


Coronary artery size as a predictor of Y-graft patency following coronary artery bypass surgery

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Abstract

This study aims to evaluate the association between target vessel size and graft patency in the right IMA–right coronary territory anastomosis.

A total of 402 patients who underwent CABG between 2005 and 2016 using the right IMA Y-graft to the posterolateral branch or posterior descending artery were enrolled. Preoperative coronary angiography was utilized to measure the size of the target coronary arteries in the right territory. Follow-up angiography and computed tomography at 6 to 12 months were used to determine graft patency.

Thirty patients (7.5%) were found to have occluded graft. Larger target vessel size was associated with lower risk of graft occlusion (OR: 0.18, 95% CI: 0.05–0.62, $P = .007$). The receiver operating characteristic (ROC) curve showed that the cutoff-value of 1.93 mm was found to have the maximum sum of sensitivity and specificity for graft patency (Area under the curve (AUC): 0.65, $P = .01$). Excluding patients with right coronary artery total occlusion, the discriminative performance of target vessel size became more prominent (AUC: 0.76, $P < .01$), with same cutoff value.

In the setting of bilateral IMA composite grafting, the patency of right IMA to right coronary territory was influenced by the size of the target coronary artery. The influence of target coronary artery size was prominent in non-total occlusion patients. Careful selection of a target anastomosis site is recommended.

Abbreviations: ARF = acute renal failure, AUC = area under the curve, CABG = coronary artery bypass grafting, CCT = coronary computed tomography, CI = confidence interval, COPD = chronic obstructive pulmonary disease, CPB = cardio pulmonary bypass, IMA = Internal Mammary Artery, LAD = left anterior descending, RCA = right coronary artery, PCI = percutaneous coronary intervention, PDA = posterior descending artery, PLB = postero-lateral branch, ROC = receiver operating characteristic, OR = odds ratio.

Keywords: internal mammary artery, patency, coronary artery bypass grafting

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DHL and HWC contributed equally to this work.

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1. Introduction

Using the internal mammary artery (IMA) as a conduit in coronary artery bypass graft (CABG) surgery is proven to have excellent early to long-term patency and clinical benefits.^[1,2] The superiority of an arterial conduit over saphenous vein graft has been widely recognized. IMA grafting showed a superior patency rate of 85% to 90% over a period of 5 to 10 years.^[3–5] Such data should encourage surgeons to utilize the IMA graft as the first choice. In recent studies, the utilization of bilateral IMA to achieve total arterial revascularization has shown to improve long-term survival when compared with single left IMA grafting.^[6–8]

In situ left IMA is strongly believed to be the best conduit for left anterior descending (LAD) anastomosis;^[6,9] therefore, other conduit such as right IMA is frequently utilized to graft non-LAD arteries. However, the length of right IMA may often be insufficient to reach the coronary artery in the posterior wall. To mitigate this insufficient length, strategies such as skeletonized harvesting and composite grafting have been proposed, increasing the length and flexibility of the right IMA.^[10,11] We utilize these techniques – in situ left IMA to LAD and right IMA Y-graft to non-LAD target in a clockwise manner – as part of our typical configuration for CABG (Fig. 1).

Given its anatomic nature, right IMA anastomosis to the right coronary territory is faced with challenges. The small end of the right IMA after full-length harvesting has been described to alter future graft patency.^[6] However, the utilization of radial and

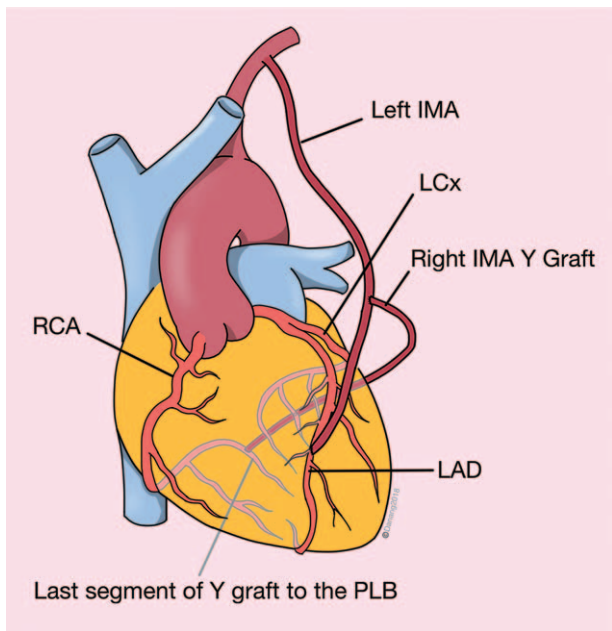


Figure 1. Illustration of a typical coronary artery bypass graft in our institution, which is comprised of left IMA to LAD and right IMA Y graft from left IMA to non-LAD targets sequentially. IMA = internal mammary artery, LAD = left anterior descending artery, LCx = left circumflex artery, and RCA = right coronary artery.

gastroepiploic arteries as alternatives also has its own challenges, including the risk of hand ischemia and abdominal complication, respectively.^[12,13]

Since coronary angiography has been widely and routinely used for coronary artery assessment,^[14] surgeons often rely on this examination to determine their strategy of revascularization. Aside from the location and degree of stenosis, the target vessel size has been discovered to be a predictor of graft patency.^[15–17] Therefore, knowing the size of the coronary artery being grafted is necessary to predict the fate of the graft. We sought to measure the size of the target right coronary artery branches using a two-point measurement of preoperative coronary angiography^[18–21] and establishing the cutoff value regarding the mid-term graft patency in our typical CABG configuration.

2. Patients and methods

2.1. Patient selection

This is a singlecenter, retrospective cohort study. The Institutional Review Board (IRB) of Seoul National University Bundang Hospital approved this study with the registration number B-1808/487-104. The requirement for informed consent was waived due to the retrospective nature of this study. All data of CABG surgery between May 2005 and December 2016 in our electronic medical record were collected. All patients who underwent primary CABG with our typical configuration were included. We excluded those without or with inadequate preoperative coronary angiography, as well as those who did not have postoperative coronary computed tomography (CCT) or coronary angiography at 6 to 12 months. Patients with I-graft configuration of bilateral IMA and anastomosis to the distal portion of the right coronary artery (before giving its branches) were also excluded. Patient selection can be seen in Figure 2.

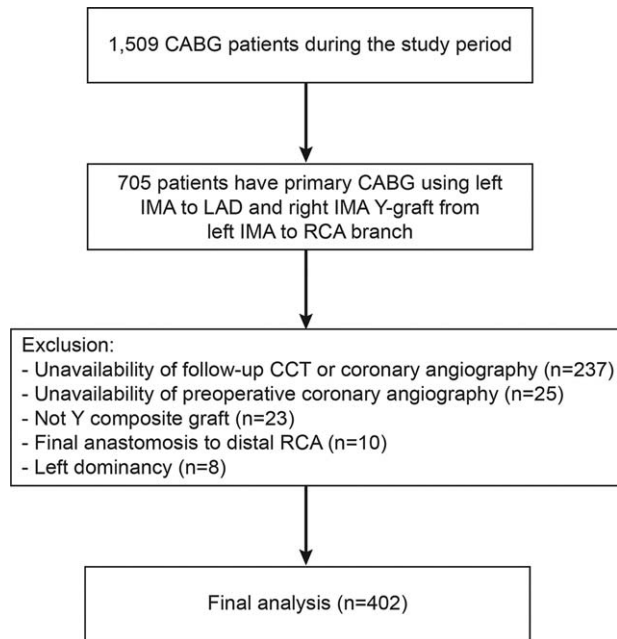


Figure 2. Diagram showing how patients were selected. CABG = coronary artery bypass graft, CCT = coronary computed tomography, IMA = internal mammary artery, LAD = left anterior descending artery, and RCA = right coronary artery.

2.2. Coronary artery measurement

Preoperative coronary angiography was analyzed using Picture Archiving and Communication System viewer integrated with the electronic medical record system. The target vessel to be measured was obtained using postoperative CCT. Right coronary artery measurement was done using two-dimensional, catheter-calibrated, two-point measurement at the proximal (right after bifurcation), middle (middle point of the vessel length), and distal points (middle point of the last one-third portion of the vessel length) of each vessel (Fig. 3). The degree of the proximal stenosis was also recorded as stated by the cardiologist on the coronary angiography report. Total occlusion was considered to have 100% stenosis.

2.3. Surgical technique

Bilateral IMA harvesting was performed after median sternotomy, using the skeletonization technique. Right IMA was divided from its origin, and the proximal stump was closed using metal clips. Heparin (300 units/kg) was administered. Cardio pulmonary bypass (CPB) or extracorporeal membrane oxygenator (ECMO) was commenced in both conventional and on-pump beating CABG, respectively. Y-composite graft of in situ left IMA and right IMA (free graft) was constructed using 8-0 polypropylene suture prior to coronary anastomosis. The order of anastomosis is as follows: Left IMA to LAD; Right IMA to left circumflex and/or its branches; and sequential Right IMA to right coronary territory. Transit time flow measurement was taken after distal anastomosis. Oral antiplatelet was routinely administered postoperatively.

2.4. Evaluation of graft patency during follow-up

Independent radiologists determined graft occlusion based on the postoperative CCT or coronary angiography obtained at post-

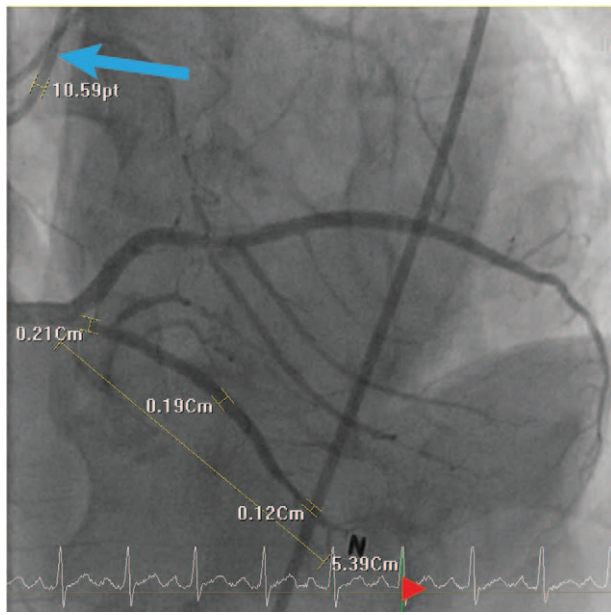


Figure 3. Measurement of the posterior descending artery in the preoperative coronary angiography. Blue arrow indicates 6Fr catheter used for contrast delivery to the right coronary artery ostium.

operative 6 to 12 months. Graft patency is defined by the visualization of mammary graft followed by runoff to the native coronary artery. When analyzing sequential graft, if the graft anastomosis proximal to the RCA-branch is occluded and no visualization to the native RCA-branch artery, the graft was considered occluded.

2.5. Statistical analyses

Descriptive statistics were analyzed for preoperative and operative characteristics, graft patency, and target vessel size. Categorical data were analyzed using Chi-Squared and Fischer exact test. Continuous data were analyzed using normalcy test and Mann–Whitney or *t* test as appropriate. Kaplan–Meier curves were drawn to describe the survival and freedom from RCA intervention. ROC curves were drawn to evaluate the sensitivity and specificity of the cutoff values in the target vessel size to predict graft patency. Univariate and multivariate binary logistic regression model with backward stepwise variable selection was used to identify the independent predictors of graft patency in the right coronary territory. Variables with *P* value less than .1 in univariate analysis were included in the multivariate analysis. All statistical analyses were performed using SPSS version 23 (IBM, Armonk, NY). *P* value of less than .05 was considered statistically significant.

3. Results

After applying the inclusion and exclusion criteria, a total of 402 subjects were included for analysis. We applied a strict rule to exclusively analyze the typical configuration of CABG in our institution. These criteria are shown in Figure 2. This study analyzed only right coronary artery branch anastomosis (posterior descending artery and posterolateral branch) using right IMA Y-graft from the left IMA.

Table 1

Preoperative and operative data of all subjects.

Variables	N = 402
Age (years)	66 ± 10
Male	299 (74.4%)
Body Mass Index (kg/m ²)	24.7 ± 2.8
Diabetes Mellitus	187 (46.5%)
Smoking	241 (60%)
Hypertension	292 (72.6%)
Hyperlipidemia	162 (40.3%)
Preoperative CRF	17 (4.2%)
Preoperative ARF	3 (0.7%)
Preoperative COPD	25 (6.2%)
Ejection Fraction (%)	55.5 ± 12.3
Preoperative Atrial Fibrillation	21 (5.2%)
Post PCI	51 (12.7%)
Vessel size (mm)	1.87 ± 0.43
Triple Vessel Disease	376 (93.5%)
Vessel stenosis (%)*	91.4 ± 11.5
Chronic Total Occlusion (100% Stenosis)	135 (33.6%)
Left Main Disease	115 (28.6%)
Isolated CABG	342 (85.1%)
CPB strategy	
Off-pump CABG	286 (71.1%)
On-Pump Beating CABG	77 (19.2%)
Conventional CABG	39 (9.7%)
Number of Distal Anastomosis	
2	18 (4.5%)
3	152 (37.8%)
4	167 (41.5%)
5	58 (14.4%)
6	7 (1.7%)
Vessel anastomosed	
PDA	321 (79.9%)
PLB	81 (20.1%)
Emergency setting	8 (2%)
Study period	
2005–2010	171 (42.5%)
2011–2016	231 (57.5%)

* 32 (8%) missing values.

ARF = acute renal failure, CABG = coronary artery bypass grafting, COPD = chronic obstructive pulmonary disease, CPB = cardio pulmonary bypass, CRF = chronic renal failure, PCI = percutaneous coronary intervention, PDA = posterior descending artery, and PLB = postero-lateral branch.

Preoperative data is shown in Table 1. The majority of patients were male (74.4%) with a mean age of 66 ± 10 years. Almost half of the patients had diabetes. Fifty one patients (12.7%) had undergone percutaneous coronary intervention prior to undergoing CABG. Most of the subjects (93.5%) had triple vessel coronary artery disease. The average of 91% ± 12% of proximal stenosis was documented and 135 patients had 100% stenosis (33.6%). Native coronary artery size was measured in 3 different segments of the vessel. The mean size of the vessel diameter was 1.87 ± 0.43 mm.

Operative data, as shown on Table 1, indicates that the majority of the cases was isolated CABG. According the use of CPB we have 3 different CABG strategy which are: Off-pump CABG, On-pump beating CABG (without aortic cross-clamping), and Conventional CABG (with aortic cross-clamping). Off-pump CABG was more common (71.1%), especially in the later years. The most common strategy regarding the number of the anastomosis was the 4 target vessels (1 LAD, 1 RCA-branch, and 2 upstream sequential anastomoses before RCA-branch).

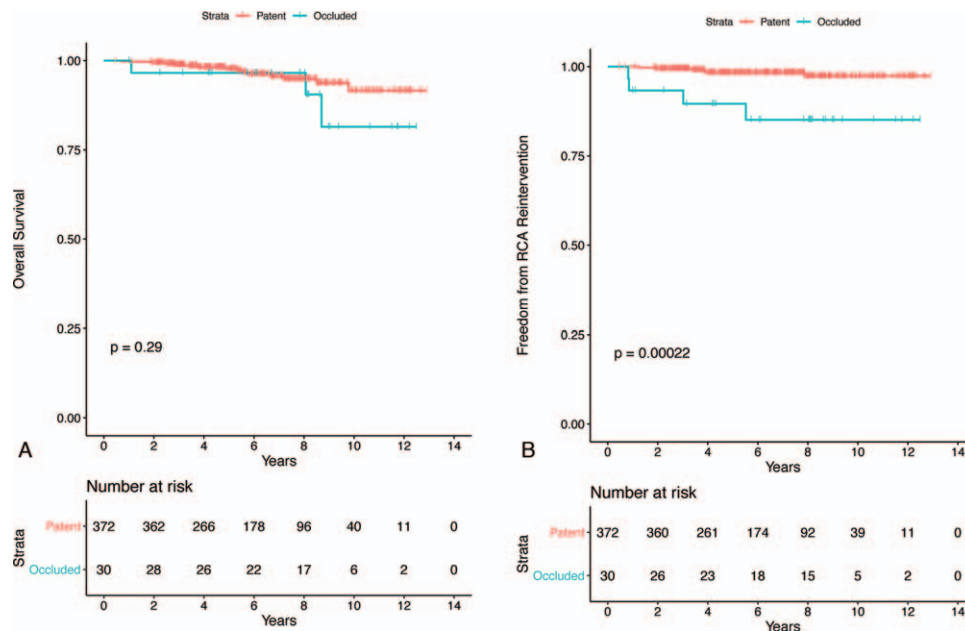


Figure 4. Kaplan–Meier Curves shows comparison between patent group ($n=372$) and occluded group ($n=30$) in terms of A. Survival and B. Freedom of RCA reintervention.

Posterior descending arteries were anastomosed more than the posterolateral branch (79.9%).

In the follow-up CCT or coronary angiography, graft occlusion in the right coronary territory was found in 30 patients (7.5%) consisted of 4 grafts to the PLB and 26 grafts to the PDA. There were a total 39 deaths out of 705 included patients, in which 12 of them happened before CCT was obtained. The remaining 17 deaths occurred after follow-up CCT or angiography during the median follow up period of 6 years (6 months to 13 years); 3 patients had occluded right IMA-right territory anastomosis, and 14 had patent anastomosis (Log-rank $P=.29$) (Fig. 4A). Conversely during the same median follow-up period, reintervention of the right coronary artery was significantly higher (Log-rank $P<.001$) in patients with graft occlusion (4 out of 30) than those with patent graft (6 out of 372) (Fig. 4B). This study had 22 superficial and 1 deep sternal wound problem.

Univariate and multivariate logistic regression analyses with backward stepwise variable selection were performed using several preoperative and operative variables shown in Table 1. Coronary artery size, proximal stenosis, ejection fraction, diabetes, and study period were identified as independent predictors in multivariate analysis, while other variables such as Age, BMI, CPB strategy, number of distal anastomosis, and the rest of the measured variables, were not significant predictors of graft patency (Table 2).

Larger target coronary artery size was associated with reduced risk of graft occlusion (Odds ratio [OR]: 0.179, 95% confidence interval [CI]: 0.052–0.618, $P=.007$). Degree of proximal stenosis was also associated with reduced risk of graft occlusion (OR: 0.943, 95% CI: 0.912–0.975, $P=.001$). Patients who were operated in later years (2010–2016) were also associated with reduced risk of graft occlusion (OR: 0.276, 95% CI: 0.103–0.742, $P=.011$). On the other hand, having diabetes mellitus was associated with reduced risk of graft occlusion (OR: 0.298, 95%

CI: 0.107–0.827, $P=.02$) and higher ejection fraction was associated with increased risk of graft occlusion (OR: 1.063, 95% CI: 1.107–1.123, $P=.03$).

ROC curve (Fig. 5A) showed that the native vessel diameter had a significant discriminative function in predicting graft patency in our configuration ($P=.01$) with AUC of 0.649. We found that future graft patency was predicted at estimated cutoff value of 1.93 mm with the highest sum of sensitivity and specificity.

Separate analysis was done regarding the degree of stenosis. One hundred thirty five patients were known to have total occlusion in the right coronary territory and only 4 of them had occluded graft ($P=.015$), compared to incidence of graft occlusion in nontotal occlusion group. Therefore, we analyzed the ROC curve of patients who did not have total occlusion in the right coronary territory ($n=267$). We found the native vessel diameter was stronger discriminative factor for graft patency with AUC 0.76 ($P<.001$) (Fig. 5B) in non-total occlusion patients. The same estimated cutoff value of 1.93 mm was also found in this model.

4. Discussions

Our study showed that the native vessel diameter might be associated with graft patency in our typical configuration. This finding confirmed the previous findings regarding the greater possibility of graft patency in CABG when a patient has a large native vessel size regardless of the configuration.^[15,22] After establishing the cutoff value in this study, it may be reasonable to assume that grafting a native coronary artery larger than 1.93 mm may result in a greater chance of patency. In the era of total arterial grafting, utilizing both mammary arteries yields substantial benefit. Thus, anastomosing the right IMA composite graft to the large right coronary artery as the last graft segment may provide good patency in the future.

Table 2**Univariate and multivariate regression analysis of possible predictor of graft occlusion.**

Variable	Univariate analysis P value	Multivariate analysis P value	OR (95%CI)
Age	.802		1.005 (0.968–1.044)
Sex	.892		0.943 (0.406–2.189)
Body Mass Index	.820		1.015 (0.890–1.159)
Diabetes mellitus	.004	.02	0.298 (0.107–0.827)
Smoking	.703		0.864 (0.408–1.832)
Hypertension	.607		1.258 (0.524–4.021)
Hyperlipidemia	.674		0.847 (0.392–1.832)
Preoperative CRF	.998		0 (0–0)
Preoperative ARF	.135		6.379 (0.562–72.464)
Preoperative COPD	.998		0 (0–0)
Ejection fraction	.022	.03	1.063 (1.006–1.123)
Preoperative atrial fibrillation	.713		1.327 (0.294–5.989)
Post PCI	.314		0.471 (0.109–2.039)
Vessel size	.007	.007	0.179 (0.052–0.618)
Vessel stenosis	.001	.001	0.943 (0.912–0.975)
Triple vessel disease	.963		0.966 (0.217–4.297)
Left main disease	.283		0.603 (0.240–1.517)
Isolated CABG	.203		2.586 (0.600–11.153)
Off-pump CABG	.134		2.126 (0.794–5.697)
On-Pump Beating CABG	.247		0.303 (0.040–2.268)
On-pump Conventional CABG	.403		0.603 (0.213–1.862)
Number of distal anastomosis	.705		1.090 (0.698–1.700)
Vessel anastomosed (PDA)	.338		1.697 (0.575–5.007)
Emergency setting	.999		0 (0–0)
Study Period (Later)	.001	.011	0.276 (0.103–0.742)

ARF = acute renal failure, CABG = coronary artery bypass grafting, COPD = chronic obstructive pulmonary disease, CRF = chronic renal failure, and PCI = percutaneous coronary intervention, PDA = posterior descending artery.

The mean of coronary artery size in our study population was 1.87 mm, which was lower than the cutoff value, however most of the grafts remained patent. We observed that total occlusion of the RCA had a very significant influence in our study, only 4 grafts were occluded in the total occlusion group. Therefore, when we remove the total occlusion patients, we got the mean coronary artery size of 1.93 mm (± 0.43 mm), the same with the cutoff value.

In order to exclusively analyzed the RCA-branch anastomosis. We excluded ten patients who had anastomosis on distal RCA to avoid diameter discrepancy that may compromise the analysis. However, these patients had patent graft in the follow up CCT. The influence of the vessel diameter in this group who had presumably bigger vessel anastomosed, need to be described in the future studies.

In our population, 7.5% of the grafts were occluded within the 6- to 12-month follow-up period. This finding is similar to a previous study regarding bilateral IMA Y graft patency.^[10] There was no significant difference in survival. The need for right coronary artery intervention after CABG was significantly higher in occluded patients. Although there were some patients whose grafts remained patent, they still needed this procedure to enlarge the native lumen distal to the anastomosis.

Previous studies described different cutoff values based on different measurement methods. O'Connor and colleagues measured the coronary artery using 0.5 mm incremental intracoronary probes.^[16] Other studies failed to clearly mention the measurement methods. Providing an exact measurement method of the native coronary artery could provide a better description of its predictability. Two-point measurement of preoperative coronary angiography – a measurement tool – has its own

advantages, such as availability and ease of use. Despite its higher possibility of measurement bias, surgeons could easily perform this method to aid in their decision prior to surgery. Careful observation was performed in this study to determine the target vessels based on the follow-up CCT and surgical notes before measuring those on the preoperative coronary angiography.

The degree of stenosis of the proximal portion of the anastomosed vessel might also be associated with graft patency in this study. Patients who had higher degree of stenosis were more likely to have patent graft in the future. We also observed significantly lower incidence of graft occlusion among those who had total occlusion in the right coronary territory compared to those who did not have. This finding might be associated with the lower probability of competitive flow that may lead to graft failure as described by previous studies.^[22,23]

We believed mid-term graft occlusion depends on several factors, which may have likely attributed to the moderate value (0.649) of the area-under-the-curve of the native vessel size in this study, despite its significance. However, its discriminative factor might increase in patients who did not have total occlusion in the right coronary territory, which was shown by the increase of AUC of 0.76. In this study, the size of the right IMA as a conduit was not investigated. This could be considered as a predictor due to its anatomic nature regarding its size after full-length harvesting. Nonetheless, future observation is necessary.

Patients in later period tended to have better graft patency. This probably happened because the use of antiplatelet and statin drugs which were more common after 2012. Unfortunately, we did not have the data regarding the medications that were taken after surgery. Our analysis showed counterintuitive findings. Higher ejection fraction may increase the risk of graft occlusion.

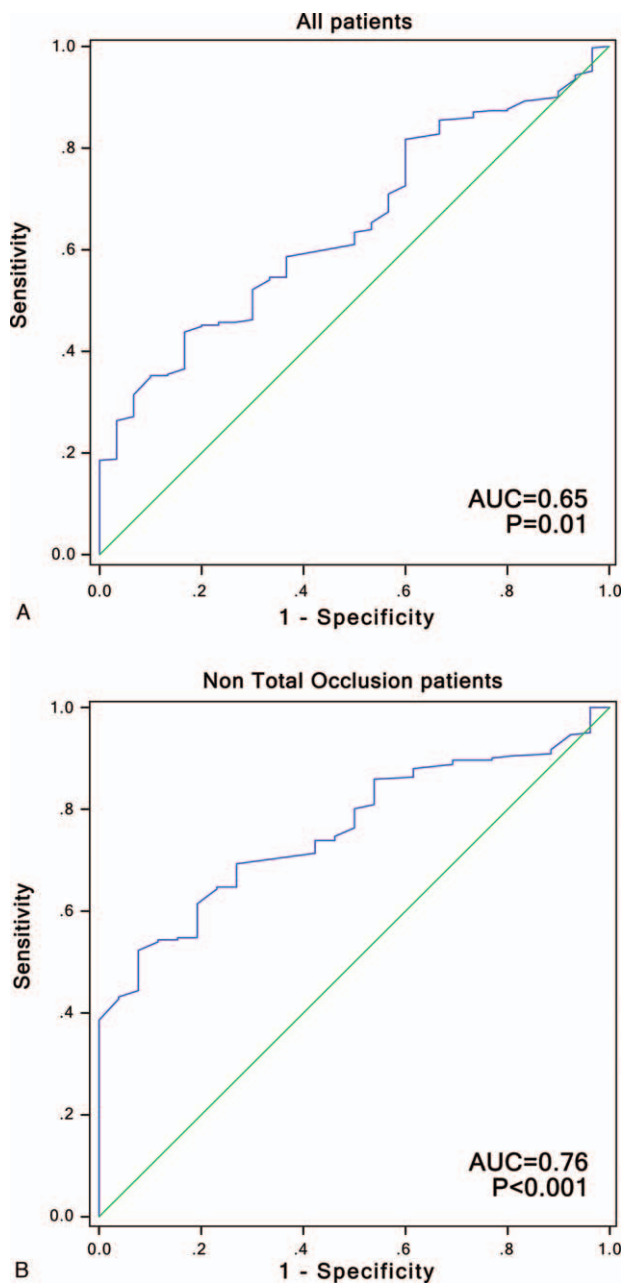


Figure 5. Receiver operating characteristic curve shows discriminative ability of native vessel diameter in predicting mid-term graft patency. A, All-patients, AUC=0.649, and B, non-total occlusion patients, AUC=0.76. AUC = area under the curve.

This might have happened because patients with higher ejection fraction had more well-functioned myocardium that may be related to the lower degree of stenosis. Having diabetes may decrease the risk of graft occlusion. Schwartz and colleagues previously investigated the relationship between diabetes and graft patency after CABG, and they found that diabetes did not affect the graft patency at 4 year follow up.^[24] Future studies are needed to better characterize these relationships.

The strategy of revascularization in CABG does not depend solely on target vessel size. Several things have to be taken into account to make any clinical decision. For example, in a younger patient with severe degree (>90% or total occlusion) of proximal

RCA stenosis, the RCA-branch size smaller than 1.93 mm might benefit from revascularization. But this might not be the case, in an old patient with moderate degree of proximal RCA stenosis.

5. Limitations

This study is prone to selection bias due to our strict criteria of graft configuration and might not represent the true demographic properties of our population. The sensitivity analysis for excluded patients was not done in this study. This study is also limited by its retrospective nature. The right coronary sizes were not a standard evaluation of preoperative coronary angiography prior to surgery, therefore we utilized our simple method calculating coronary artery size. We understood its lack of accuracy especially due to its two-dimensional plane that might be prone to foreshortening. Further study measuring the exact size of the coronary artery with better methods, such as three-dimensional quantitative coronary angiography, may be needed to better describe this factor as a predictor of graft occlusion.^[25]

Medications, such as antiplatelets, which were taken after surgery and Transit time flow measurement were not recorded in our database, thus making it impossible for us include these 2 important variables in the analysis. As suggested by the reviewers, longitudinal mixed modelling can better explain relationship between variables that were measured at variable times, however we could not confirm the exact time of graft occlusion when we obtained the CCT or angiography. Thus, logistic regression was used assuming cross-sectional outcome.

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