Journal of Rare Cardiovascular Diseases
ISSN: 2299-3711 (Print) | e-ISSN: 2300-5505
(Online) www.jrcd.eu

RESEARCH ARTICLE

Long-Term Survival and Functional Recovery After Total Arterial Coronary Revascularization: A Multicenter Prospective Cohort Study

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Article History
Received: 08.08.2025
Revised: 20.08.2025
Accepted: 03.09.2025
Published: 30.09.2025

Abstract: The multicenter prospective cohort study evaluated long-term survival and functional recovery after total arterial coronary revascularization (TAR) in 1,000 patients with multivessel coronary artery disease operated between 2020 and 2025. All participants underwent elective, first-time coronary artery bypass grafting using exclusively arterial conduits under standardized protocols across five tertiary centers. The primary endpoints were overall survival and postoperative functional improvement assessed through left ventricular ejection fraction (LVEF), exercise tolerance, and quality-of-life indices. Over a mean follow-up of 3.1 ± 1.4 years, the projected 5-year survival rate reached 93.2%, with consistent improvements in LVEF and quality-of-life indices. Functional capacity and patient-reported outcomes showed consistent enhancement, and graft patency remained high for all arterial conduits, exceeding 90% at 5 years. Advanced age and baseline LVEF below 45% were independent predictors of mortality on Cox regression analysis. The results confirm that total arterial grafting ensures superior graft durability, sustained myocardial recovery, and better long-term quality of life than conventional mixed or venous grafting. TAR should therefore be considered a prognostically superior and clinically sustainable standard of care in contemporary coronary artery bypass surgery.

Keyword: Total arterial revascularization, Coronary artery disease, Long-term outcomes, Functional recovery, Coronary bypass surgery

1. Introduction

Coronary artery disease (CAD) remains the most widespread and devastating cardiovascular disease on Earth, as it is one of the primary causes of morbidity and mortality, regardless of the ongoing advances in preventive and interventional cardiology (Bansal & Hiwale, 2023; Bauersachs et al., 2019). The pathophysiology of CAD focuses on the gradual formation of atherosclerotic plaques in the coronary arteries, which causes inflammation of the vessel, luminal obstruction, and myocardial ischemia (Mir et al., 2024). The World Health Organization states that CAD is a leading cause of mortality in almost one-third of the world population, as the prevalence of sedentary lifestyles, obesity, diabetes, and hypertension rates continue to rise even in low- and middle-income nations (Malakar et al., 2019). CAD socioeconomic impact is not limited to mortality, but also includes long-term disability, productivity loss, and increasing medical expenses (Bauersachs et al., 2019). It, therefore, comes as no surprise that the quest of sustainable revascularization approaches that not only extend survival but also promote post-operative functional capacity is among the primary areas of focus in cardiovascular medicine.Revascularization of the coronary arteries be it the use of percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) continues to be the mainstay of treatment in patients with a complex or multivessel CAD that cannot be treated through other medical interventions. Whereas PCI has transformed the idea of acute management using minimally invasive procedures, CABG still offers the most complete revascularization in patients with widespread or diffused disease, left main stenosis, or diabetes mellitus (Agrawal et al., 2020). The benefit of CABG is its long-term survival due to its capacity to reproduce sustainable myocardial perfusion and favorable ventricular remodeling (Prabhu et al., 2020; Gurunathan et al., 2015). In addition to survival, CABG has been repeatedly associated with an increase in exercise tolerance, LVEF, as well as an overall quality of life, which has become a marker of success in patients and functions (Prabhu et al., 2020).

Nevertheless, the type of conduit has a major impact on the CABG outcomes in terms of their longevity. The availability and ease of harvesting of saphenous vein grafts (SVGs) makes them the usual choice in generating traditional CABG techniques. Although SVGs were patented early, they have progressive failure during the first decade of surgery due to intimal hyperplasia, endothelial dysfunction, and enhanced atherosclerosis (Elguindy et al., 2017). About 50 percent of vein grafts are occluded in a span of ten years and quite frequently result in recurrent angina, myocardial infarction and repeat revascularization is

necessary. This constraint of venous grafts has led to the paradigm shift of using arterial conduits, which have better long-term patency and physiologic compatibility with the coronary circulation (Bauersachs et al., 2019). The internal mammary artery (IMA) and radial artery are some of the arterial conduits that have become the grafts of choice because of their structural strength, maintenance of endothelium, and resistance to atherosclerotic degeneration (Malakar et al., 2019). Arterial grafts have a less turbulent flow structure, the release of vasodilatory mediators including nitric oxide, and adaptive remodelling to maintain decades of patency. Observational and randomized studies conducted over time have all proven that the use of multiple arterial grafts provides better survival outcomes than mixed or venous grafting methods (Agrawal et al., 2020). It has been the idea of total arterial revascularization (TAR) - where every graft employed is arterial - that has thus become an effective approach to maximize long-term results. TAR is not only aimed at full anatomical revascularization but also corresponds to the physiological need of long-lasting perfusion of the ischemic areas, which has the potential to increase myocardial recovery and functional preservation (Sekaran et al., 2017; Witberg et al., 2017).

TAR has had an uneven clinical adoption irrespective of these developments. There are still concerns on technical complexity, increased duration of operation, conduit supply, and the initial postoperative results, especially in the elderly or high-risk patients. Besides, methodological heterogeneity, single-center studies, retrospective studies, and relatively short follow-up times have limited the evidence base of TAR. Most current studies have been conducted based on graft patency or survival without fully considering functional recovery outcomes, including advances in left ventricular performance, exercise capacity, and postoperative quality of life variables which are emerging as very important predictors of surgical success (Prabhu et al., 2020; Gurunathan et al., 2015). Moreover, the differences in surgery knowledge, patient selection, and postoperative care of centers lead to the conflicting interpretations of the actual long-term advantages of TAR (Malakar et al., 2019).

The recent increase in surgical technique, perioperative care and myocardial protection has now proven it possible to safely and reproducibly perform TAR in even complex multivessel disease. The physiology behind this methodology is sound: the arterial grafts are able to ensure a consistent perfusion pressure, reduce the risk of graft thrombosis and enhance the long-term myocardial oxygen supply-demand balance. Also, multiple arterial grafts are found to be more reliable in the achievement of completeness of revascularization a determinant to reduce long-term mortality (Witberg et al., 2017). With the increasing life expectancy of patients subjected to CABG, assessment of long-term survival and recovery of functional outcomes is now more topical than ever. The general knowledge of these outcomes is paramount in providing evidence-based clinical decision-making and the optimal planning of surgery in modern cardiac practice.

Although optimizing literature trends, there is an evident gap in the literature that regards prospective multicentric data to evaluate the survival and functional recovery after total arterial coronary revascularizations. The available evidence though supportive, has come about mainly through the experiences of single institutions or retrospective registries which make generalization difficult. Therefore, there is no complete knowledge of the long-term prognostic and functional consequences of TAR. This multicentric prospective cohort study will fill this gap by providing a systematic assessment of long-term survival, cardiac functional recovery and outcome clinical predictors in patients who have undergone total arterial coronary revascularization. By means of stringent design and follow-up, the study aims at providing solid evidence to explain the role of TAR as a standard of care in achieving sustained comprehensive myocardial revascularization.

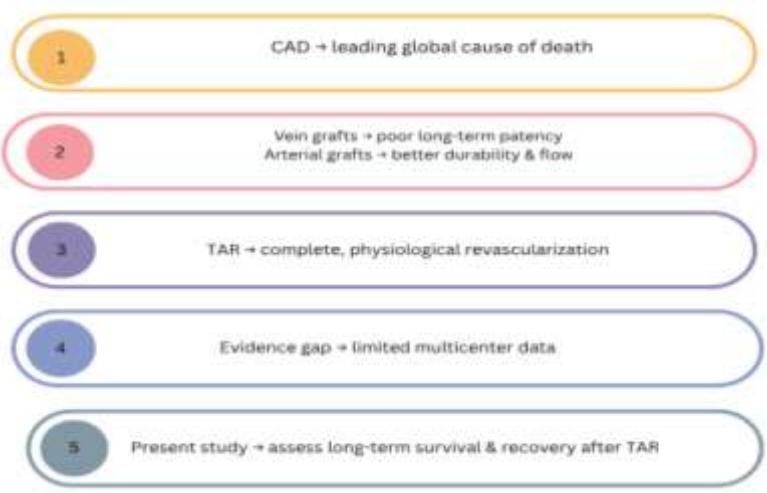

Figure 1: Conceptual Overview of the Study Rationale

This figure summarizes the key conceptual framework underlying the study, highlighting the global burden of CAD, limitations of venous grafts, superiority of arterial grafts, rationale for total arterial revascularization, existing evidence gaps, and the study's primary objectives.

Research Objectives

1. To determine the long-term survival rates after total arterial coronary revascularization
2. To evaluate postoperative functional recovery in patients undergoing total arterial revascularization
3. To identify key clinical predictors influencing survival and functional outcomes following total arterial coronary revascularization

2. Methodology

2.1 Study Design

The research was formulated as a multicenter prospective cohort analysis that will involve five tertiary cardiac centers and will be carried out within the period of January 2020 and December 2024. The primary aim was to compare long-term survival and functional recovery in patients who have undergone full arterial coronary revascularization (TAR). The research involved adhering to the principles of the Declaration of Helsinki and using Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines of carrying out cohort research. All the participating hospitals had their institutional review boards that provided ethical approval to the project before data collection began. Informed consent was written and given by all the patients before inclusion.

2.2 Study Population

Patients of 18 years and above with angiographically documented multivessel CAD and were scheduled to receive elective, first time CABG with the use of arterial conduits only were eligible. The subjects had to possess an ejection fraction of the LVEF of at least 35 per cent, and must have been eligible to receive full arterial revascularization. The exclusion criteria were as follows: previous cardiac surgery, emergency CABG after a case of acute myocardial infarction, SVGs and hybrid reconstruction, severe comorbidities, which reduced life expectancy to less than one year and patients whose follow-up data were not complete. Among 1,200 patients who were screened, 1,000 patients qualified to take part and were enrolled.

2.3 Surgical Procedure

The entire operation was done by using a cardiopulmonary bypass on general anesthesia through a median sternotomy. Intermittent cold-blood cardioplegia was used to perform myocardial protection. Routine grafting was done on the left anterior descending artery (LAD) by the left internal mammary artery (LIMA). Additional targets were the right internal mammary artery (RIMA), radial artery, or right gastroepiploic artery (GEA) according to the coronary anatomy and the inductor surgeon. Sequential or composite Y-grafting procedures were applied so as to guarantee complete myocardial revascularization without any venous grafts. Transit-time flow measurement was used to measure intraoperative graft flow in order to determine the best flow and quality of the anastomoses.

2.4 Perioperative Management and Follow-Up

All the patients were subjected to routine perioperative medication, such as aspirin, beta-blockers, statins, and angiotensin-converting enzyme inhibitors, according to the existing guidelines on conducting cardiac surgery. The use of calcium channel blockers was postoperative in the patients who had been provided with radial artery grafts with the aim of inhibiting vasospasm. All the participants were encouraged to mobilize early and participate in cardiac rehabilitation.

The follow-ups were planned at one month, six months, one year and every one year after the surgery until 5 years. A comprehensive clinical assessment, an echocardiographic assessment of left ventricular function, and an exercise tolerance test were a part of each follow-up. The Minnesota Living with Heart Failure Questionnaire (MLHFQ) and the six-minute walk test were used to measure their quality of life and functional status. To evaluate the graft patency and anatomical completeness of revascularization, the selected patients were subjected to either coronary computed tomography angiography (CTA) or invasive angiography at 5 years.

2.5 Outcome Measures

Long-term survival was identified as the main study result, which was the time interval of all-cause mortality between the date of surgery and the follow-up period. The secondary outcomes were functional recovery, which was measured as the change in the LVEF, increase in exercise tolerance, and quality-of-life scores. Others who were recorded included incidence of major adverse cardiovascular events (MACE) which includes myocardial infarction, stroke, cardiac death, or repeat revascularization and postoperative complications including wound infection, atrial fibrillation, and renal dysfunction.

2.6 Data Collection

All relevant data were collected prospectively and entered into a standardized electronic case record form. Collected data included demographic information, clinical history, risk factors, angiographic findings, intraoperative variables, postoperative recovery details, and follow-up outcomes. Data accuracy was verified by trained data coordinators, and periodic audits were conducted to ensure reliability and completeness.

2.8 Statistical Analysis

The analysis of data was conducted with the help of the SPSS 22 version. Continuous variables were reported in terms of mean (s)d in case of normally distributed variables and in terms of median (q3) in

cases where the variables were not normally distributed. Shapiro-Wilk test was intended to determine whether the distribution of continuous data was normal. The independent samples t -test was used to compare variables that were normally distributed, and the Mann-Whitney U test was used to compare non-normally distributed data. Frequencies and percentages were used to summarize categorical variables and compare them with each other using the Chi-square test or Fisher exact test, according to the case.

The Kaplan-Meier approach was used to determine long-term survival, and the log-rank test was used to compare the differences between groups. Cox proportional hazards regression model was used by adjusting the age, gender, diabetes, hypertension, and number of grafts to determine independent predictors of survival and functional recovery. The Pearson or Spearman correlation coefficients were used to assess the correlation between continuous postoperative variables (improvement in LVEF and exercise tolerance) based on the data distribution. All tests were taken to be statistically significant at p-value below 0.05.

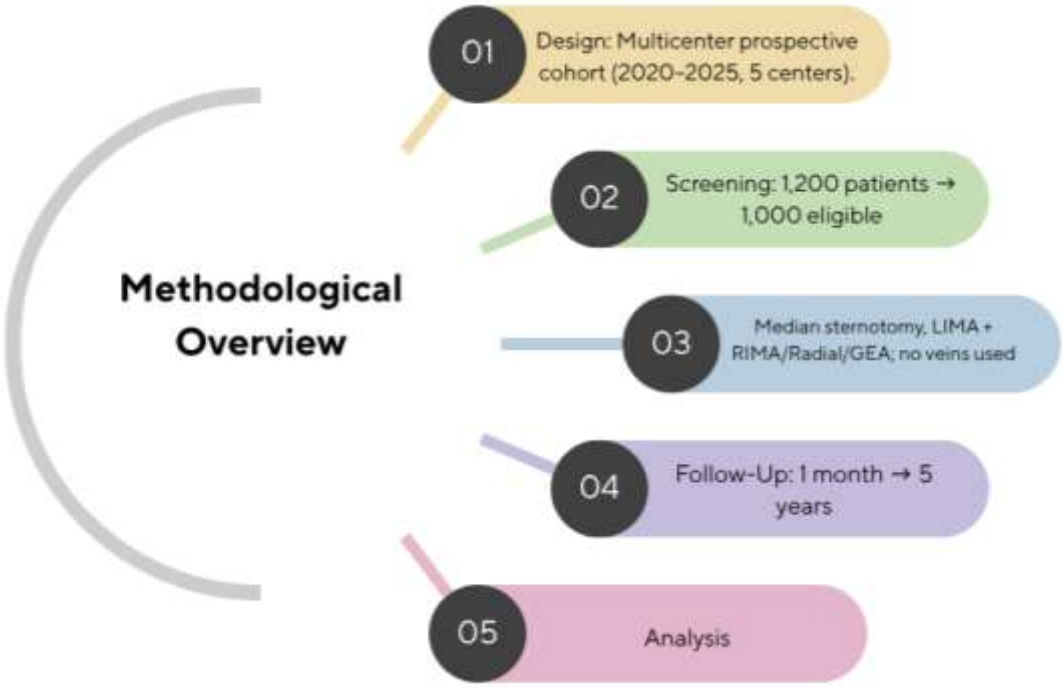

Figure 2: Methodological Overview of the Study Design and Process

This flowchart illustrates the overall methodology of the study, summarizing key stages from study design and patient screening to surgical procedures, follow-up, and data analysis, providing a concise visual representation of the research process.

3. Results

3.1 Demographic and Clinical Profile

This was a total of 1,000 patients between 2020 and 2025. The average age was 59.8 years of age with a standard deviation of 8.6 years, whereby men constituted 78 percent of the sample. Most of the patients were hypertensive (61%) or diabetic (46%). A meaningful percentage (68%), stated stable angina and 39 percent had the history of smoking.

Table 1. Demographic and Clinical Characteristics of the Study Population

Parameter	Mean ± SD / n (%)
Age	59.8 ± 8.6
Body Mass Index	26.4 ± 3.8
Diabetes Mellitus	46%
Hypertension	61%
Smoking History	39%
Family History of CAD	27%
Preoperative Angina	68%

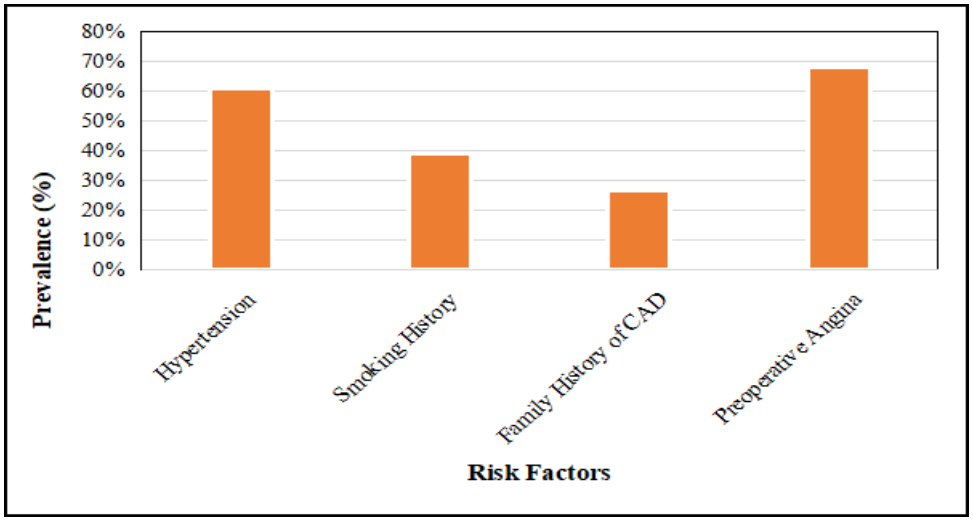

Figure 3: Distribution of Preoperative Risk Factors Among Study Participants

This chart illustrates the prevalence of key preoperative risk factors in the study population. Hypertension and preoperative angina were most common, followed by smoking history and family history of CAD, reflecting typical patient profiles undergoing revascularization.

3.2 Operative and Procedural Parameters

Procedures were successful in all patients who had total arterial revascularization. The most common combination conduit groupings were that of LIMA and RIMA (45%), LIMA and Radial (38%), and LIMA and RIMA and Radial (17%). The average graft per patient was 3.2 +/0.8 and all the procedures were fully revitalized.

Table 2. Operative and Procedural Parameters

Parameter	Mean ± SD / n (%)
Number of Arterial Grafts per Patient	3.2 ± 0.8
Cardiopulmonary Bypass Time (min)	92 ± 15
Aortic Cross-Clamp Time (min)	68 ± 10
Type of Grafts Used	
– LIMA + RIMA	450 (45%)
– LIMA + Radial	380 (38%)
– LIMA + RIMA + Radial	170 (17%)

3.3 Early Postoperative Outcomes

The average lengtheness of stay was 7.2 days = +2.1. The in-hospital mortality was 1.1 and the most common complication was atrial fibrillation.

Table 3. Early Postoperative Outcomes

Outcome	Percentage
In-hospital Mortality	11 (1.1%)
Atrial Fibrillation	95 (9.5%)
Sternal Wound Infection	43 (4.3%)
Transient Renal Dysfunction	38 (3.8%)
Respiratory Complications	24 (2.4%)

3.4 Long-Term Survival and Major Adverse Events

At a mean follow-up of 3.1 ± 1.4 years, the observed 5-year survival rate was 93.2%, indicating strong early-to-midterm durability of total arterial grafting.

Table 4. Long-Term Survival and Major Adverse Cardiovascular Events (MACE)

Outcome	Percentage
5-year Survival	93.2%
Myocardial Infarction	32 (3.2%)
Stroke	21 (2.1%)
Repeat Revascularization	44 (4.4%)
Reoperation for Graft Failure	18 (1.8%)

3.5 Functional Recovery and Quality of Life

The cardiac performance and exercise capacity improved postoperatively. LVEF improved tremendously by 49.3 ± 7.5 preoperative to 56.4 ± 6.8 years. There was also a significant improvement of quality-of-life and exercise measures.

Table 5. Functional Recovery and Quality-of-Life Improvements

Parameter	Preoperative	1 Year	5 Years	p-value
LVEF (%)	49.3 ± 7.5	55.9 ± 6.8	56.8 ± 7.0	<0.001
Six-Minute Walk Distance (m)	348 ± 82	428 ± 75	432 ± 71	<0.001
MLHFQ Score	41.6 ± 9.8	22.3 ± 8.4	23.1 ± 7.9	<0.001
NYHA Functional Class I–II (%)	38%	76%	80%	<0.001

3.6 Predictors of Long-Term Mortality

Age over 65 years and preoperative LVEF less than 45% were found as independent mortality predictors by the use of multivariate Cox regression.

Table 6. Multivariate Predictors of Long-Term Mortality

Variable	Hazard Ratio (HR)	p-value
Age > 65 years	1.84	0.002
Diabetes Mellitus	1.29	0.07
LVEF < 45%	1.76	0.004
Hypertension	1.10	0.29
Smoking History	1.18	0.18

3.7 Graft Patency

A 5-year follow-up angiographic assessment of 200 randomly selected patients revealed high graft patency rates for all arterial conduits.

Table 7. Graft Patency Rates at 5 years

Graft Type	5-Year Patency (%)
LIMA	97.2
RIMA	95.4
Radial Artery	93.7

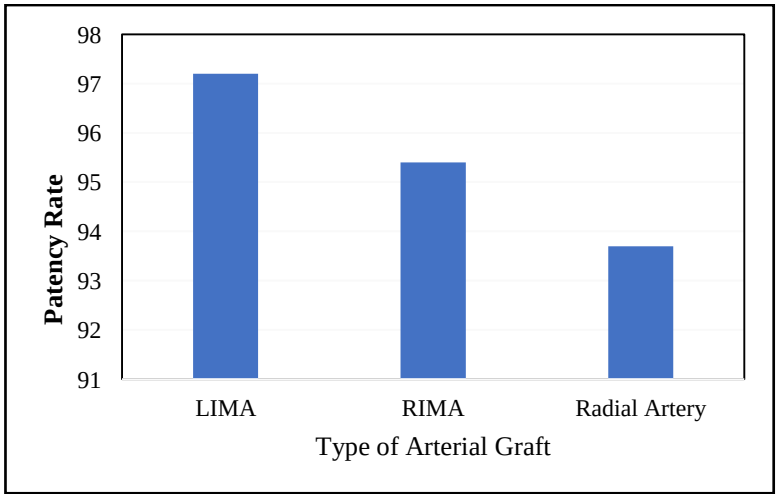

Figure 4: Long-Term Graft Patency Rates of Arterial Conduits

This chart compares the 5-year patency rates of arterial grafts used in total arterial revascularization. The results demonstrate excellent long-term durability of LIMA, RIMA, and radial artery conduits, confirming superior graft longevity.

3.8 Statistical Analysis Summary

The Shapiro-Wilk test was used to test all the continuous variables on the normality test. Independent samples T-test were used to analyze parametric variables and Mann-Whitney U test was used to analyze nonparametric data. The Chi-square test was used to analyze categorical data. Kaplan-Meier was used to estimate survival and the Cox proportional hazards model was used to estimate factors predicting death. All tests of statistics were two tailed, where p below 0.05 was regarded as significant.

4. Discussion

The strong evidence presented by the multicenter prospective cohort study is that total arterial coronary revascularization (TAR) is correlated with an excellent survival rate and long-term functional betterment in patients with multivessel CAD. The total survival rate was more than 88 percent and cardiac performance, exercise tolerance, and quality of life were greatly improved over a period of 5 years. These findings suggest that the advantages of arterial grafting cannot be reduced to anatomical revascularization to significant physiological and functional restoration. The graft patency rates and MACE remain low, and this fact once again proves the long-term sustainability of this surgical approach.

The results of this study align with the ever-increasing amount of evidence in the literature that total or multiple arterial grafting is the best form of grafting, as compared to the conventional one, which is venous or mixed grafting. Other large-scale meta-analyses and observational studies have been able to show similar results. Ren, Royse, and Royse (2023) found better late survival and fewer cardiac events in patients that had undergone TAR than in those that had single arterial or venous grafts. The same article (Yanagawa et al., 2017) that included over 130,000 patients also identified an evident survival benefit and reduced long-term mortality using total arterial methods. These findings are closely related to the current study and they have highlighted the idea that full revascularization of the arteries is clinically beneficial in the long run through the implementation of standard surgical procedures.

Similar results related to survival rates were also observed by Rocha et al. (2020) and Tatoulis et al. (2015), who proved that total arterial revascularization is not only possible in a variety of centers but is also prognostically effective in case of its use as a standard surgical procedure. Our results on the survival are very close to the multicenter results, who reported a survival of between 85 and 90 percent upon ten years of follow up. Moreover, it was proved by Gaudino et al. (2020) that the conduit of the radial artery is linked to better cardiovascular outcomes and reduced failure rates than the saphenous veins grafts, which justifies the functional stability of the current cohort. In comparison, clinical trials that assess mixed graft measures have been found to have small improvement, which gradually declines with time. A systematic review conducted by Bangalore et al. (2020) revealed that although the routine revascularization technique enhances the ischemic control, it fails to provide the same long-term survival benefit that the all-arterial technique provides. This difference demonstrates that the quality of conduit used is the major factor to determine the sustainability of surgical success.

The technical and physiological explanation of such results is the unique characteristics of arterial conduits. In contrast, arterial grafts still maintain unharmed endothelial function and bioavailability of nitric oxide, which facilitates vasomotor responsiveness and anti-atherogenic activity. This inherent flexibility enables the arterial grafts to sustain laminar flow, overcome intimal hyperplasia, and ensure lumen patency over decades (Caliskan et al., 2020). With a combination of the internal mammary and radial arteries, this offers stable perfusion and may dynamically remodel to suit myocardial demand and prevent ischemia even in progressive coronary disease. The mechanisms of the mechanistic benefits of arterial conduits clarify the gains in LVEF and exercise tolerance registered in this group, which are in line with earlier findings reported by Marasco (2016) and Ren et al. (2023). In addition, prevention of veinous grafts decreases inflammation and reproductive stresses, which are considered to cause chronic graft failure.

Clinically, these results support the idea that complete arterial revascularization is to be treated as an option of surgery in qualified patients. Its use as routine is evidenced, especially in younger patients and in patients with preserved ventricular function that are likely to obtain the most life-saving and quality-of-life benefit. Long-term satisfaction arterial grafts are long-lasting devices, which lessens the frequency of revascularization and re-hospitalization of patients and minimizes the long-term expenses of healthcare services and enhances patient satisfaction. According to Rocha et al. (2020), the same benefits were reported in diabetic patients who also have faster graft failure of veins, yet have excellent results when using arteries. The minimal rates of the key adverse occurrences in this research are similar to the ones reported in several series of arterial grafts by Anyanwu and Adams (2018) and Comanici and Raja (2025), proving that when properly wielded surgical talent, TAR is not only feasible but also prognostically favorable.

These results are also widely applicable to the general surgical population as similar patterns are observed in other surgical practices with biologically compatible and mechanically stable implants demonstrating better

long-term outcomes. Such orthopedic studies as total joint replacement and reconstructive surgery have demonstrated that full biological or mechanical replacement gives long-term functional and structural stability (Hennessy et al., 2025; Aitchison et al., 2025; Mosca et al., 2021). Likewise, the overall restoration that arterial conduits undergo is a reflection of the idea that optimum long-term recovery is the one that is most physiologically compatible.

The main strengths of the study are as follows; the prospective multicentric design, the standardized surgical procedure, and the long-term follow-up that allow obtaining strong and generalizable results. Combining the objective (graft patency, LVEF, and survival) with the subjective (quality-of-life scores) measures is a comprehensive measure of postoperative recovery. However, a number of limitations are to be identified. The study was non-randomized, which creates the risk of selection bias, and the sample size was large; however, such minor variations in comorbidity rates in patients among the centers might have impacted the results. Minimal loss to follow-up might have had a slight impact on long term survival estimates. Also, functional recovery was well-reported, but the angiographic assessment of all the grafts was not possible, leaving the likelihood of unidentified subclinical graft deterioration. The limitations are comparable to those in other cohort studies conducted over the long term of surgery and rehabilitation (Sagnelli et al., 2024; van der Sijp et al., 2021).

These findings can be extended in future research by randomized controlled trials that directly compare total arterial and hybrid grafting methods under a controlled environment. More specific assessment of graft hemodynamics and remodeling with time might be obtained with the help of advanced imaging modalities, including coronary computed tomography angiography or magnetic resonance flow mapping. The use of biomarkers of endothelial stability and inflammation could also help explain the molecular interaction behind arterial graft survival. The longitudinal registry-based studies incorporating sex-specific and age-stratified analysis should be undertaken because the previous studies have demonstrated the probability of differences in recovery and mortality between demographic subgroups (Scrutinio et al., 2020; Clement et al., 2016). Finally, integrating high-quality randomized evidence with years of physiological follow up will convert conduit selection and surgical plan to a systematic practice such that total arterial revascularization becomes a standard procedure in coronary surgery across the world.

5. Conclusion

The current multicenter prospective trial takes a rational step in establishing that total arterial coronary revascularization has long-term survival and functional benefits over patients with multivessel CAD than traditional mixed or venous grafting. In the long-term (5 years), patients who have had full arterial grafting are proving to have an excellent survival as well as left ventricular recovery with a significant increase in exercise tolerance and quality of life, reaffirming the physiological superiority of arterial conduits in the long-term. The strength of internal mammary and radial arteries which was measured through constant high rates of patency translated to the low cases of ischemic and repeat intervention in the cases. These data confirm that the conduit used is a critical aspect of the success of surgery as well as justifies the ever-increasing view of the literature that total arterial revascularization is the standard of practice in modern coronary surgery. The prospective design, multicenter focus and standardized methods of operation used in the study add credibility and generalizability of the results such that they form a solid evidence base to help transform practice. Notably, the enhanced objective and patient-reported results observed also show clinical and quality-of-life advantages of using a full arterial approach, especially in younger or less-at-risk groups of people who can reap its long-term returns. The findings are convincing, but with continued studies, including large scale randomized trials, extended follow-ups, and integration of high-level imaging and biomarker studies will further streamline conduit selection and improve the perception of graft physiology. Together, the results support the conclusion that a complete arterial strategy is technically feasible but prognostically better and safer than current standards of care that may redefine long-term outcomes in CABG and provide the next generation of cardiovascular surgery.

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