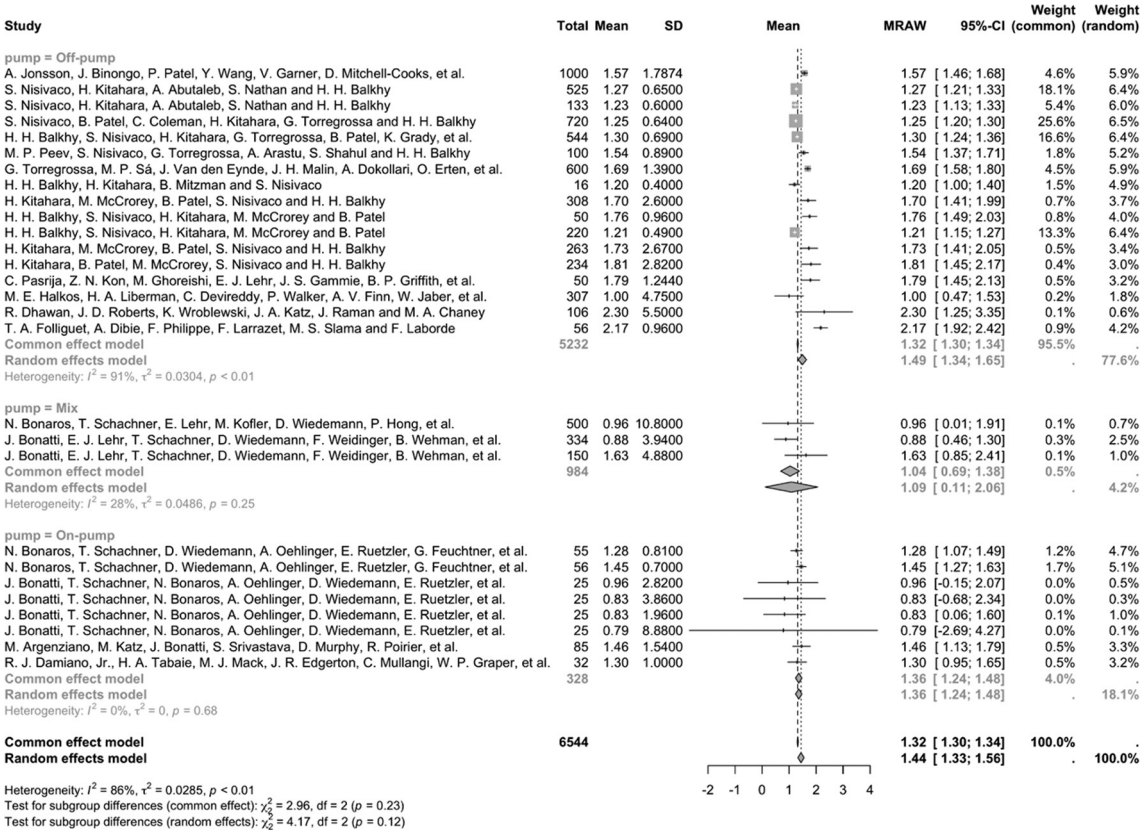

Figure S12 Forest plot for pump-stratified ICU length of stay.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

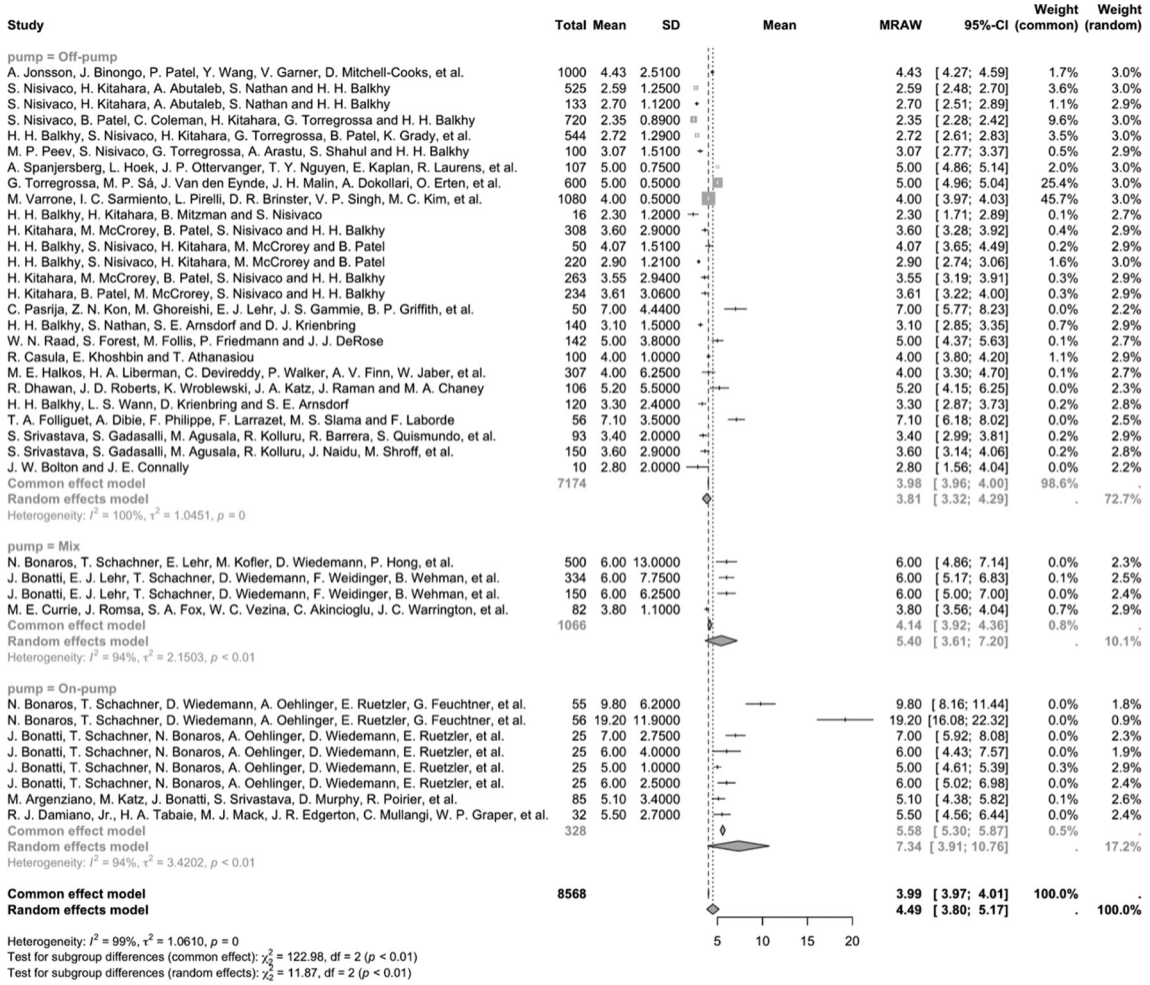

Figure S13 Forest plot for pump-stratified hospital length of stay.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

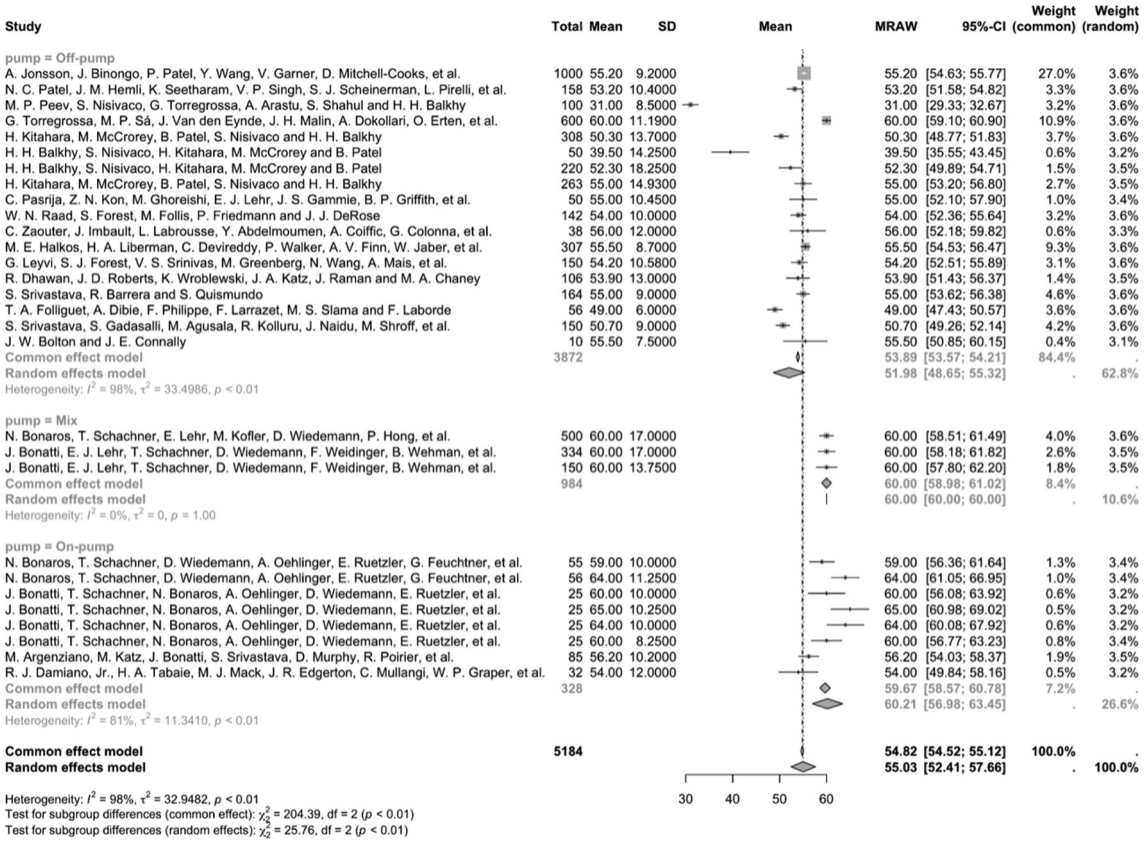

Figure S14 Forest plot for pump-stratified LVEF preoperatively.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

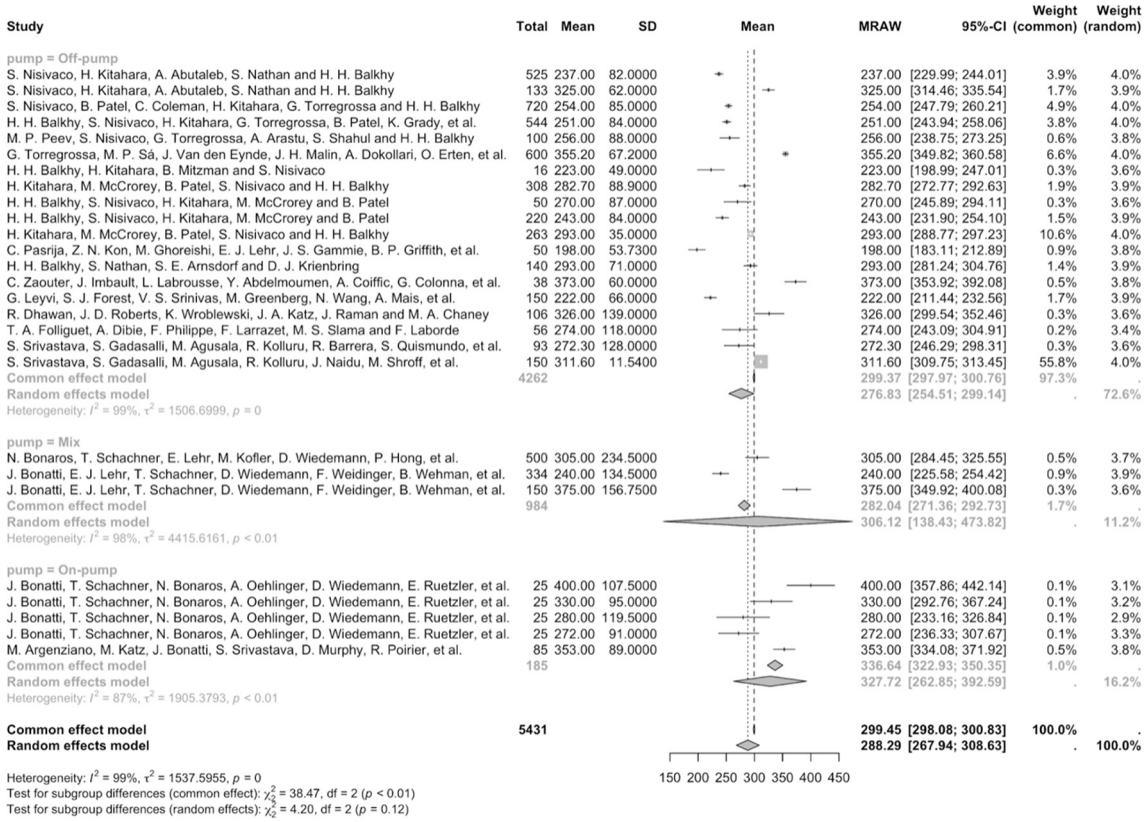

Figure S15 Forest plot for pump-stratified operation timing.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

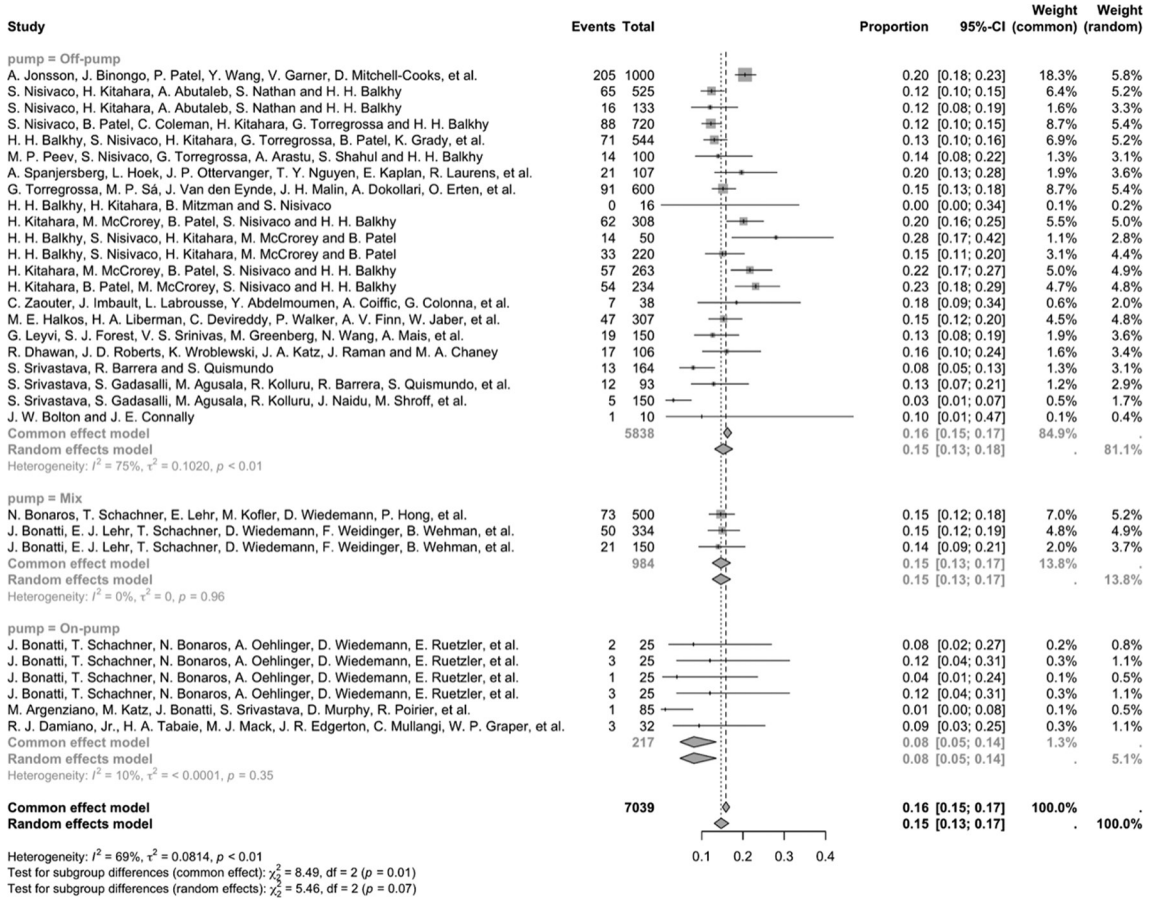

Figure S16 Forest plot for pump-stratified post-operative atrial fibrillation.

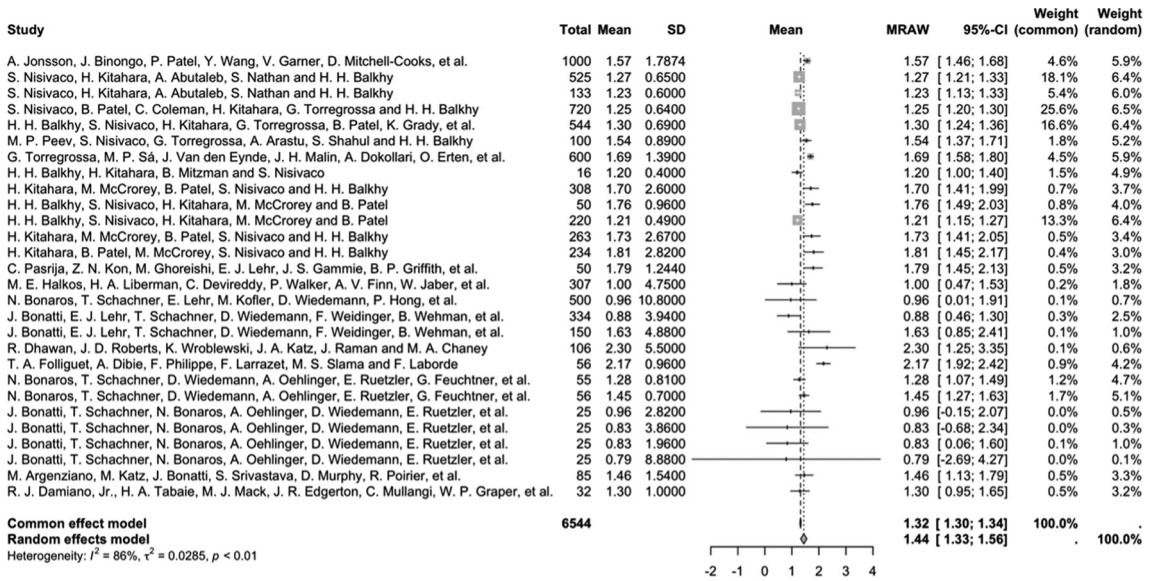

Figure S17 Forest plot for total ICU length of stay.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

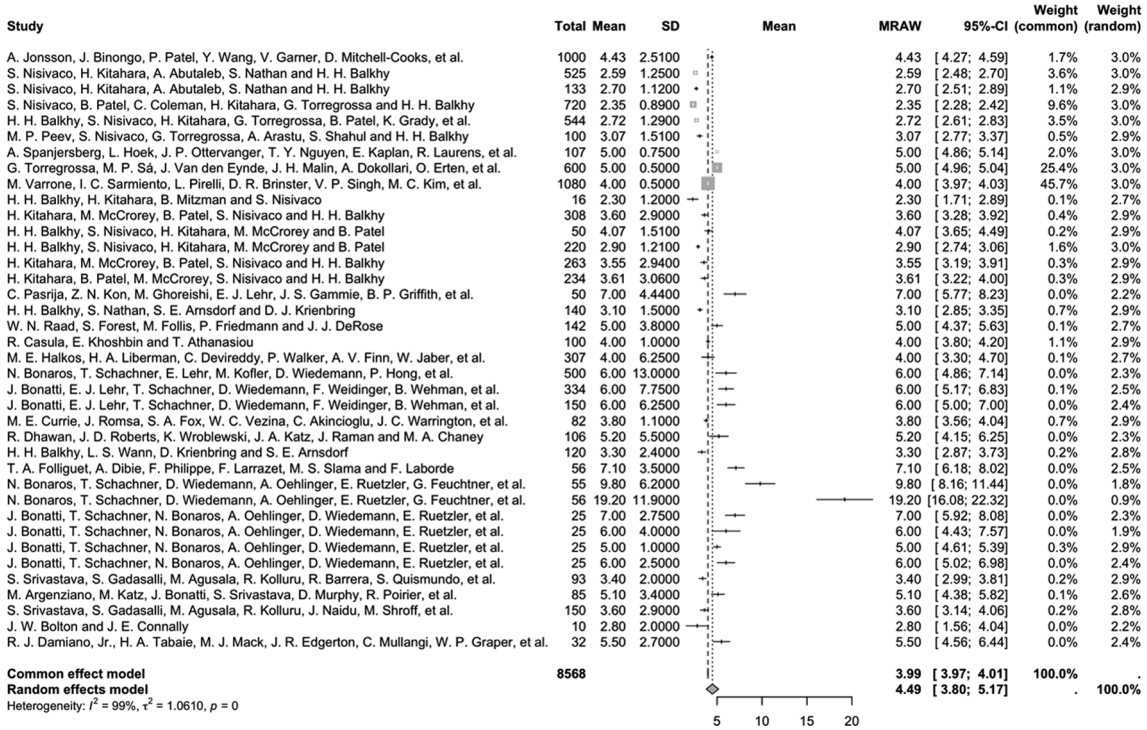

Figure S18 Forest plot for total hospital length of stay.

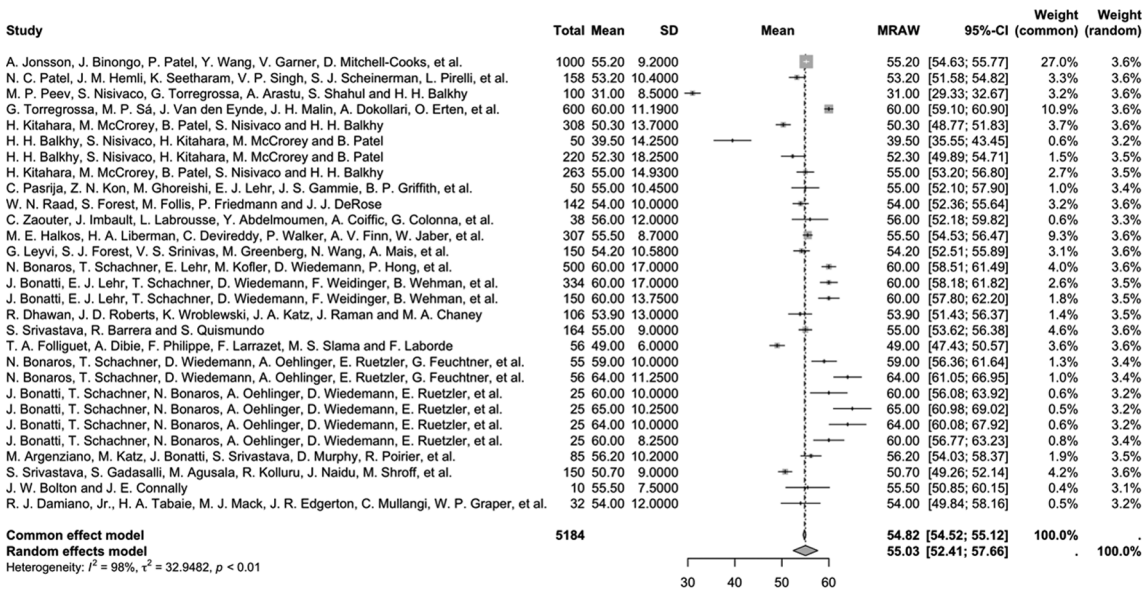

Figure S19 Forest plot for total LVEF.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

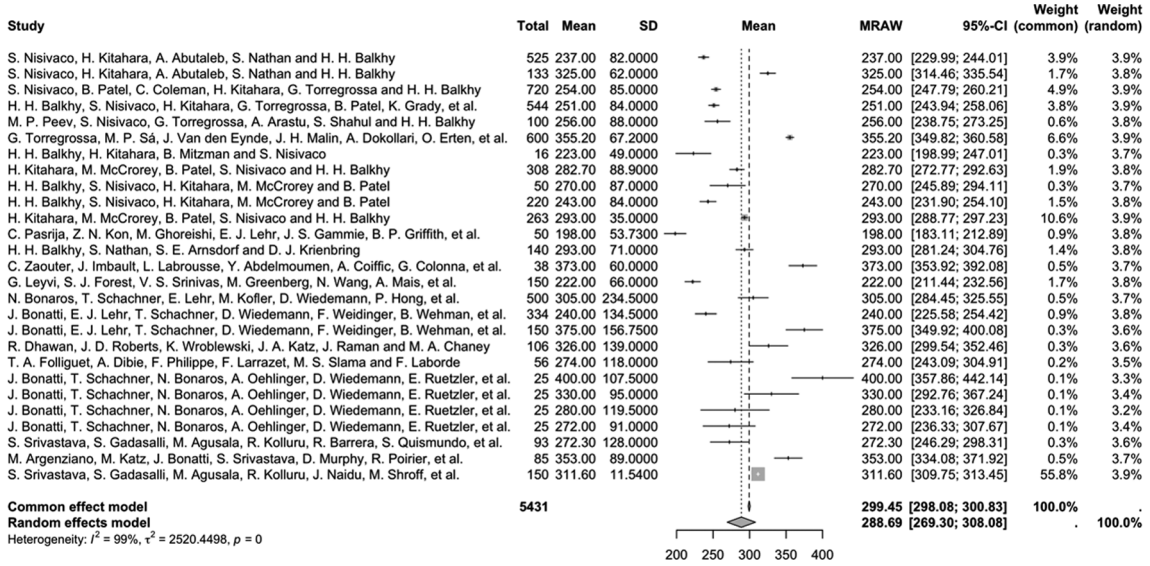

Figure S20 Forest plot for total operation time.

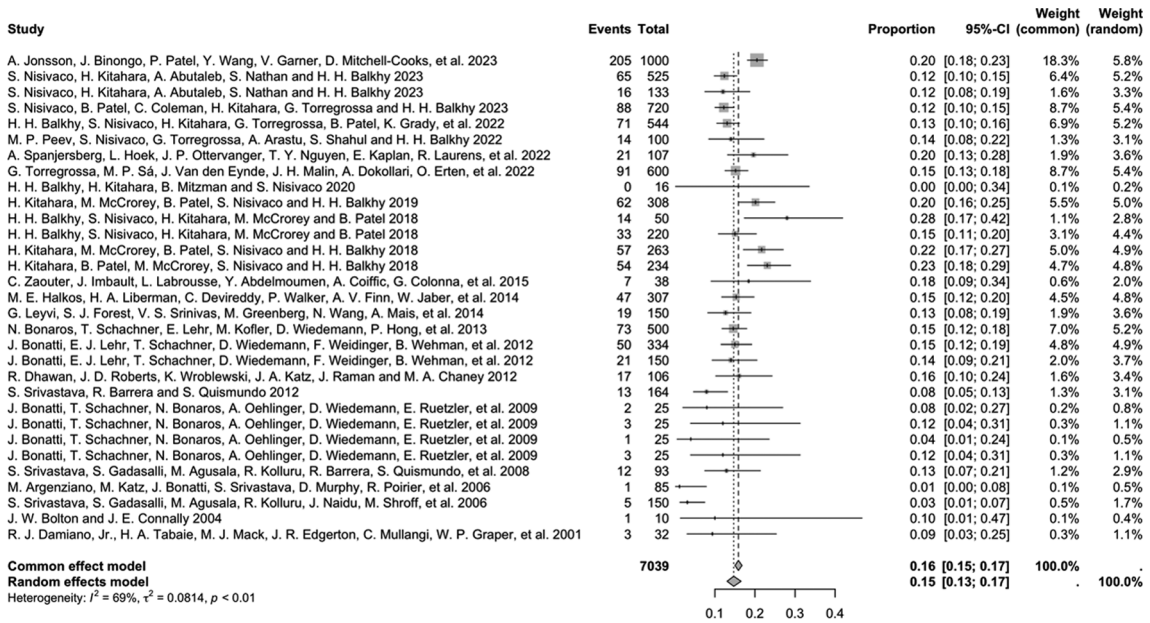

Figure S21 Forest plot for total post-operative atrial fibrillation.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

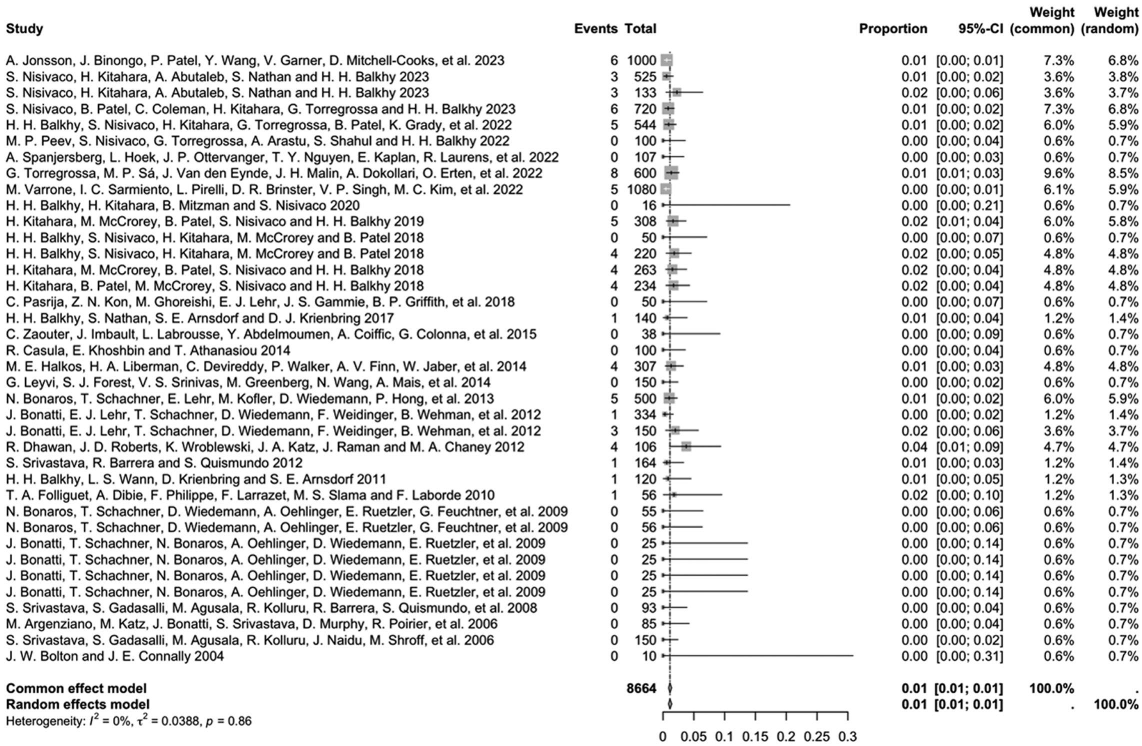

Figure S22 Forest plot for total 30-day mortality.

 https://dx.doi.org/10.21037/acs-2024-rcabg-15

Table S1 Detailed study characteristics (I)

Primary author	Year	Country	Study design	Males	Age ± SD (years)	HTN	T2DM	Dyslipidemia	MI history (all)	PVD	30-D Mort
A. Jonsson	2023	USA	SC; RCS	758	64±11	915	356	–	479	–	6
S. Nisivaco	2023	USA	SC; RCS	117	66	447	209	402	128	50	3
S. Nisivaco	2023	USA	SC; RCS	29	67	117	64	110	33	18	3
S. Nisivaco	2023	USA	SC; RCS	557	66	615	294	564	187	74	6
H. H. Balkhy	2022	USA	SC; RCS	411	66±10.5	451	219	410	149	62	5
N. C. Patel	2022	USA	SC; RCS	113	62.6	–	73	–	51	14	–
M. P. Peev	2022	USA	SC; RCS	76	66	91	48	80	38	17	0
A. Spanjersberg	2022	Netherlands	SC; PCS	77	65.3	56	16	–	20	–	0
G. Torregrossa	2022	USA	SC; RCS	0	74	532	266	548	336	88	8
M. Varrone	2022	USA	SC; RCS	809	66.3±10.9	–	556	–	374	109	5
H. H. Balkhy	2020	USA	SC; RCS	12	60.6±13.5	9	2	–	7	–	0
H. Kitahara	2019	USA	SC; RCS	83	65.6	254	123	230	–	41	5
H. H. Balkhy	2018	USA	SC; RCS	27	72.8±10.2	48	33	36	–	19	0
H. H. Balkhy	2018	USA	SC; RCS	168	63.8±10.0	173	76	166	–	15	4
H. Kitahara	2018	USA	SC; RCS	192	65.4±10.6	219	106	199	81	35	4
H. Kitahara	2018	USA	SC; RCS	62	66	193	94	177	74	–	4
C. Pasrija	2018	USA	SC; RCS	36	62	36	17	33	–	5	0
H. H. Balkhy	2017	USA	SC; RCS	106	63.4±11.2	–	–	–	–	–	1
W. N. Raad	2016	USA	SC; RCS	96	64.2	128	73	–		22	–
C. Zaouter	2015	France	SC; RCS	33	64	28	14	36	–	5	0
R. Casula	2014	UK	SC; RCS	95	62±11	–	17	–	18	–	0
M. E. Halkos	2014	USA	SC; PCS	219	62.7±11.6	282	109	296	161	38	4

SD, standard deviation; HTN, hypertension; T2DM, type 2 diabetes; MI, myocardial infarction; PVD, peripheral vascular disease; 30-D Mort, thirty-day mortality; SC, single-center; RCS, retrospective cohort study; PCS, prospective cohort study.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

Table S2 Detailed study characteristics (II)

Primary author	Year	COPD	CKD	Operation time (min)	Post-op AF	ICU stay (days)	Hospital stay (days)	Cohort N	Graft number
A. Jonsson	2023	–	20	–	–	1.6±1.8	4.43±2.51	1000	–
S. Nisivaco	2023	45	108	237±82	205	1.27±0.65	2.59±1.25	525	836
S. Nisivaco	2023	8	39	325±62	65	1.23±0.6	2.70±1.12	133	272
S. Nisivaco	2023	61	159	254±85	16	1.25±0.64	2.35±0.89	720	–
H. H. Balkhy	2022	52	112	251±84	88	1.30±0.69	2.72±1.29	544	892
N. C. Patel	2022	–	–	–	71	–	–	158	158
M. P. Peev	2022	16	33	256±88	–	1.54±0.89	3.07±1.51	100	162
A. Spanjersberg	2022	15	–	–	14	–	5 (4–7)	107	107
G. Torregrossa	2022	115	–	355.2 [315–405]	21	1.7 [1–2.9]	5.00 [4.00; 6.00]	600	689
M. Varrone	2022	–	46	–	91	–	4 (3–5)	1080	–
H. H. Balkhy	2020	0	1	223±49	–	1.2±0.4	2.3±1.2	16	16
H. Kitahara	2019	31	62	282.7±88.9	0	1.7±2.6	3.6±2.9	308	513
H. H. Balkhy	2018	13	28	270±87	62	1.76±0.96	4.07±1.51	50	80
H. H. Balkhy	2018	14	27	243±84	14	1.21±0.49	2.90±1.21	220	375
H. Kitahara	2018	26	54	293 (210–350)	33	1.73±2.67	3.55±2.94	263	–
H. Kitahara	2018	23	49	295	57	1.81±2.82	3.61±3.06	234	399
C. Pasrija	2018	–	–	198	54	1.8 (IQR 1–2.7)	7 (IQR 6–12)	50	50
H. H. Balkhy	2017	–	50	293±71	–	–	3.1±1.5	140	288
W. N. Raad	2016	22	–	–	–	–	5 (3.8)	142	–
C. Zaouter	2015	7	–	373±60	–	0.88	8	38	38
R. Casula	2014	7	–	–	7	–	4±1	100	100
M. E. Halkos	2014	–	10	–	–	1.0 (0–19)	4 (2–27)	307	307

COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease; AF, atrial fibrillation; ICU, intensive care unit.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

Table S3 Detailed study characteristics (III)

Primary author	Year	Country	Study design	Males	Age ± SD (years)	HTN	T2DM	Dyslipidemia	MI history (all)	PVD	30-D Mort
G. Leyvi	2014	USA	PCS	103	64.76	–	76	–	59	–	0
N. Bonaros	2013	USA; Austria	MC; RCS	364	62±9	406	133	419	162	32	5
J. Bonatti	2012	Austria; USA	MC; RCS	233	60 (31–90)	–	–	–	91	22	1
J. Bonatti	2012	Austria; USA	MC; RCS	117	61 (38–83)	–	–	–	61	9	3
M. E. Currie	2012	Canada	SC; RCS	77	55.5±9.8	–	10	–	7	2	–
R. Dhawan	2012	USA	SC; RCS	79	63.6±11.5	98	36	78	30	5	4
S. Srivastava	2012	USA	SC; RCS	128	63	91	9	0	26	2	1
H. H. Balkhy	2011	USA	SC; RCS	86	66.3±10.4	73	23	67	–	7	1
T. A. Folliguet	2010	France	SC; PCS	46	66±11	32	14	–	37		1
N. Bonaros	2009	USA	SC; RCS	43	60.2±6.0	49	7	44	–	0	0
N. Bonaros	2009	USA	SC; RCS	49	64.2±7.3	41	9	50	–	2	0
J. Bonatti	2009	USA	SC; RCS	17	59 (46–70)	22	3	21	10	0	0
J. Bonatti	2009	USA	SC; RCS	21	54 (38–67)	19	1	20	8	1	0
J. Bonatti	2009	USA	SC; RCS	25	58 (38–76)	20	4	22	5	0	0
J. Bonatti	2009	USA	SC; RCS	18	58 (40–74)	22	1	22	5	1	0
S. Srivastava	2008	USA	SC; PSC	47	67.4	73	38	31	26	–	0
M. Argenziano	2006	USA; Austria	MC; RCS	69	58±10	47	18	68	32	2	0
S. Srivastava	2006	USA	SC; RCS	99	67.2	117	69	–	42	21	0
J. W. Bolton	2004	USA	SC; PCS	6	61±11.4	–	2	–	3	–	0
R. J. Damiano	2001	USA	MC; PCS	24	63±9	–	–	–	–	–	–

SD, standard deviation; HTN, hypertension; T2DM, type 2 diabetes; MI, myocardial infarction; PVD, peripheral vascular disease; 30-D Mort, thirty-day mortality; PCS, prospective cohort study; MC, multi-center; SC, single-center; RCS, retrospective cohort study.

https://dx.doi.org/10.21037/acs-2024-rcabg-15

Table S4 Detailed study characteristics (IV)

Primary Author	Year	COPD	CKD	Operation time (min)	Post-op AF	ICU stay (h)	Hospital stay (days)	Cohort N	Graft number
G. Leyvi	2014	103	–	222±66	19	–	6	150	–
N. Bonaros	2013	364	8	305 (112–1050)	73	23 (11–1,048)	9 (0–704)	500	683
J. Bonatti	2012	233	1	240 (112–650)	50	21 (11–389)	6 (2–33)	334	334
J. Bonatti	2012	117	0	375 (168–795)	21	39 (12–480)	6 (2–27)	150	300
M. E. Currie	2012	77	–	–	–	–	3.8±1.1	82	–
R. Dhawan	2012	79	–	326±139	17	2.3 (0–22)	5.2 (2–24)	106	192
S. Srivastava	2012	128	2	–	13	–	–	164	243
H. H. Balkhy	2011	86	3	–	–	–	3.3±2.4	120	167
T. A. Folliguet	2010	46	2	274±118		52±23	7.1±3.5	56	59
N. Bonaros	2009	43	–	–	–	30.6±19.5	9.8±6.2	55	55
N. Bonaros	2009	8	–	–	–	46±21.1	–	9	123
N. Bonaros	2009	49	–	–	–	34.7±16.8	–	56	25
J. Bonatti	2009	17	0	400 (260–690)	2	23 (11–282)	7 (4–15)	25	25
J. Bonatti	2009	21	0	330 (240–620)	3	20 (18–389)	6 (5–21)	25	25
J. Bonatti	2009	25	0	280 (205–683)	1	20 (14–61)	5 (4–8)	25	25
J. Bonatti	2009	18	0	272 (178–542)	3	19 (17–230)	6 (4–14)	25	136
S. Srivastava	2008	47	3	272.3±128	12	–	3.4±2.0	93	85
M. Argenziano	2006	69	1	353±89	1	35±37	5.1±3.4	85	390
S. Srivastava	2006	99	7	311.6±11.54	4.7	–	3.6±2.9	150	12
J. W. Bolton	2004	6	0	200	1	–	2.8 (1–9)	10	90
R. J. Damiano	2001	24	–	–	3	31±24	5.5±2.7	32	–

COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease; AF, atrial fibrillation; ICU, intensive care unit.

https://dx.doi.org/10.21037/acs-2024-rcabg-15