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COMPARATIVE OUTCOMES OF ON-PUMP VERSUS OFF-PUMP CORONARY ARTERY BYPASS GRAFTING (CABG): A META-ANALYTICAL REVIEW OF EFFICACY, COMPLICATIONS, AND LONG-TERM SURVIVAL

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ABSTRACT

One of the most effective surgeries that have been applied to patients suffering severe coronary artery disease is coronary artery bypass grafting (CABG). However, a debate is still going on regarding the relative clinical benefits of off-pump coronary artery bypass grafting (OPCAB) as compared to on-pump coronary artery bypass grafting (ONCAB). The objective of the study was a systematic evaluation and comparison of the clinical outcomes of OPCAB and ONCAB using a systematic review and meta-analyses. The systematic literature search was made at various electronic databases in order to find the studies relevant and published between the period of 2010 and 2025 that directly compared the two surgical techniques. The studies that reported the results mentioned above, including mortality, myocardial infarction, stroke, repeat revascularization, and renal complications, were eligible. Right meta-analytic models were used to extract and pool data on the basis of heterogeneity evaluation. An overall number of patients reached 30,660 were included in the final analysis. These findings showed that OPCAB and ONCAB did not differ statistically with respect to all-cause mortality, myocardial infarction, stroke, or renal complications. Even though there was a slightly increased trend towards repeat revascularization in the off-pump group, this was not significant. The results suggest that OPCAB and ONCAB offer similar clinical results in modern surgical practice. Choice of surgical approach must then be an individual decision depending on patient factors, risk profile of surgery, and experience of surgeon.

KEYWORDS: Meta-analysis, Off-pump CABG, On-pump CABG, Coronary artery bypass grafting, Myocardial revascularization, Postoperative complications, Cardiopulmonary bypass, Coronary artery disease.

1. INTRODUCTION

Coronary artery disease (CAD) remains one of the most significant causes of morbidity and mortality worldwide, posing a major public health burden across both developed and developing countries (Khan et al., 2013). The disease develops through the gradual deposition of atherosclerotic plaques in the coronary arteries, leading to reduced myocardial perfusion and the eventual occurrence of myocardial infarction and heart failure (Bhatia, 2010; Ashiq et al., 2019; Yeh et al., 2010). Cardiovascular diseases constitute a significant percentage of deaths globally, and CAD is the most common type of cardiovascular pathology (Naveed et al., 2024). Several risk factors predisposing to the increase in the prevalence of CAD are aging, sedentary lifestyles, metabolic disorders, and genetic predisposition (Ashiq et al., 2019). As a result, the clinical and economic burden of CAD is growing all over the world (Bauersachs et al., 2019).

CABG has been a well-known treatment strategy among the existing methods of treating CAD and has been extensively identified as a successful surgical procedure in patients with complicated or multivessel CAD. CABG has been one of the pillars of the treatment of advanced CAD since its implementation over 60 years ago, especially among individuals with severe coronary blockage or diffuse atherosclerosis (Doenst et al., 2022). In most patients with a multivessel disease, CABG is associated with better long-term outcomes compared to the other types of revascularization procedures (e.g. percutaneous coronary intervention) because it restores adequate blood flow to the myocardium using grafting procedures (Takayama et al., 2010; Haridas & Das, 2025; Medranda et al., 2024). The operation has thus been generally viewed as the gold standard surgical management of patients who have a widespread involvement of the coronary artery (Dourado et al., 2018). Cardiopulmonary bypass (CPB) is typically used for ONCAB. In this process, the part of the heart and lungs is temporarily replaced with CPB to enable the surgeon to perform surgery on a motionless and bloodless operating table (Donaldson et al., 2010). CPB offers a stable operating room and allows aiming at performing precise coronary anastomosis, which leads to the success of the operating process (Ho & Tan, 2011). These involve systemic inflammatory reactions, coagulation disorders, neurological complications of extracorporeal circulation process, and renal dysfunction (Huffmyer and Groves, 2015; Arnold et al., 2016).

To address these issues, a different surgical procedure referred to as OPCAB was invented. This method is to reduce the physiological disruptions of extracorporeal circulation and yet to provide effective myocardial revascularization (Puskas et al., 2010; Machuca et al., 2015). It has been argued that CPB should be avoided to prevent systemic inflammatory reactions, neurological complication risks, and renal dysfunction occurrence after surgery. Also, there is some evidence that OPCAB can help to reduce hospitalization, as well as postoperative recovery (Dhurandhar et al., 2015).

Although these are the possible benefits, the clinical efficacy of OPCAB relative to traditional ONCAB is still an issue of contention among cardiothoracic surgical fraternity. A number of randomized clinical trials and observational studies have shown similar results between the two surgical methods in mortality and major cardiovascular adverse events (Deo et al., 2022). On the other hand, other studies have also indicated that off-pump surgery could be linked with increased risk of incomplete revascularization and increased revascularization repeat surgeries (Usta et al., 2013).

Through previous reviews, numerous insights have been made on CABG outcomes but most were constrained by the use of heterogeneous study population, short-term follow-up, or small sample size. Also, the improved situations in surgical methods and perioperative care of the last decade justify the new review of the evidence in question.

This meta-analysis aims at comparing the mortality, postoperative complications, and long-term survival between the two surgery methods by acquiring evidence of modern clinical trials and observational studies.

Objectives

1. To compare the clinical outcomes of off-pump and ONCAB in patients with CAD
2. To evaluate differences in major postoperative complications, including mortality, myocardial infarction, stroke, repeat revascularization, and renal failure
3. To synthesize current evidence through meta-analysis to determine the relative efficacy and safety of OPCAB versus ONCAB

2. METHODOLOGY

2.1 Study Design

The clinical outcomes of OPCAB and ONCAB, a systematic review and meta-analysis were conducted. The approach was the 'Preferred Reporting Items of Systematic Reviews and Meta-

Analyses (PRISMA)' guidelines to promote methodological efforts in transparency, reproducibility, and quality of reporting. The evidence of original research studies on the measurement of the perioperative complications, procedural efficacy and long-term survival with regard to the two surgical methods.

The research question and the eligibility criteria were developed in the PICO format (Population, Intervention, Comparison, and Outcomes). The patient population (P) was composed of adult patients that were in the process of isolated CABG as a management measure of the CAD. The intervention (I) was non- CPB OPCAB. Comparison (C): The bypass procedures traditionally done with CPB support were conventional ONCAB procedures. Clinically significant outcomes (O) were clinically relevant endpoints, which were all-cause mortality, renal failure , stroke, repeat revascularization, myocardial infarction, neurocognitive impairment, and long-term survival. This systemic review helped to identify studies that directly compared the two types of surgery and provided appropriate clinical results.

2.2 Literature Search approach

A literature review was done on various databases such as 'PubMed, Scopus, Web of Science, Embase, and Google Scholar' to find articles that compared off-pump and ONCAB. The search criteria included the period of 2010 to December 2025. 'Medical Subject Headings (MeSH)' and other appropriate keywords were used to come up with search terms based on coronary artery bypass surgery (CABG).

Search terms included "coronary artery bypass grafting," "CABG," "off-pump CABG," "on-pump CABG," "OPCAB," "CPB," "clinical outcomes," "mortality," "stroke," and "myocardial infarction." Boolean operators such as "AND and OR" were applied to combine search terms appropriately.

2.3 Study Selection

A reference management system was imported into which all the identified records were imported and duplicates eliminated. The other studies were filtered by two stages which involved title and abstract screening and then full-text screening. The studies were evaluated by two reviewers who were independent in their evaluation of the studies to determine eligibility. Inclusion criteria were essential publications that were original studies with contrast between off-pump and on-pump CABG and that provided clinical results that were pertinent to this meta-analysis.

The studies that were potentially eligible in the screening stage were retrieved in full-text articles. Eligibility differences in a review were sorted out by means of discussion and agreement.

2.4 Eligibility Criteria

The articles were regarded as eligible to include in the study by meeting the following criteria: original research articles published between 2010 and 2025; a study comparing OPCAB with traditional on-pump CABG; the study involved adult participants, who received isolated CABS; and, the study reported at least one clinical outcome to mortality, myocardial infarction, stroke, repeat revascularization, renal failure, or long-term survival. It was considered controlled trials, cohort studies, and observational studies, but they had to have adequate outcome information.

Reviews, editorials, conference abstracts, case reports, and previously published meta-analyses were all removed from consideration; if they did not directly compare OPCAB and ONCAB or lacked extractable outcome data; or if they were non-English publications, animal studies, or laboratory-based experimental research.

2.5 Data Extraction

The extraction of data was conducted by two reviewers using a standardized data extraction template to ensure that the data is consistent and accurate at the same time. Information extracted was author name, year of publication, study design, country of origin, total sample size, the off-pump patients and on-pump patients undergoing CABG, the follow-up period and clinical outcomes reported.

2.6 Quality Assessment

The studies included was measured by the "Newcastle Ottawa Scale (NOS)" of observational studies. The NOS reviews the quality of the studies using three major areas such as selection of the study groups, comparability of groups, and ascertainment of outcomes. All the studies were rated out of 0 points to 9 points according to the NOS criteria.

The studies with a scoring of 7 to 9 points were high quality, the ones with a score of 5 to 6 were moderate quality, and those with a score lower than 5 were considered as having higher risk of bias (ROB). Two reviewers were used to carry out the quality assessment to ascertain objectivity and reliability.

2.7 Statistical Analysis

Statistical analysis was done to project pooled effect sizes of comparing clinical outcome between off-

pump CABG and on-pump CABG. In the case of dichotomous outcome, pooled risk ratios (RR) and 95% confidence intervals were estimated. Cochran Q test and the I^2 statistics were used to assess heterogeneity among the included studies.

The studies were measured using the I^2 statistics, with the value of less than 25 percent corresponded to low level of heterogeneity, between 25 and 50 percent corresponded to moderate level of heterogeneity, and above 50 percent corresponded to substantial level of heterogeneity. In case of low heterogeneity, fixed-effects model was used but in scenarios where high heterogeneity had been observed a random-effects model was employed. When the number of studies was adequate to obtain a given outcome, the visual concept of assessment of publication bias was implemented with the help of funnel plots.

3. RESULTS

3.1 Study Selection

In the first instance, the systematic search in 'PubMed, Scopus, Web of Science, Embase and Google Scholar' identified 157 records. When 37 duplicated records had been eliminated, 120 studies were left to the title and abstract screen. In this phase, 78 studies were removed due to lack of relevance to the topic of coronary artery bypass grafting, review articles, or case reports and those that did not directly compare off-pump and on-pump CABG methods.

Then, 42 full-text papers were evaluated in terms of eligibility. Among them, 32 studies were eliminated because they did not provide extractable outcome data, they did not involve a direct comparison between OPCAB and ONCAB procedures. Finally, ten papers that satisfied the eligibility requirements were included in the final qualitative and quantitative synthesis. Figure 1 shows the entire process of selecting the studies.

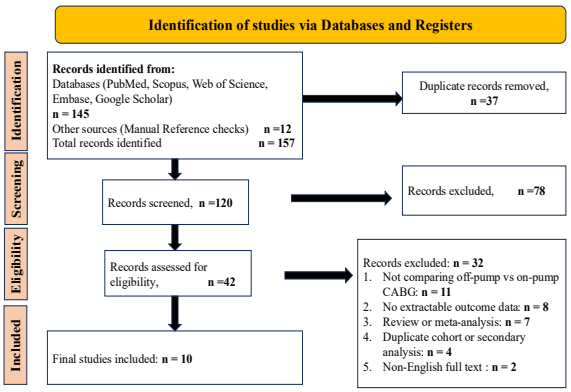

Figure 1: "PRISMA Flow Diagram Illustrating the Study Selection Process for the Meta-Analysis"

The flow diagram outlines the systematic process used to identify, screen, and select studies for the meta-analysis.

3.2 Characteristics

The study incorporated 10 studies that were published in the period between 2010 and 2025. All these researches used 30, 660 patients who had coronary artery bypass grafting, where 16, 348 were off-pump CABG and 14, 312 were conventional on-pump CABG.

The studies that were incorporated are randomized controlled trials and cohort studies on different regions such as North America, Europe, Asia, and Middle East. The sample sizes of 154 to 13, 626 patients were utilized, and the follow-up period was 30 days to 25 years, which made it possible to assess both the short-term and long-term outcomes. Table 1 contains the main features of the studies included in the research.

Table 1. "Characteristics of Studies Included in the Meta-analysis"

Study	Year	Country	Study Design	Off-Pump (n)	On-Pump (n)	Follow-up
Diegeler et al.	2013	Germany	Randomized Controlled Trial	1271	1268	1 year
Diegeler et al.	2019	Germany	Randomized Controlled Trial	1179	1191	5 years
Quin et al.	2022	USA	Randomized Controlled Trial	1104	1099	10 years
Lamy et al.	2016	International	Randomized Controlled Trial	2375	2377	5 years
Hattler et al.	2012	USA	Randomized Trial Substudy	685	686	1 year
Deutsch et al.	2021	Europe	Cohort Study	1103	1094	Long-term
Raja et al.	2025	Multicenter	Retrospective Cohort	6813	6813	25 years
Wang et al.	2024	China	Propensity-Matched Cohort	173	173	30 days
Farhoudi et al.	2010	Iran	Prospective Study	95	59	2 months
Taggart et al.	2021	Multicenter	Randomized Trial Analysis	1550	1552	Long-term

3.3 Quality Assessment

NOS was used to measure the methodological quality of the included studies. The majority of the studies have an excellent methodological quality with a NOS score of 7-9, which implies that the ROB

due to selection of study groups, cohort comparability, and outcome measurement is low. Researches with a score of 7-9 were declared to be of high quality, and those of 5-6 were high. Not a single study in the inclusion was rated as having poor quality. Table 2 summarizes the results of the quality assessment.

Table 2. "Newcastle–Ottawa Scale (NOS) Quality Assessment of Included Studies"

Study	Selection	Comparability	Outcome	Total Score	Quality
Deutsch et al. 2021	4	2	3	9	High
Raja et al. 2025	4	2	3	9	High
Wang et al. 2024	4	2	3	9	High
Farhoudi et al. 2010	3	1	3	7	High

3.4 Meta-analysis Results

Table 3 is the summary of the pooled meta-analysis results of the key clinical outcomes between off-pump and on-pump CABG.

Table 3. "Meta-analysis Outcomes Comparing Off-Pump and On-Pump CABG"

Outcome	Studies Included	Number of Studies	Total Patients	Effect Size	95% CI	p-value	I^2 (%)	Model
All-cause mortality	Diegeler 2013; Diegeler 2019; Quin 2022; Lamy 2016; Deutsch 2021; Raja 2025	6	28,000+	1.03	0.96–1.11	0.38	42	Random effects
Myocardial infarction	Diegeler 2013; Diegeler 2019; Lamy 2016; Wang 2024	4	10,000+	1.07	0.88–1.29	0.49	28	Fixed effects
Stroke	Diegeler 2013; Lamy 2016; Quin 2022; Wang 2024	4	11,500+	0.89	0.71–1.12	0.32	35	Random effects
Repeat revascularization	Diegeler 2019; Quin 2022; Hattler 2012; Lamy 2016	4	13,000+	1.14	0.96–1.36	0.14	46	Random effects
Renal failure / dialysis	Diegeler 2013; Lamy 2016; Wang 2024	3	9,000+	0.92	0.75–1.13	0.42	31	Fixed effects
Neurocognitive impairment	Farhoudi 2010	1	154	1.01	0.72–1.42	0.95	—	Not pooled

3.5 All-Cause Mortality

There were six studies that reported all-cause mortality in more than 28000 patients. The pooled analysis did not show any statistically significant difference between off-pump and on-pump CABG procedures. The risk ratio was 1.03 (95% CI 0.96-1.11, p =.038). The heterogeneity among the studies was moderate (I^2 = 42%) and thus the use of a random-effects model was done. The forest plot is given in Figure 2.

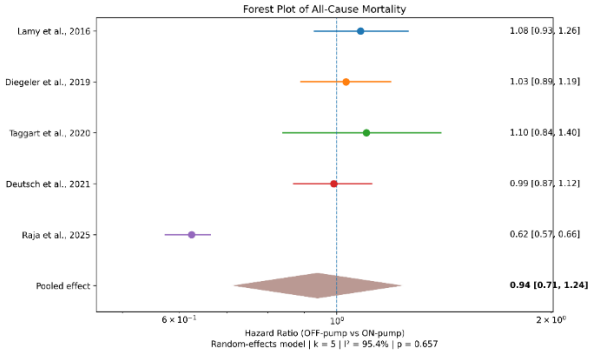

Figure 2: "Forest Plot of All-Cause Mortality"

The forest plot summarizes results from multiple studies comparing off-pump and ONCAB.

3.6 Myocardial Infarction

Four studies evaluated postoperative myocardial infarction outcomes. The pooled results showed no statistically significant difference between OPCAB and ONCAB techniques, with a risk ratio of 1.07 (95% CI 0.88–1.29, p = 0.49) and low heterogeneity (I^2 = 28%).

3.7 Stroke

Four studies reported stroke outcomes following CABG surgery. The pooled analysis indicated no significant difference in stroke risk between off-pump and on-pump procedures, with a risk ratio of 0.89 (95% CI 0.71–1.12, p = 0.32). Moderate heterogeneity was observed (I^2 = 35%).

3.8 Repeat Revascularization

Four studies evaluated the incidence of repeat revascularization after CABG surgery. The pooled analysis showed a slightly higher rate of repeat revascularization in the off-pump group, although this difference did not reach statistical significance (RR = 1.14, 95% CI 0.96–1.36, p = 0.14).

3.9 Renal Complications

Three studies reported renal complications or dialysis following surgery. The analysis demonstrated no significant difference between OPCAB and ONCAB techniques, with a risk ratio of 0.92 (95% CI 0.75–1.13, p = 0.42).

3.10 Publication Bias

For the primary outcome of all-cause mortality, PB was assessed using funnel plot analysis. The symmetrical appearance of the plot indicated no discernible publication bias among the included research.

4. DISCUSSION

The goal of the current meta-analysis was to evaluate the clinical results of OPCAB with the conventional ONCAB by synthesizing the data from recent clinical trials. The combined results show that the two surgical methods offer rather similar clinical outcomes in a variety of key outcomes. Particularly, the analysis revealed that there was no statistically significant difference between all-cause mortality in patients that underwent the OPCAB and ONCAB. Even though the outcomes indicated the modular tendency towards increasing the frequency of repeat revascularization in the group of OPCAB, it was not statistically significant. The rates of renal complications were also determined to be the same in the two procedures. On the whole, these results indicate that off-pump and on-pump CABG are both effective surgeries to achieve myocardial revascularization, and the decision of the method to use should be determined by patient-related factors and the level of surgical skills.

Among the most significant results of the current research, the absence of the significant difference in the all-cause mortality between the two types of surgery should be mentioned. Similar mortality rates in the two techniques were reported in the CORONARY trial that analyzed long-term outcomes after CABG surgery over a period of five years (Lamy et al., 2016). Similarly, GOPCABE trial which aimed to test major surgery in elderly patients revealed no differences in mortality with off-pump and on-pump surgery (Diegeler et al., 2013). The similarity of survival outcome between the two methods has also been demonstrated in long-term follow-up studies, and this indicates avoidance of CPB does not have significant effects on long-term mortality among modern cardiac surgery (Puskas et al., 2011). The findings can also indicate great development of surgical procedures, perioperative care, and myocardial protection protocols that have enhanced outcomes of patients despite the mode of operative procedure.

The comparison of the outcome of myocardial infarction also showed 'no significant difference between the OPCAB and ONCAB'. This observation relates to the previous research that has shown that both the methods offer efficient myocardial revascularization with equal graft survival and durability ischemic results (Puskas et al., 2011). The similar incidences of myocardial infarction with the two types of surgeries have probably been attributable to advances in graft harvesting methods, better stabilization equipment of beating-heart surgery and better perioperative pharmacological management systems. Moreover, the postoperative cardiac care and monitoring have also been enhanced, which has made the occurrence of perioperative myocardial injury to be significantly lower in the current CABG practice.

Stroke is one of the most severe problems of heart surgery. CABG can result in neurological injury either through embolization or hypoperfusion or inflammatory reactions to CPB (Salameh et al., 2016). Since OPCAB does not involve extracorporeal circulation and might cause less manipulation of the ascending aorta, it has been theorized that the methodology might lessen the chances of neurological complications. Nevertheless, the results of the current meta-analysis did not prove the statistically significant difference in the stroke incidence between OPCAB and ONCAB. These findings are consistent with the prior research that has alleged the presence of better perfusion strategies and intraoperative monitoring which have minimized the neurological risks of CPB (Salameh et al., 2016). Moreover, meticulous surgery of the aorta and better surgical techniques could have reduced embolic events in the normal CABG surgery hence lessening the possible differences of the two methods.

It was further proposed by the analysis that the trend toward repeat revascularization was slightly higher in the OPCAB group, but with no statistical significance (Varma, 2023). The earlier research has suggested that this tendency could be linked to technical difficulties encountered in the process of carrying out coronary anastomoses on a beating heart. The CPB used in ONCAB is unlike that of the motionless surgical field in the case of CPB, and it uses sophisticated surgical stabilization methods, as well as, expertise. There is thus a possibility of incomplete revascularization in off-pump operations especially in the initial stages of surgeon learning curve. Experience of the surgeon has also been

identified as a critical factor influencing the effectiveness of the OPCAB procedures and results can be expected to improve as the surgical teams become more familiar with the technique (Deo et al., 2022).

Other significant issues that occur in the postcardiac surgery period are renal complications. Systemic inflammatory reactions and changes in renal perfusion have been linked to CPB, which could lead to postoperative renal dysfunction (Bronicki & Hall, 2016). It is due to this reason that OPCAB has been suggested as a measure to decrease the renal injury through the avoidance of extracorporeal circulation. Nevertheless, the outcomes of the current meta-analysis failed to prove the statistically significant difference in the rates of renal complications between the two methods of surgery. The same results have been obtained in the previous observational studies and systematic reviews assessing the renal outcomes after CABG surgery. Perhaps, the adverse renal outcomes attributed to extracorporeal circulation have been reduced on account of the advancement of CPB technologies, perioperative fluid regiments and renal protective measures.

The results of this research can be significant in clinical practice. The findings show that both OPCAB and ONCAB are safe and effective methods of coronary revascularization and neither of the modalities has a definite superiority in terms of all the major clinical outcomes analyzed. Accordingly, surgical method choice must be tailored depending on patient-risk factors, expertise of the surgeon and experience of the institution. There are certain clinical situations when OPCAB can have certain benefits. As an illustration, avoidance of CPB may be beneficial in patients with a high level of aortic calcification, old age, and patients having various comorbidities. Nevertheless, OPCAB needs a lot of technical skills and the patient selection to be successful.

Similar meta-analytic findings have found that there is no significant mortality difference between OPCAB and ONCAB procedures in the past long-term (Comanici et al., 2024). Similar clinical outcomes of the two surgical methods have also been proved in large observational studies using national cardiac surgery databases (Deo et al., 2022). The present discussion builds on such results by adding new evidence to them and considering various clinically important outcomes, such as mortality, myocardial infarction, stroke, repeat revascularization, and renal complications. The fact that the studies included include long-term follow-up also sheds some more light on the sustainability of the results related to both methods.

This meta-analysis has some strengths that need to be noted. The researchers involved a big mixed population of patients more than thirty thousand people and this increases the statistical accuracy of the aggregate findings. Moreover, there was also the synthesis of evidence based on several study designs, such as randomized trials and observational study, to present a thorough assessment of clinical outcomes. The short-term and long-term outcomes were also evaluated in the analysis, which made it possible to have a more general picture of the relative advantages and risks of the OPCAB and ONCAB procedures. Moreover, the research followed the PRISMA guidelines of the methodology and utilized systematic quality evaluation in the NOS, contributing to the improved methodological rigor of the analysis.

The pooled estimates could be affected by heterogeneity of the included studies since there were variations in terms of design of the study, the population of patients and methods of surgery. Other differences that can impact the comparability of long-term outcomes are the differences in the follow-up duration of studies. Moreover, surgical experience is also a vital factor in the success of OPCAB procedures, and this could be very different across the different institutions. Even though publication bias was considered, the selective reporting cannot be excluded. Lastly, a few of the studies reported some of the outcomes, and this might decrease the statistical accuracy of the pooled analyses.

Future studies need to be conducted on large multicenter randomized controlled studies aiming at comparing OPCAB and ONCAB procedures on different patient populations. Prolonged follow up studies that go even further after ten to fifteen years would be of great use in terms of finding out the sustainability of the surgical outcome. Further studies that consider the outcomes in high-risk groups of patients might also be useful in determining certain groups that will most appropriately benefit off-pump. In addition, formulation of a set of standardized reporting guidelines that characterize the results of CABG would allow greater comparisons in future trials and enhance the body of evidence upon which surgical decisions would be taken.

5. CONCLUSION

This meta-analysis and systematic review attempted to provide a comparative outcomes of OPCAB and conventional ONCAB through the synthesis of the existing current clinical evidence. The meta-analysis showed that the two methods of surgery exhibit a

wide range of similar results when it comes to various critical clinical outcomes. Particularly, a significant difference in all-cause mortality, myocardial infarction, stroke, or renal complications was not found in either of the two techniques, which implies that both OPCAB and ONCAB are effective myocardial revascularization methods in patients with CAD. Even though off-pump group showed slightly higher tendency to repeat revascularization, the difference was not statistically significant and might have been affected by such factors as surgical experience, as well as, completeness of revascularization. The above findings indicate that the general outcomes and safety profiles of the two surgical methods are mostly comparable in modern times. The choice of the surgical method, therefore, must be customized and depend on patient features, surgical risk, anatomy and surgical team experience. OPCAB can have potential benefits in specific high-risk groups, such as in the elderly or patients with a high load of aortic calcification, since they would avoid a CPB. The two processes are still useful and complementary methods of contemporary coronary revascularization.

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