Section: CTVS

Original Research Article

ASSOCIATION BETWEEN RADIAL ARTERY CALCIFICATION AND FOLLOW-UP PATENCY OF RADIAL ARTERY GRAFTS AFTER CORONARY ARTERY BYPASS GRAFTING: A RETROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Radial artery grafts provide favourable patency after coronary artery bypass grafting (CABG). However, pre-existing radial artery calcification may impair conduit quality and increase the risk of graft failure.
Objective: To determine the association between radial artery calcification and follow-up patency of radial artery grafts after CABG.
Materials and Methods: This retrospective observational study included 164 patients aged 35–75 years who underwent isolated CABG using a radial artery graft at SRM Medical College Hospital and Research Centre, Kattankulathur, Tamil Nadu, between January 2023 and June 2025. Calcification was assessed using preoperative duplex ultrasonography. Graft patency was evaluated using coronary computed tomography angiography or invasive coronary angiography. Graft failure was defined as complete occlusion or ≥50% luminal stenosis. Multivariable logistic regression was used to identify factors independently associated with graft failure.
Results: Radial artery calcification was detected in 46 patients (28.0%). At six-month follow-up, graft failure occurred in 14 of 46 patients with calcification (30.4%) and 13 of 118 patients without calcification (11.0%; *P*=0.003). Calcification was associated with increased odds of graft failure on unadjusted analysis (odds ratio [OR], 3.53; 95% confidence interval [CI], 1.52–8.23; *P*=0.004). After adjustment for age, diabetes mellitus, chronic kidney disease and target-vessel stenosis, calcification remained independently associated with graft failure (adjusted OR, 2.84; 95% CI, 1.15–7.02; *P*=0.024).
Conclusion: Preoperative radial artery calcification was independently associated with reduced follow-up graft patency after CABG. Prospective multicentre studies are required to confirm its role in conduit selection.
Keywords: Coronary artery bypass grafting; radial artery; vascular calcification; graft patency; duplex ultrasonography.

INTRODUCTION

Coronary artery disease is a major cause of morbidity and mortality and frequently requires revascularisation in patients with complex multivessel or left-main coronary disease. Coronary artery bypass grafting (CABG) remains an established treatment for selected patients, particularly those with diabetes mellitus, extensive coronary disease or anatomy unsuitable for percutaneous coronary intervention. The durability of CABG depends largely on the long-term performance of the selected conduits. Although the left internal thoracic artery is the preferred conduit for the left anterior descending coronary artery, the choice of a second conduit remains clinically important. Current revascularisation guidelines recommend the radial artery over the saphenous vein for grafting a suitable, significantly stenosed non-left-anterior-descending target vessel.[1]

The radial artery was initially used for coronary revascularisation in the 1970s but was abandoned because of early graft occlusion, predominantly attributed to vasospasm, traumatic harvesting and inappropriate target-vessel selection. Improved harvesting techniques, antispasmodic therapy and postoperative angiographic observations led to renewed interest in the radial artery during the 1990s.[2] The radial artery offers several practical advantages, including sufficient length, an appropriate luminal diameter, a relatively thick arterial wall and ease of harvesting. It can be used as an aortocoronary graft or as part of a composite arterial grafting configuration.

Randomised evidence has demonstrated that radial artery grafts have better angiographic outcomes than conventionally harvested saphenous vein grafts. In the Radial Artery Patency Study, radial artery grafts had a lower rate of complete occlusion at one year than saphenous vein grafts.[3] Five-year angiographic follow-up from the Radial Artery Versus Saphenous Vein Patency trial similarly demonstrated superior radial artery graft patency when the conduit was placed on a severely stenosed circumflex coronary artery.[4] A pooled analysis of randomised trials subsequently found that the use of a radial artery rather than a saphenous vein graft was associated with fewer adverse cardiac events and better graft patency at five years.[5]

The clinical benefits of radial artery grafting appear to extend beyond early angiographic outcomes. An individual-participant-data meta-analysis with a median follow-up of approximately 10 years showed that radial artery grafting was associated with a lower risk of death, myocardial infarction or repeat revascularisation than saphenous vein grafting.[6] A network meta-analysis of randomised trials ranked the radial artery among the most durable CABG conduits and reported a lower graft-occlusion rate than conventionally harvested saphenous vein grafts.[7] Long-term observational angiographic studies have also demonstrated sustained radial artery graft patency when the conduit is used for appropriately selected coronary targets.[8]

Despite these advantages, the radial artery is not uniformly suitable for every patient. As a muscular artery, it has a prominent medial layer and is more susceptible to vasospasm than the internal thoracic artery. Pre-existing structural abnormalities, including intimal hyperplasia, atherosclerosis and medial calcification, may also be present before harvesting. Histopathological examination of radial artery segments has demonstrated that intimal disease and calcification occur more frequently among older patients and those with diabetes mellitus, hypertension, smoking exposure, peripheral arterial disease or chronic kidney disease.[9] Comparative histopathological studies have further shown that the radial artery may exhibit more intimal hyperplasia and atherosclerotic changes than the internal thoracic artery.[10]

Preoperative assessment is therefore important for identifying an unsuitable radial artery and confirming adequate collateral circulation to the hand. Duplex ultrasonography can provide information about arterial diameter, flow, intimal thickening, atherosclerosis and calcification. A preoperative ultrasonographic study reported that radial arteries were rejected because of small diameter, diffuse atherosclerosis, calcification or severe neointimal hyperplasia, demonstrating the potential value of imaging in conduit selection.[11] Doppler-based assessment may also help identify focal distal disease and allow the surgeon to use an unaffected proximal segment when clinically appropriate.

Radial artery graft patency is influenced by factors beyond the structural quality of the conduit. Competitive flow from a moderately stenosed native coronary artery is a recognised cause of radial graft failure. Small target-vessel diameter, diabetes mellitus and peripheral vascular disease may also increase the risk of graft occlusion, whereas severe proximal target-vessel stenosis generally favours radial artery graft patency.[12] Meta-analyses comparing radial artery and saphenous vein conduits have demonstrated better long-term survival and graft-related outcomes with radial artery grafting, although differences in patient selection, target-vessel anatomy and operative technique must be considered.[13] Postoperative calcium-channel blocker therapy may reduce radial artery spasm and has been associated with improved radial graft outcomes.[14] However, pharmacological vasodilatation may not fully overcome the adverse mechanical and biological effects of established arterial-wall calcification.

Radial artery calcification may reduce arterial compliance, impair endothelial-dependent vasodilatation and limit adaptive remodelling after the conduit is exposed to coronary circulation. Calcified segments may also be more difficult to harvest and anastomose, potentially increasing endothelial injury, technical stenosis or thrombosis. Studies comparing Doppler measurements with radial artery morphometry and histopathology support the value of preoperative imaging for evaluating conduit dimensions and structural quality.[15] Nevertheless, direct evidence regarding the association between radial artery calcification and subsequent graft patency remains limited, particularly among Indian patients undergoing CABG.

Therefore, the present study aimed to evaluate the association between radial artery calcification and follow-up patency of radial artery grafts among patients aged 35–75 years who underwent CABG at SRM Medical College Hospital and Research Centre, Kattankulathur, between January 2023 and June 2025. The secondary objectives were to determine the prevalence and severity of radial artery calcification, identify clinical factors associated with calcification and compare major adverse cardiovascular events and repeat revascularisation between patients with and without radial artery calcification.

MATERIALS AND METHODS

Study Design

This was a hospital-based, single-centre, retrospective observational cohort study. The medical records of patients aged 35–75 years who underwent coronary artery bypass grafting using at least one radial artery graft at SRM Medical College Hospital and Research Centre, Kattankulathur, Tamil Nadu, India, between January 2023 and June 2025 were reviewed. Patients were classified according to the presence or absence of radial artery calcification, and follow-up graft patency was compared between the two groups.

Study Setting

The study was conducted in the Department of Cardiothoracic and Vascular Surgery at SRM Medical College Hospital and Research Centre, Kattankulathur, Chengalpattu District, Tamil Nadu, India. The institution is a tertiary-care teaching hospital providing comprehensive cardiac evaluation, coronary angiography, coronary artery bypass grafting and postoperative cardiac follow-up services. Patient information was obtained from hospital medical records, operative registers, preoperative imaging reports, discharge summaries and follow-up graft-imaging records.

Study Population

The study included 164 consecutive patients aged 35–75 years who underwent primary isolated coronary artery bypass grafting using at least one radial artery graft at SRM Medical College Hospital and Research Centre, Kattankulathur. Patients were eligible if they had documented preoperative radial artery assessment, complete operative records and an interpretable graft-patency assessment during the six-month postoperative follow-up. Patients with previous coronary artery bypass grafting, concomitant valve or aortic surgery, emergency salvage surgery, previous radial artery harvesting, inadequate collateral hand circulation, significant upper-limb arterial disease, incomplete medical records or unavailable six-month graft-patency data were excluded.

Inclusion Criteria

1. Patients aged 35–75 years at the time of surgery.
2. Patients who underwent primary isolated coronary artery bypass grafting using at least one radial artery graft.
3. Patients with documented preoperative radial artery assessment, including duplex ultrasonographic evaluation for calcification.
4. Patients with complete clinical, operative and postoperative medical records.
5. Patients with completed six-month clinical follow-up and interpretable graft-patency assessment by coronary computed tomography angiography or invasive coronary angiography.

Exclusion Criteria

1. Patients with previous coronary artery bypass grafting, concomitant major cardiac surgery or emergency salvage surgery.
2. Patients with previous radial artery harvesting, transradial intervention or significant trauma involving the radial artery selected for grafting.
3. Patients with inadequate collateral hand circulation or significant upper-limb arterial disease.
4. Patients with incomplete preoperative radial artery assessment or missing essential operative information.
5. Patients without six-month follow-up or with unavailable, incomplete or uninterpretable graft-patency imaging.

Sampling Method and Sample Size

A consecutive census sampling method was used, and all patients who fulfilled the eligibility criteria during the study period were included. As this was a retrospective study involving a fixed hospital-based cohort, no prospective sample-size calculation was performed. A total of 164 eligible patients with complete preoperative radial artery assessments and six-month graft-patency data were included in the final analysis.

Preoperative Assessment of the Radial Artery

Before surgery, the suitability of the radial artery for harvesting was evaluated by clinical examination, the modified Allen test and duplex ultrasonography. The modified Allen test was used to confirm adequate collateral circulation through the ulnar artery and palmar arch; restoration of normal palmar colour within 5–10 seconds after release of ulnar artery compression was considered satisfactory. Duplex ultrasonography was used to assess radial artery diameter, luminal patency, blood-flow pattern, intimal thickening, atherosclerotic changes, focal stenosis and arterial-wall calcification. Calcification was defined as a focal or diffuse echogenic lesion within the radial arterial wall accompanied by posterior acoustic shadowing and was classified as mild when involving less than 25% of the arterial circumference, moderate when involving 25%–50%, and severe when involving more than 50%. For the primary analysis, patients were categorised as having either any detectable radial artery calcification or no calcification.

Surgical Technique

The decision to use the radial artery as a coronary conduit was made after confirming adequate collateral hand circulation and reviewing the preoperative duplex ultrasonography findings. The non-dominant radial artery was preferred when both upper limbs were suitable. The conduit was harvested using an open pedicled technique with careful preservation of the surrounding tissue and avoidance of excessive manipulation, mechanical dilatation and thermal injury. After harvesting, the radial artery was flushed and stored in a papaverine-containing vasodilator solution. It was used either as an aortocoronary free graft or as part of a composite arterial graft, depending on the coronary anatomy, conduit length and surgeon's preference. The radial artery was predominantly grafted to the circumflex or right coronary artery territory, preferably when the target vessel had at least 70% proximal stenosis to minimise competitive flow. The left internal thoracic artery was preferentially used for grafting the left anterior descending coronary artery.

Postoperative Treatment

All patients received antiplatelet therapy after CABG unless clinically contraindicated. Aspirin was initiated within the early postoperative period and continued during follow-up. Dual antiplatelet therapy was prescribed when indicated by the patient's clinical condition. All patients received statin therapy, and beta-blockers, angiotensin-converting enzyme inhibitors or angiotensin receptor blockers were administered when appropriate. Calcium-channel blocker therapy was initiated postoperatively to reduce radial artery vasospasm and was continued for six months unless limited by hypotension, bradycardia, intolerance or another contraindication. Medication use and adherence were assessed from discharge summaries and follow-up records.

Assessment of Graft Patency

Radial artery graft patency was assessed at six months after CABG, within an acceptable follow-up window of five to seven months, using coronary computed tomography angiography or invasive coronary angiography. The imaging modality, date of examination and interval from surgery were documented. A graft was classified as patent when there was uninterrupted contrast opacification with less than 50% luminal stenosis, significantly stenosed when luminal narrowing was 50% or greater with maintained distal opacification, and occluded when there was complete absence or interruption of contrast flow. The primary outcome was radial artery graft failure, defined as complete occlusion or stenosis of 50% or greater. When both imaging modalities were available, the invasive coronary angiography finding was used for outcome classification.

Data Collection

Patient information was obtained retrospectively from electronic medical records, operative registers, anaesthesia records, preoperative coronary angiograms, radial artery duplex ultrasonography reports, discharge summaries and six-month graft-imaging records. Data were entered into a standardised data-collection form. The collected variables included age, sex, body mass index, diabetes mellitus, hypertension, dyslipidaemia, smoking status, chronic kidney disease, peripheral arterial disease, previous myocardial infarction, left ventricular ejection fraction, serum creatinine, radial artery calcification status and severity, harvesting technique, graft configuration, target coronary artery, target-vessel diameter and stenosis, cardiopulmonary bypass use, postoperative medications, graft-patency findings and six-month clinical outcomes. The recorded outcomes included graft failure, all-cause mortality, myocardial infarction and repeat coronary revascularisation.

Control of Bias

Consecutive inclusion of all eligible patients was used to reduce selection bias. The definitions of radial artery calcification, graft patency and graft failure were established before data analysis. Preoperative ultrasonography and postoperative graft-imaging findings were reviewed using standardised criteria. Investigators assessing graft patency were blinded to the preoperative calcification category wherever possible. Clinical and operative information was cross-checked using multiple source documents to reduce data-entry and classification errors. The number of patients excluded because of missing records, unavailable follow-up or uninterpretable imaging was documented. A sensitivity analysis excluding patients who underwent symptom-driven invasive coronary angiography was performed to evaluate the potential effect of verification bias.

Statistical Analysis

Statistical analysis was performed using R statistical software, version 4.3.2 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were assessed for normality using the Shapiro–Wilk test and expressed as mean with standard deviation or median with interquartile range, as appropriate; comparisons were performed using the independent-samples *t* test or Mann–Whitney *U* test. Categorical variables were presented as frequency and percentage and compared using the chi-square test or Fisher's exact test. Univariable logistic regression was used to estimate the crude association between radial artery calcification and six-month graft failure. Because of the limited number of outcome events, Firth penalised multivariable logistic regression was performed using the logistf package, with adjustment for age, diabetes mellitus, chronic kidney disease and percentage target-vessel stenosis. Results were reported as odds ratios with 95% confidence intervals. Calcification severity was evaluated as an ordinal variable in a secondary analysis, and sensitivity analyses were conducted by restricting the outcome to complete graft occlusion and excluding symptom-driven invasive angiography. All statistical tests were two-sided, and a *P* value below 0.05 was considered statistically significant.

Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee of SRM Medical College Hospital and Research Centre, Kattankulathur. As this study involved a retrospective review of existing medical records without direct patient contact or additional intervention, ethical requirements regarding informed consent were followed in accordance with institutional policy. All patient data were de-identified before analysis, confidentiality was maintained throughout the study, and no personally identifiable information was included in the manuscript.

RESULTS

Participant Selection

A total of 187 patients who underwent CABG using a radial artery graft were assessed for eligibility. Twenty-three patients were excluded: nine did not have interpretable six-month graft imaging, six had incomplete preoperative radial artery assessments, five underwent concomitant major cardiac surgery and three had incomplete operative records. The final analysis included 164 patients who fulfilled the eligibility criteria and completed the six-month follow-up.

Baseline Characteristics

The mean age of the study population was 59.8 ± 9.1 years, and 126 patients (76.8%) were men. Diabetes mellitus was present in 85 patients (51.8%), hypertension in 119 (72.6%), dyslipidaemia in 103 (62.8%), chronic kidney disease in 23 (14.0%) and current or previous smoking in 74 (45.1%).

Preoperative duplex ultrasonography identified radial artery calcification in 46 patients (28.0%), while 118 patients (72.0%) had no detectable calcification. Patients with calcification were older than those without calcification (64.2 ± 7.1 versus 58.1 ± 9.2 years; P<0.001). Diabetes mellitus (65.2% versus 46.6%; P=0.032) and chronic kidney disease (26.1% versus 9.3%; P=0.006) were more frequent in patients with calcification. Other baseline characteristics were comparable between the groups. [Table 1]

Table 1: Baseline characteristics according to radial artery calcification status

Characteristic	Overall (N=164)	Calcification (n=46)	No calcification (n=118)	*P* value
Age, years, mean ± SD	59.8 ± 9.1	64.2 ± 7.1	58.1 ± 9.2	<0.001
Male sex, n (%)	126 (76.8)	36 (78.3)	90 (76.3)	0.783
Body mass index, kg/m², mean ± SD	26.3 ± 3.5	26.8 ± 3.4	26.1 ± 3.6	0.260
Diabetes mellitus, n (%)	85 (51.8)	30 (65.2)	55 (46.6)	0.032
Hypertension, n (%)	119 (72.6)	36 (78.3)	83 (70.3)	0.306
Dyslipidaemia, n (%)	103 (62.8)	31 (67.4)	72 (61.0)	0.451
Current/former smoking, n (%)	74 (45.1)	24 (52.2)	50 (42.4)	0.260
Chronic kidney disease, n (%)	23 (14.0)	12 (26.1)	11 (9.3)	0.006
Previous myocardial infarction, n (%)	53 (32.3)	18 (39.1)	35 (29.7)	0.245
LVEF, %, mean ± SD	48.6 ± 8.4	47.2 ± 8.8	49.1 ± 8.2	0.192
Serum creatinine, mg/dL, median (IQR)	1.10 (0.90–1.40)	1.20 (1.00–1.60)	1.00 (0.90–1.30)	0.018

IQR: interquartile range; LVEF: left ventricular ejection fraction; SD: standard deviation.

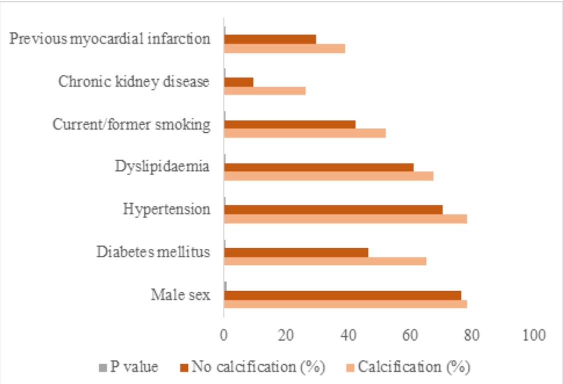

Figure 1: Comparison of baseline clinical characteristics between patients with and without radial artery calcification

Notes: Bars represent the percentage of patients with each categorical baseline characteristic in the radial artery calcification group (n=46) and no-calcification group (n=118). Between-group comparisons were performed using the chi-square test or Fisher's exact test, as appropriate. A *P* value <0.05 was considered statistically significant. Diabetes mellitus (*P*=0.032) and chronic kidney disease (*P*=0.006) were significantly more frequent in patients with radial artery calcification. Continuous variables such as age, body mass index, left ventricular ejection fraction, and serum creatinine are not included in this figure.

Calcification Severity

Among the 46 patients with radial artery calcification, mild calcification was observed in 25 patients (54.3%), moderate calcification in 15 (32.6%) and severe calcification in six (13.0%). In the overall cohort, these categories represented 15.2%, 9.1% and 3.7% of patients, respectively.

Operative and Graft Characteristics

The radial artery was grafted to the circumflex coronary territory in 119 patients (72.6%) and to the right coronary territory in 45 patients (27.4%). An aortocoronary radial artery graft was used in 137 patients (83.5%), while 27 (16.5%) received a composite radial artery graft. The median target-vessel stenosis was 85% (IQR, 80%–90%). No statistically significant differences were observed between the groups in cardiopulmonary bypass use, target coronary territory, graft configuration, target-vessel stenosis or discharge medication. [Table 2]

Table 2: Operative and graft characteristics

Characteristic	Overall (N=164)	Calcification (n=46)	No calcification (n=118)	*P* value
On-pump CABG, n (%)	134 (81.7)	38 (82.6)	96 (81.4)	0.852
Circumflex target territory, n (%)	119 (72.6)	31 (67.4)	88 (74.6)	0.354
Right coronary target territory, n (%)	45 (27.4)	15 (32.6)	30 (25.4)	0.354
Aortocoronary graft, n (%)	137 (83.5)	37 (80.4)	100 (84.7)	0.508
Composite graft, n (%)	27 (16.5)	9 (19.6)	18 (15.3)	0.508
Target-vessel stenosis, %, median (IQR)	85 (80–90)	85 (80–90)	85 (80–90)	0.681
Calcium-channel blocker at discharge, n (%)	156 (95.1)	44 (95.7)	112 (94.9)	1.000
Antiplatelet therapy at discharge, n (%)	164 (100)	46 (100)	118 (100)	—
Statin therapy at discharge, n (%)	160 (97.6)	45 (97.8)	115 (97.5)	1.000
CCTA for patency assessment, n (%)	149 (90.9)	40 (87.0)	109 (92.4)	0.271

CABG: coronary artery bypass grafting; CCTA: coronary computed tomography angiography; IQR: interquartile range.

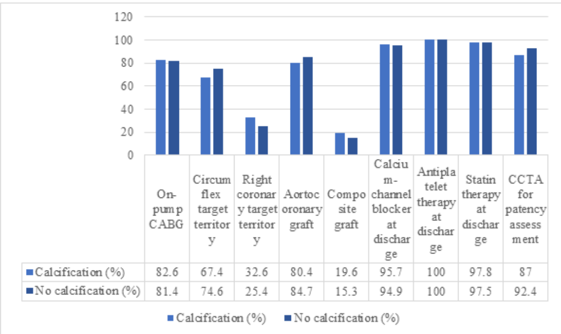

Figure 2: Comparison of operative, graft, and postoperative treatment characteristics between patients with and without radial artery calcification

Notes: Bars represent the percentage of patients for categorical operative and graft-related characteristics in the radial artery calcification group (n=46) and no-calcification group (n=118). No statistically significant between-group differences were observed for on-pump CABG, target coronary territory, graft configuration, calcium-channel blocker use, statin therapy, or CCTA use for graft-patency assessment (*P*>0.05 for all comparisons). Antiplatelet therapy was prescribed to 100% of patients in both groups; therefore, no *P* value was calculated. Target-vessel stenosis is not included in the bar chart because it is a continuous variable reported as median (IQR).

Abbreviations: CABG, coronary artery bypass grafting; CCTA, coronary computed tomography angiography; IQR, interquartile range.

Six-Month Graft Patency

At six months, graft patency was assessed using CCTA in 149 patients (90.9%) and invasive coronary angiography in 15 patients (9.1%). Overall, 137 of 164 radial artery grafts (83.5%) were patent, while 27 (16.5%) met the definition of graft failure.

Graft failure occurred in 14 of 46 patients with radial artery calcification (30.4%) and 13 of 118 patients without calcification (11.0%; *P*=0.003). Complete graft occlusion occurred in nine patients with calcification (19.6%) and seven patients without calcification (5.9%; *P*=0.009). Significant stenosis without complete occlusion was observed in five patients with calcification (10.9%) and six patients without calcification (5.1%; *P*=0.188).

Graft failure increased with calcification severity: 13 of 118 patients without calcification (11.0%), five of 25 with mild calcification (20.0%), six of 15 with moderate calcification (40.0%) and three of six with severe calcification (50.0%; *P* for trend <0.001).

Table 3: Six-month graft-patency and clinical outcomes

Outcome	Calcification (n=46)	No calcification (n=118)	Unadjusted OR (95% CI)	*P* value
Patent radial artery graft,	32 (69.6)	105 (89.0)	—	0.003

n (%)				
Overall graft failure, n (%)	14 (30.4)	13 (11.0)	3.53 (1.52–8.23)	0.004
Complete graft occlusion, n (%)	9 (19.6)	7 (5.9)	3.86 (1.34–11.15)	0.009
Graft stenosis ≥50%, n (%)	5 (10.9)	6 (5.1)	2.28 (0.66–7.87)	0.188
Major adverse cardiovascular events, n (%)	10 (21.7)	12 (10.2)	2.45 (0.97–6.20)	0.052
All-cause mortality, n (%)	3 (6.5)	3 (2.5)	2.68 (0.52–13.75)	0.347
Myocardial infarction, n (%)	4 (8.7)	4 (3.4)	2.71 (0.65–11.28)	0.222
Repeat revascularisation, n (%)	7 (15.2)	6 (5.1)	3.35 (1.06–10.58)	0.032

CI: confidence interval; OR: odds ratio. Graft failure was defined as complete graft occlusion or ≥50% luminal stenosis.

Factors Associated with Graft Failure

On univariable analysis, radial artery calcification was associated with increased odds of six-month graft failure (OR, 3.53; 95% CI, 1.52–8.23; *P*=0.004). After adjustment for age, diabetes mellitus, chronic kidney disease and percentage target-vessel stenosis using Firth penalised logistic regression, calcification remained independently associated with graft failure (adjusted OR, 2.84; 95% CI, 1.15–7.02; *P*=0.024). Greater target-vessel stenosis was independently associated with lower odds of graft failure (adjusted OR per 10% increase, 0.72; 95% CI, 0.53–0.98; *P*=0.038). [Table 4]

Table 4: Regression analysis of factors associated with six-month graft failure

Variable	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	*P* value
Any radial artery calcification	3.53 (1.52–8.23)	2.84 (1.15–7.02)	0.024
Age, per one-year increase	1.07 (1.01–1.13)	1.03 (0.97–1.10)	0.321
Diabetes mellitus	1.68 (0.74–3.83)	1.31 (0.53–3.23)	0.558
Chronic kidney disease	2.42 (0.93–6.31)	1.75 (0.61–5.04)	0.299
Target-vessel stenosis, per 10% increase	0.69 (0.52–0.92)	0.72 (0.53–0.98)	0.038

CI: confidence interval; OR: odds ratio. Adjusted estimates were obtained using Firth penalised multivariable logistic regression.

Six-Month Clinical Outcomes and Sensitivity Analyses

Major adverse cardiovascular events occurred in 10 patients with calcification (21.7%) and 12 patients without calcification (10.2%; *P*=0.052). Repeat revascularisation occurred in seven patients with calcification (15.2%) and six patients without calcification (5.1%; *P*=0.032). Six patients died during follow-up, including three patients in each group. Myocardial infarction occurred in four patients with calcification and four patients without calcification.

When the primary outcome was restricted to complete graft occlusion, calcification remained significantly associated with graft failure (adjusted OR, 3.21; 95% CI, 1.10–9.38; *P*=0.033). The association remained significant after excluding patients who underwent symptom-driven invasive coronary angiography (adjusted OR, 2.67; 95% CI, 1.04–6.84; *P*=0.041).

DISCUSSION

The present study evaluated the association between preoperative radial artery calcification and six-month radial artery graft patency following coronary artery bypass grafting. The principal finding was that graft failure occurred significantly more frequently among patients with radial artery calcification than among those without calcification (30.4% vs. 11.0%). After adjustment for age, diabetes mellitus, chronic kidney disease and target-vessel stenosis, radial artery calcification remained independently associated with graft failure (adjusted odds ratio, 2.84; 95% confidence interval, 1.15–7.02). Furthermore, the frequency of graft failure increased progressively with increasing calcification severity, from 11.0% in patients without calcification to 20.0%, 40.0% and 50.0% among those with mild, moderate and severe calcification, respectively. These findings suggest that pre-existing calcification may be an important marker of radial artery conduit quality and early graft performance.

Current coronary revascularisation guidelines recommend the radial artery over the saphenous vein as the second conduit for a suitable, significantly stenosed non-left-anterior-descending coronary target because of its superior patency and clinical outcomes.[1] However, this recommendation assumes that the radial artery is anatomically and functionally suitable for harvesting. The renewed use of the radial artery in CABG was supported by improvements in harvesting techniques, atraumatic conduit preparation and perioperative antispasmodic treatment.[2] Despite these advances, pre-existing structural abnormalities of the radial artery may adversely affect graft function and cannot necessarily be corrected through surgical technique or pharmacological treatment alone.

Randomised evidence has demonstrated better angiographic outcomes with radial artery grafts than with saphenous vein grafts. The Radial Artery Patency Study reported a lower incidence of complete graft occlusion with the radial artery at one year, although the radial artery was more frequently associated with diffuse narrowing or the string sign.[3] Similarly, the Radial Artery Versus Saphenous Vein Patency trial demonstrated superior five-year patency of radial artery grafts placed on severely stenosed circumflex coronary arteries.[4] A pooled analysis of randomised trials also showed that the use of the radial artery was associated with better graft patency and fewer adverse cardiovascular events than the use of the saphenous vein.[5] The present study extends these observations by suggesting that the expected benefit of radial artery grafting may be reduced when the selected conduit contains preoperative calcification.

The clinical advantages of the radial artery may persist beyond angiographic patency. An individual-participant-data meta-analysis demonstrated that radial artery grafting was associated with lower rates of death, myocardial infarction and repeat revascularisation during long-term follow-up compared with saphenous vein grafting.[6] A network meta-analysis of randomised trials similarly ranked the radial artery among the most durable CABG conduits and demonstrated a lower graft-occlusion rate than conventionally harvested saphenous vein grafts.[7] Long-term observational angiographic evidence has also shown favourable radial artery graft patency when appropriate conduits and coronary targets are selected.[8] Nevertheless, these overall benefits should not be interpreted as evidence that every radial artery is suitable for use. Appropriate patient, conduit and target-vessel selection remain essential.

Several biological and mechanical mechanisms may explain the association observed in the present study. Radial artery calcification may reduce vascular compliance, impair endothelial-dependent vasodilatation and limit adaptive remodelling after the artery is exposed to coronary circulation. A calcified conduit may also be more vulnerable to endothelial injury during harvesting and may be technically difficult to manipulate or anastomose. Histopathological studies have demonstrated that radial arteries may contain intimal hyperplasia, medial calcification and atherosclerotic changes before harvesting, particularly among older patients and those with diabetes mellitus, hypertension, smoking exposure, peripheral vascular disease or chronic kidney disease.[9] Comparative histopathological evaluation has further demonstrated that the radial artery has a higher prevalence of intimal hyperplasia, atherosclerosis and medial calcification than the internal thoracic artery.[10] These pre-existing abnormalities may contribute to early graft stenosis, thrombosis or complete occlusion.

Patients with radial artery calcification in the present study were older and had higher frequencies of diabetes mellitus and chronic kidney disease. These findings are clinically plausible because advancing age, metabolic disease and renal dysfunction contribute to arterial-wall calcification. However, calcification remained independently associated with six-month graft failure after adjustment for these variables. This suggests that direct assessment of conduit morphology may provide clinically useful information beyond conventional cardiovascular risk factors. Nevertheless, residual confounding remains possible because of the retrospective observational design.

The progressive increase in graft failure with increasing calcification severity supports a possible dose–response relationship. Mild calcification was associated with a moderate increase in failure, whereas moderate and severe calcification were associated with substantially higher failure rates. However, only six patients had severe calcification; consequently, this subgroup estimate is imprecise and should be interpreted cautiously. The findings do not establish that every radial artery with mild calcification should be rejected. Instead, the severity, distribution and length of calcification should be evaluated together with arterial diameter, blood flow, collateral hand circulation and the availability of alternative conduits.

Preoperative duplex ultrasonography may be particularly valuable in this setting. Ultrasonography can assess radial artery diameter, blood flow, luminal stenosis, intimal thickening, atherosclerotic plaques and calcification. Previous preoperative ultrasonographic assessment has shown that radial arteries may be unsuitable for harvesting because of small diameter, diffuse atherosclerosis, calcification or severe neointimal hyperplasia.[11] When disease is confined to the distal radial artery, an unaffected proximal segment may occasionally remain suitable. Therefore, systematic ultrasonographic assessment may improve conduit selection and help avoid harvesting arteries with extensive or severe structural disease.

Target-vessel anatomy also influences radial artery graft performance. In the present analysis, greater target-vessel stenosis was independently associated with a lower likelihood of graft failure. This finding is consistent with evidence that radial artery grafts are susceptible to competitive flow when placed on coronary arteries with moderate native stenosis.[12] Persistent native coronary flow may reduce flow through the radial artery graft, resulting in vasoconstriction, diffuse narrowing, the string sign or occlusion. Therefore, the radial artery should preferably be grafted to a coronary target with severe and physiologically significant stenosis.

Meta-analyses comparing the radial artery with the saphenous vein have reported favourable survival and graft-related outcomes with radial artery grafting, but these benefits are influenced by patient selection, target-vessel anatomy, operative technique and postoperative treatment.[13] In clinical practice, conduit selection should therefore be individualised. When moderate or severe radial artery calcification is detected, alternative conduits such as the contralateral radial artery, right internal thoracic artery or saphenous vein may be considered, depending on the patient's anatomy, comorbidities and surgical strategy.

Most patients in the present cohort received a calcium-channel blocker for six months after surgery. Calcium-channel blocker therapy is commonly used to reduce radial artery graft spasm and has been associated with improved radial artery graft patency and cardiovascular outcomes.[14] However, pharmacological vasodilatation may not fully overcome the mechanical stiffness, endothelial dysfunction and structural abnormalities associated with established calcification. Antiplatelet therapy, intensive lipid-lowering treatment and appropriate management of diabetes, hypertension and renal disease remain essential components of postoperative secondary prevention.

The correlation demonstrated between Doppler assessment, manual morphometry and histopathological examination supports the usefulness of preoperative imaging for assessing radial artery dimensions and structural quality.[15] Nevertheless, ultrasonographic grading of calcification is operator-dependent, and standardised definitions are required. Future studies should evaluate interobserver agreement and compare ultrasonographic calcification with histopathological findings or quantitative computed-tomography measurements. Establishing a validated calcification threshold could help identify radial arteries that are unsuitable for use.

This study has several strengths. It included consecutive eligible patients, applied predefined definitions of calcification and graft failure, examined calcification severity and adjusted the association for clinically relevant confounders. Graft patency was assessed at a defined six-month follow-up interval, allowing consistent evaluation of early graft performance. The sensitivity analyses also supported the direction of the primary findings.

Strengths and Limitations

Strengths

This study has several strengths. Consecutive sampling was used to include all eligible patients, thereby reducing selective enrolment. Preoperative radial artery calcification and six-month graft failure were defined using prespecified criteria. Calcification was evaluated both as a binary variable and according to severity, enabling assessment of a possible dose–response relationship. Graft patency was objectively assessed using computed tomography coronary angiography or invasive coronary angiography. The multivariable analysis adjusted for clinically relevant factors, including age, diabetes mellitus, chronic kidney disease and target-vessel stenosis. Firth penalised logistic regression was used to reduce small-sample bias, and sensitivity analyses supported the robustness of the principal findings.

Limitations

This study has several limitations. First, its retrospective, single-centre design limits causal inference and the generalisability of the findings to other populations and institutions. Second, the sample size was relatively small, particularly in the moderate- and severe-calcification subgroups, resulting in limited statistical precision. Third, conduit selection was influenced by the operating surgeon, which may have introduced selection bias. Fourth, patients without complete or interpretable six-month graft imaging were excluded, creating the possibility of attrition bias. Fifth, graft patency was evaluated using two different imaging modalities, and differences between computed tomography coronary angiography and invasive coronary angiography may have affected outcome classification. Sixth, duplex ultrasonography is operator-dependent, and interobserver agreement for calcification grading was not evaluated. Seventh, information regarding calcification distribution, arterial-wall thickness and intraoperative conduit quality may not have been consistently available in retrospective records. Eighth, residual confounding from unmeasured factors, including surgeon experience, graft flow, anastomotic quality, medication adherence and target-vessel diameter, cannot be excluded. Finally, the six-month follow-up period assessed early graft performance and does not establish the effect of radial artery calcification on long-term graft patency, cardiovascular events or survival.

CONCLUSION

Preoperative radial artery calcification was independently associated with an increased risk of radial artery graft failure at six months following coronary artery bypass grafting. Graft failure increased progressively with the severity of calcification, indicating that the extent of arterial-wall calcification may have clinical relevance. Routine preoperative duplex ultrasonography may improve conduit selection by identifying structural abnormalities not detected by clinical examination alone. These findings should be interpreted cautiously because of the retrospective, single-centre design and require confirmation through larger prospective multicentre studies with standardised imaging and longer follow-up.

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Conflict of Interest

The authors declare that they have no conflicts of interest related to this study.

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