Interactive CardioVascular and Thoracic Surgery 28 (2019) 868–875
doi:10.1093/icvts/ivy346 Advance Access publication 10 January 2019

ORIGINAL ARTICLE

Cite this article as: Akita S, Tajima K, Kato W, Tanaka K, Goto Y, Yamamoto R *et al.* The long-term patency of a gastroepiploic artery bypass graft deployed in a semiskeletonized fashion: predictors of patency. Interact CardioVasc Thorac Surg 2019;28:868–75.

The long-term patency of a gastroepiploic artery bypass graft deployed in a semiskeletonized fashion: predictors of patency

Sho Akita[a,b,*], Kazuyoshi Tajima[a], Wataru Kato[a], Keisuke Tanaka[a], Yuki Goto[a], Ryota Yamamoto[a], Tubasa Yazawa[a], Motoshi Kozakai[a] and Akihiko Usui[b]

[a] Department of Cardiovascular Surgery, Nagoya Daini Redcross Hospital, Nagoya, Aichi, Japan
[b] Department of Cardiac Surgery, Nagoya University Graduate School of Medicine, Nagoya, Aichi, Japan

* Corresponding author. Department of Cardiovascular Surgery, Nagoya Daini Redcross Hospital, 2-9, Myoken-cho, Showa-ku, Nagoya, Aichi 466-8650, Japan. Tel: +81-52-8321121; fax: +81-52-8321130; e-mail: sakita0613@nagoya2.jrc.or.jp (S. Akita).

Received 14 August 2018; received in revised form 31 October 2018; accepted 27 November 2018

Key question

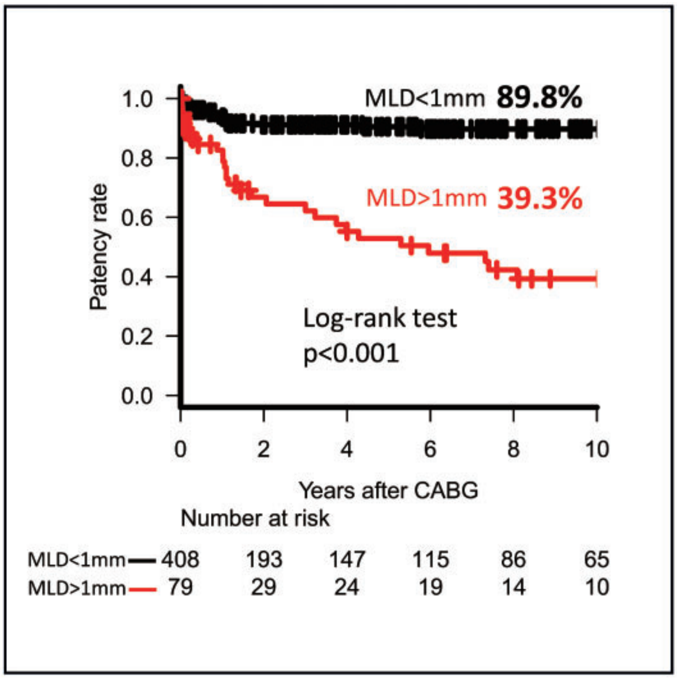
Does the minimum luminal diameter of the preoperative target vessel predict patency of the gastroepiploic artery?

Key finding(s)

A minimum luminal diameter >1 mm was the independent risk factor of the graft occlusion.

Take-home message

Preoperative quantitative angiography measurements of the minimum luminal diameter of the target vessel strongly predicted graft patency.



Abstract

OBJECTIVES: Whether or not using the gastroepiploic artery (GEA) is associated with improved outcomes of coronary artery bypass grafting (CABG) remains unclear. Previous research has shown that the short-term function of the GEA was strongly associated with the degree of native vessel stenosis. We assessed the association between long-term GEA patency and the degree of stenosis of the coronary artery.

METHODS: We retrospectively examined 517 patients who underwent CABG with an *in situ* semiskeletonized GEA from January 2000 to January 2015. In this cohort, 282 (54.5%) patients underwent distant radiological evaluations for >1 year post-surgery (range 1–18 years after surgery). Quantitative coronary angiography was used to measure the degree of stenosis of the native coronary artery. Preoperative angiographic parameters include the minimal lumen diameter (MLD) and the percentage of target vessel stenosis. A multivariable stepwise Cox proportional hazards regression analysis was used to identify predictors of angiographic occlusion.

Presented at the 32nd Annual Meeting of the European Association for Cardio-Thoracic Surgery, Milan, Italy, 18–20 October 2018.

RESULTS: The cumulative patency rate of the GEA was 79.3% at 10 years. A multivariable analysis showed that an MLD (hazard ratio 4.43, 95% confidence interval 3.25–6.82; $P < 0.001$) was an independent risk factor of GEA occlusion. A time-dependent receiver operating characteristic (ROC) curve analysis identified that an MLD >1 mm was set as the cut-off value for graft occlusion. Patients with an MLD <1 mm had a 10-year patency rate of 89.8%.

CONCLUSIONS: The long-term patency of the semiskeletonized GEA was acceptable. The target vessel MLD obtained using quantitative coronary angiography was a strong predictor of patency. Good long-term patency can be expected for an MLD <1 mm.

Keywords: Coronary artery bypass grafting • Gastroepiploic artery • Quantitative coronary angiography • Minimum luminal diameter

INTRODUCTION

Isolated coronary artery bypass grafting (CABG) was performed in 14 454 cases in Japan in 2014. The operative and hospital mortality rates associated with primary elective CABG procedures in 12 335 cases were 0.8% and 1.3%, respectively [1].

The saphenous vein (SV), the internal thoracic artery (ITA), the radial artery (RA) and the gastroepiploic artery (GEA) have been deemed suitable graft materials for CABG [2]. Although the left ITA to the left anterior descending artery is a gold standard strategy, several recent reports revealed that bilateral ITAs to the left coronary artery improved the long-term results of CABG [3–5]. However, the third ideal graft for the right coronary artery (RCA) remains controversial [6–8]. Most surgeons use the SV as a graft for the right coronary system, despite its poor long-term patency, and only a few surgeons prefer to use the GEA as the third graft for the RCA lesion, even in Japan [9]. Surgeons rarely use the GEA for several reasons [2]. Basically, the GEA contains a considerable amount of smooth muscle tissue in the vessel wall, which can easily cause vascular spasm [10–12]. Most surgeons believe that such spasm makes manipulation difficult and can potentially cause graft occlusion. In addition, the competitive flow of the GEA is another major concern, as moderate stenosis of the native coronary artery can cause flow competition [13, 14]. As relatively few surgeons have used the GEA for such purposes, the long-term graft patency associated with this artery, thus, remains unclear. We have been using a semiskeletonized GEA for the RCA as in *in situ* fashion, because we prefer to use the aorta no-touch technique to avoid using a free graft such as the SV. We believe that this approach helps reduce the risk of embolism such as cerebral infarction. In this study, we retrospectively analysed the long-term patency of the semiskeletonized GEA to clarify the validity of our strategy and tried to evaluate the relationship between flow competition, patency and the degree of stenosis of native vessels.

METHODS

This study was approved by the institutional review board of Nagoya Daini Red Cross Hospital. The first and final authors take complete responsibility for the integrity of the data and accuracy of the data analysis.

Patient population

From January 2000 to January 2015, 1113 consecutive patients underwent isolated CABG at our institution with the *in situ* semiskeletonized GEA used in 517 patients. The mean age of the patients at surgery was 65.6 ± 8.5 years (range 34–87 years). A total of 446 (86%) patients had triple-vessel disease and 71 (14%) patients had double-vessel disease, whereas 105 (20%) patients had left main trunk disease. Seventy-five (15%) patients underwent urgent or emergent operation.

Indication of the gastroepiploic artery

Poor outcomes have been reported when using the GEA for mild stenosis of the native coronary artery, and our surgical indication of graft selection for the RCA was determined on the basis of the preoperative degree of the RCA lesion. Target vessels ≥75% stenosis were thought to be good candidates for *in situ* GEA grafting. Patients <75% stenosis of RCA were principally treated with the SV.

Surgical technique

All patients received a computed tomography scan and evaluation of the GEA before surgery. The use of the GEA was principally avoided when significant narrowing of the coeliac axis or calcification of the GEA was found on preoperative computed tomography, when the diameter of the GEA at the anastomosis site was <2.0 mm or when the GEA's free flow was <30 ml/min, which was based on the personal experience of the team. The GEA was harvested using a Harmonic Scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA) with a coagulating shears tip, as previously reported [15]. We employed a semiskeletonized approach to prevent damage or vasospasm of the GEA. The anterior layer of the greater omentum was isometrically incised with the necessary graft length. The small omental and gastric branches of the GEA were then divided and cut with the Harmonic Scalpel. Consequently, the GEA was harvested with the satellite veins.

After systemic heparinization, olprinone hydrochloride (INN; Eisai Co, Ltd, Tokyo, Japan) was injected into the harvested graft, and then the graft was wrapped with a papaverine-soaked gauze. Nicorandil and diltiazem were continuously administered intravenously during the operation and thereafter until the second postoperative day to prevent the graft spasm. The GEA was anastomosed to the posterior descending artery or the posterior lateral artery. The sequential grafting technique was used in 140 patients. Sequential anastomosis was performed when there was no communication between the posterior descending artery and the posterior lateral artery of the RCA or when anastomosing to the distal circumflex artery. All coronary anastomoses were performed with 7-0 polypropylene sutures. We performed off-pump surgery in 194 patients, using the strategy of our institution for CABG as follows: off-pump CABG, mainly performed in patients with ≦3 simple anastomoses, low renal function, bad ascending aorta; on-pump beating CABG, mainly performed in patients with a low left ventricular ejection fraction or bad ascending aorta, who were unsuited for cross clamping; and on-pump arrest CABG, mainly performed in patients excluded from off-pump surgery. Postoperative antiplatelet therapy was performed in all patients. Aspirin was orally administered on the first day after surgery. Principally, dual antiplatelet therapy was not used in this study.

Follow-up

All patients underwent outpatient examinations at 2, 4 and 12 weeks after surgery, followed by a visit to our hospital or clinic every year. The latest information was acquired by telephone or through the medical records of our hospital. The 95% follow-up rate had been achieved by April 2018. The mean duration of follow-up was 8.3 ± 4.9 years. Seven patients underwent gastrectomy for stomach cancer during the follow-up period. A cardiac surgeon participates in the operation to preserve GEA grafts. These patients safely underwent gastrectomy without sacrificing the GEA. After CABG, stomach or duodenal ulcers were found in 7 patients, but the presence of any adverse effects associated with using the GEA was uncertain.

Evaluation of the long-term gastroepiploic artery patency

Postoperative angiography was routinely performed in our institution within 1 year, and 494 (95.5%) patients received catheter-based angiography. Of them, immediate postoperative angiography (before discharge after the CABG) was performed in 470 patients and reviewed to evaluate the graft function and the run-off grade of distal anastomosis of the GEA. The graft function was stratified as follows: functional, when the native coronary flow was fully opacified by the graft; competitive, when the native coronary flow and the graft flow was balanced; a non-functional graft, when the native coronary flow was dominant; occluded, when occlusion or the string sign was noted. The distal run-off was graded by the number of contrasted medium was a branch of the target vessel when the angiography contrast was injected to the graft: a single branch, only 1 branch (either the posterior descending artery or the posterior lateral artery) and multiple branches, more than 1 branch.

A total of 282 patients underwent distant angiography using catheter-based angiography or computed tomography angiography, from 1 year to 18 years after surgery. The remaining patients were unable to receive distant angiography for the following reasons: 71 patients died during the follow-up period (including 8 patients due to cardiac or sudden death), 48 patients were asymptomatic elderly individuals for whom clinicians considered that further examinations were not required, 46 were unwilling to undergo an examination, 34 had low renal function and 20 were missing in the follow-up period. A total of 156 patients were able to be evaluated for more than 5 years after surgery. The mean duration between first angiography assessment and the latest assessment was 6.6 years (range 1–18 years).

Quantitative angiographic measurement

Quantitative coronary angiography (QCA) was used to calculate the degree of stenosis as previously reported [16]. Preoperative angiograms were analysed with the QAngio®XA system (Medis medical imaging systems BV, Schuttersveld, Netherlands). The minimal lumen diameter (MLD) and % diameter stenosis of the target vessels for the GEA were measured in 2 near orthogonal projections, and the mean value was calculated.

Table 1: Preoperative characteristics

Variables	
Age (years), mean ± SD	65.6 ± 8.5
Male	435 (84)
Urgency	75 (15)
History of MI	191 (37)
Inferior OMI	96 (19)
LVEF (%), mean ± SD	55 ± 15
Diseased vessel	
1- or 2-vessel disease	79 (15)
3-vessel disease	438 (85)
LMT disease	105 (20)
History of PCI	83 (16)
Previous cardiac surgery	6 (1.1)
CRF (creatinine >200 μmol/l)	60 (12)
ESRF on dialysis	42 (8.1)
Diabetes mellitus	294 (57)
Hypertension	367 (71)
Hypercholesterolaemia	341 (66)
PAD	70 (14)

Unless otherwise indicated, values are presented as *n* (%).

CRF: chronic renal failure; ESRF: end-stage renal failure; LMT: left main trunk; LVEF: left ventricular ejection fraction; MI: myocardial infarction; OMI: old myocardial infarction; PAD: peripheral arterial disease; PCI: percutaneous coronary intervention; SD: standard deviation.

The % area stenosis of the target vessel of the GEA was 100% in 251 cases, 90–99% in 56 cases, 75–90% in 169 cases and 75% or less in 45 cases. The MLD of the target vessel was 0 mm in 251 cases, 0–0.7 mm in 45 cases, 0.7–1.0 mm in 105 cases, 1–1.3 mm in 45 cases and 1.3 mm or more in 35 cases.

Statistical analysis

The JMP 13 software programme (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis. The data are presented as the frequency or mean ± standard deviation. Long-term graft patency curves were made using the Kaplan–Meier method. To identify the risk factors of the graft occlusion, baseline variables were evaluated with a univariable analysis using the log-rank test. To set the cut-off value for predicted graft patency, a time-dependent ROC curve analysis was performed to convert angiographic quantitative variables into binary variables. The multivariable analysis includes the factors that clinicians considered to be involved in graft occlusion with *P*-value <0.5 set to indicate a significant factor using a Cox proportional hazards regression analysis.

RESULTS

The patient preoperative and perioperative characteristics are shown in Tables 1 and 2. The GEA was used for all patients. The ITA was used for 495 (97.1%) patients, and the bilateral ITAs were used for 376 (66.9%) patients. The number of distal anastomoses/patient was 3.5 ± 1.1. On-pump CABG was performed in 323 (63%) patients, and the off-pump technique was performed in 194 (37%) patients. A total of 489 (95.1%) patients received total arterial reconstruction. The postoperative hospital mortality rate was 1.1% (6 cases). A total of 470 patients underwent catheter-based angiography evaluation before their discharge after operations (immediate angiogram evaluation), and of which 30 GEAs were found to be occluded, 29 were non-functional grafts, 41 were competitive grafts and 370 were functional grafts. The early patency rate of the semiskeletonized GEAs was 94.7%.

In the follow-up period, 132 deaths occurred (malignancy in 36 patients, infection in 19 patients, cardiac in 12 patients, stroke in 11 patients, sudden death in 8 patients, renal failure in 7 patients, peripheral disease in 6 patients, natural death in 13 patients, unknown in 10 patients and others in 10 patients). The overall survival rates according to the Kaplan–Meier analysis were 97.6%, 89.2% and 73.3% for 1 year, 5 years and 10 years, respectively.

Cardiac death, including sudden death, occurred in 20 cases. The freedom from cardiac or sudden death rate was 99.3%, 97.4% and 93.5% at 1 year, 5 years and 10 years, respectively.

Table 2: Perioperative characteristics

Variables	
Redo case	6 (1.1)
Number of anastomoses, mean ± SD	3.5 ± 1.1
Conduit	
LITA	495 (96)
RITA	387 (75)
SVG	28 (5.4)
RA	4 (0.8)
GEA	517 (100)
GEA grafting territory	
RCA	507 (98)
LCX	59 (11)
GEA grafting technique	
In situ single	374 (72)
In situ sequential	143 (28)
Off-pump surgery	194 (37)

Unless otherwise indicated, values are presented as *n* (%).

GEA: gastroepiploic artery; LCX: left circumflex brunch; LITA: left internal thoracic artery; RA: radial artery; RCA: right coronary artery; RITA: right internal thoracic artery; SD: standard deviation; SVG: saphenous vein graft.

Long-term patency of the gastroepiploic artery

A total of 282 patients underwent distant angiography during the follow-up period, and 30 GEAs turned out to be occluded between the immediate evaluation and 18 years after the operation, of which 20 patients had non-functional grafts and 7 patients had shown a competitive flow pattern on the immediate angiogram. Including 30 cases of early occlusion, 60 GEAs were occluded within the follow-up period. Of these 60 patients, 16 patients underwent percutaneous coronary intervention to the RCA. The remaining cases received medical treatment because ischaemia in the RCA region was not clear. The cumulative patency rate of the semiskeletonized GEA graft was 92.2%, 83.4% and 79.3% at 1 year, 5 years and 10 years, respectively.

Predictors of gastroepiploic artery occlusion by univariable analysis

Preoperative and perioperative factors were analysed using the log-rank test in a univariable analysis. The age [hazard ratio (HR) 1.04, 95% confidence interval (CI) 1.00–1.07; $P = 0.03$] and the MLD (HR 4.10, 95% CI 2.66–6.33; $P < 0.001$) were significant predictive factors of GEA graft occlusion, whereas the sequential graft was a protective factor for predictors of the graft patency (HR 0.33, 95% CI 0.15–0.72; $P = 0.005$) (Table 3).

A time-dependent ROC curve analysis was performed immediately after CABG and 1 year, 3 years, 5 years and 7 years after CABG. The area under the curve at 3 years after CABG was the highest for identifying the cut-off value of the MLD. An MLD >1 mm was set as the cut-off value for the graft occlusion (area under the curve 0.76; 95% CI 0.67–0.84, sensitivity 68%, specificity 76%) (Fig. 1).

Predictors of gastroepiploic artery occlusion by multivariable analysis

Angiographic and clinical variables were analysed using the Cox proportional hazard regression analysis. The MLD (HR 4.43, 95% CI 3.25–6.82; $P < 0.001$) and inferior old myocardial infarction (HR 2.15, 95% CI 1.09–4.22; $P = 0.02$) were independent risk factors for GEA graft occlusion, whereas the sequential graft was a

Table 3: Univariable and multivariable analyses

Variables	Univariable analysis			Multivariable analysis		
	HR	95% CI	*P*-value	HR	95% CI	*P*-value
Age	1.04	1.00–1.07	0.03	1.03	0.99–1.06	0.12
Diabetes mellitus	0.80	0.48–1.33	0.38	0.85	0.49–1.49	0.57
Chronic renal failure	0.96	0.84–1.11	0.60			
LVEF <0.40	1.00	0.98–1.01	0.63			
PAD	0.97	0.46–2.06	0.95			
MLD	4.10	2.66–6.33	<0.001	4.43	3.25–6.82	<0.001
CTO lesion of RCA	0.33	0.18–0.59	<0.001	2.13	0.81–5.63	0.13
Sequential anastomosis	0.33	0.15–0.72	0.005	0.40	0.17–0.92	0.03
Inferior OMI	1.42	0.76–2.66	0.27	2.15	1.09–4.22	0.02
Off-pump surgery	1.23	0.73–2.07	0.43	1.05	0.60–1.85	0.85

CI: confidence interval; CTO: chronic total occlusion; HR: hazard ratio; LVEF: left ventricular ejection fraction; MLD: minimal lumen diameter; OMI: old myocardial infarction; PAD: peripheral arterial disease; RCA: right coronary artery.

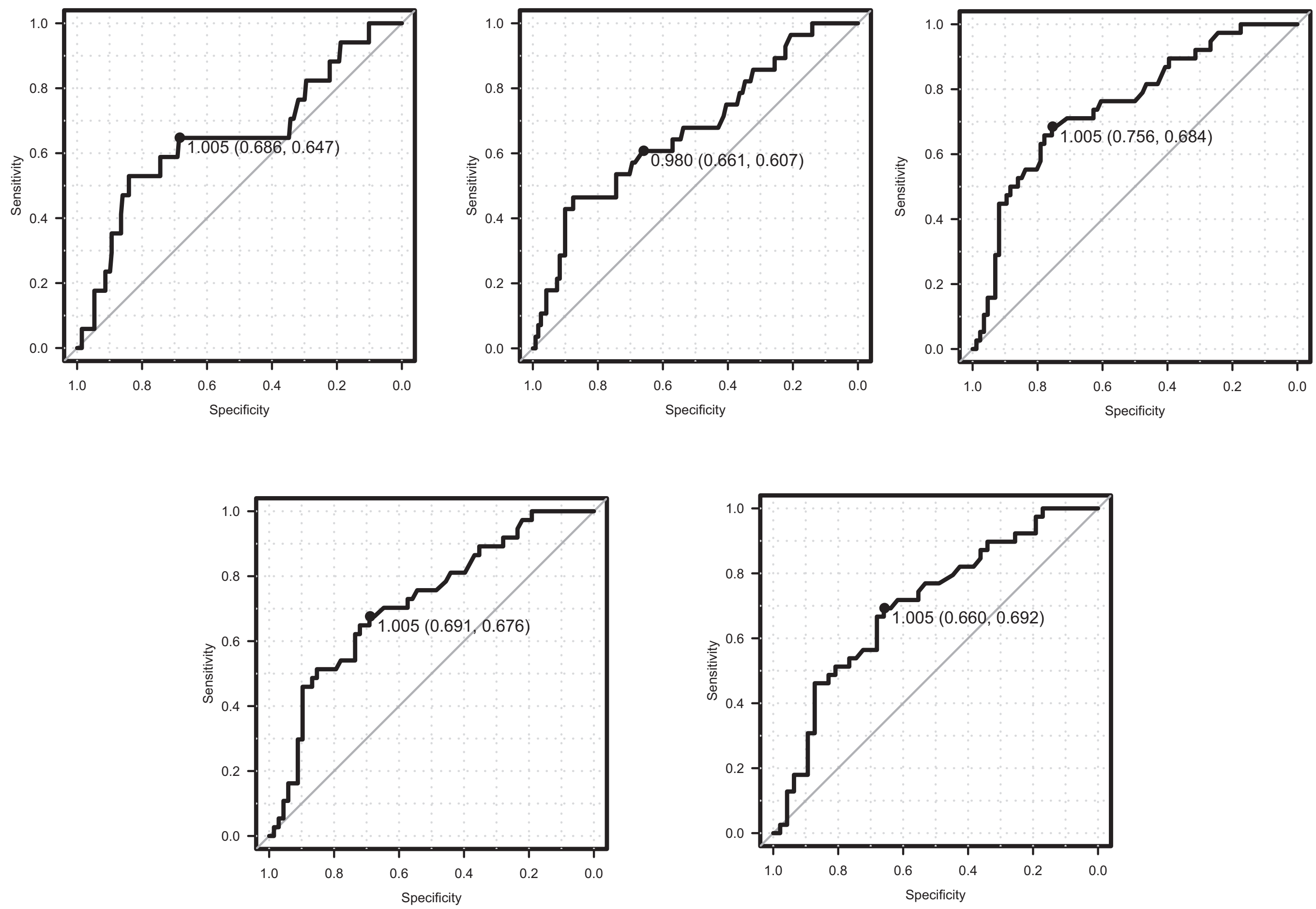


Figure 1: (**A**–**E**) ROC curves for immediately after coronary artery bypass grafting and 1, 3, 5 and 7 years after coronary artery bypass grafting, respectively. The ROC curve shows the cut-off value of the minimal lumen diameter to graft occlusion.

protective factor for GEA graft patency (HR 0.40, 95% CI 0.17–0.92; $P = 0.03$) (Table 2). In the MLD <1-mm group, 10-year GEA graft patency was significantly higher than the MLD >1-mm group (89.8% vs 40.0%, $P < 0.001$), and the trend of patency was not changed after the risk adjusted for inferior old myocardial infarction and sequential anastomosis (Fig. 2).

Impact of the minimal lumen diameter on the graft function

The graft function was stratified from the angiogram obtained immediately after CABG. The mean MLD was measured for each group. There was a significant difference in the MLD among groups. The functional graft group had the lowest mean MLD, whereas the non-functional graft had the highest. The Kaplan–Meier curve analysis was performed to evaluate the long-term GEA patency for each group. In the functional graft group, the 10-year GEA graft patency was significantly higher than in other groups (functional graft 99.3% vs competitive graft 73.2% vs non-functional graft 5.6%, $P < 0.001$) (Fig. 3). However, in the competitive graft group, the cases with an MLD <1 mm had a significantly higher 10-year patency rate than those with an MLD >1 mm (100% vs 56%, $P = 0.029$) (Fig. 3).

Sequential graft and distal run-off

The mean number of run-off branches was significantly higher for sequential grafts than non-sequential grafts (1.89 vs 1.36, $P < 0.001$). Multiple run-off grafts had a significantly higher patency rate than single run-off grafts ($P = 0.0254$) (Fig. 4).

Subgroup analysis of the minimal lumen diameter

A subanalysis was performed by subdividing the MLD by the vessel diameter. All patients were divided into 5 groups of 0 mm, >0 mm to 0.7 mm, >0.7 mm to 1.0 mm, >1.0 mm to 1.3 mm and >1.3 mm. The 10-year patency rate was 89.7%, 91.2%, 86.1%, 54.8% and 20.7% in the 0 mm, >0 to 0.7 mm, >0.7 mm to 1.0 mm, >1.0 mm to 1.3 mm and >1.3 mm, respectively. The groups with an MLD <1 mm showed no significant difference among the groups (0 mm vs >0 mm to 0.7 mm; $P = 0.941$, >0 mm to 0.7 mm vs >0.7 mm to 1.0 mm; $P = 0.624$) (Fig. 4). On comparing the 10-year patency rate between the >0.7-mm to 1.0-mm and the >1.0-mm to 1.3-mm groups, the >0.7-mm to 1.0-mm group had a significantly higher rate than the >1.0-mm to 1.3-mm group ($P = 0.018$) (Fig. 3).

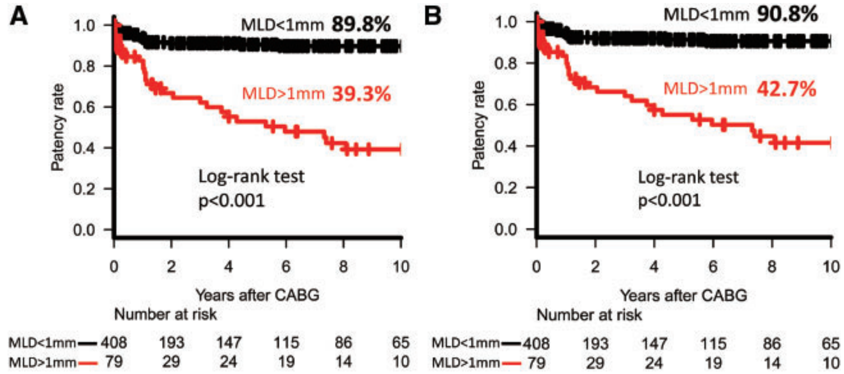


Figure 2: (**A**) The Kaplan–Meier curve showing the gastroepiploic artery patency of MLD <1 mm (black line) vs >1 mm (red line). (**B**) The Kaplan–Meier curve adjusted for an inferior old myocardial infarction and sequential anastomosis. CABG: coronary artery bypass grafting; MLD: minimum luminal diameter.

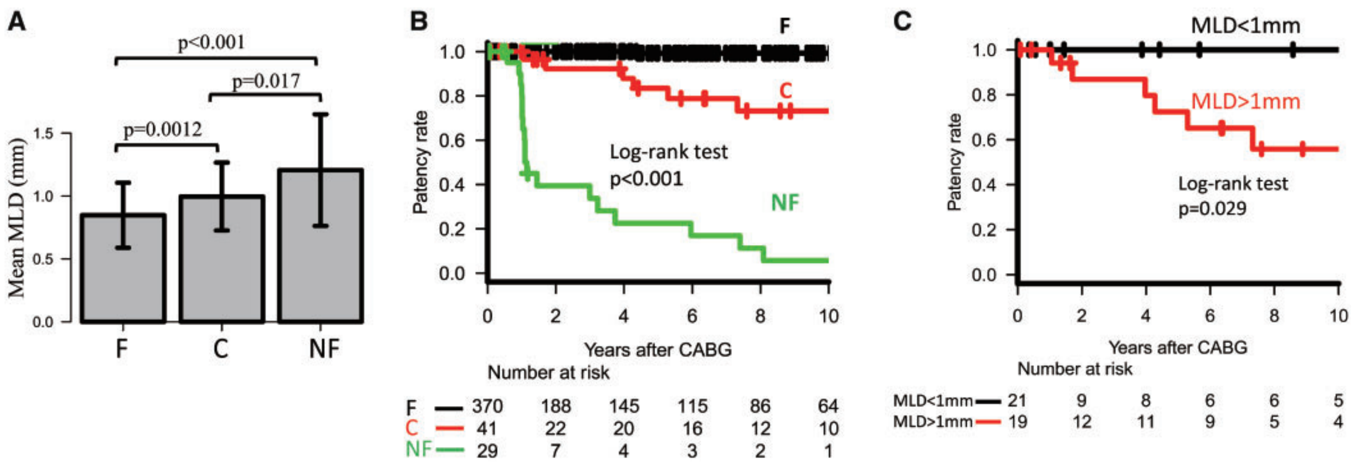


Figure 3: (**A**) The mean MLD for each graft function. (**B**) The Kaplan–Meier curve showing the gastroepiploic artery patency of a functional graft (black line) vs a competitive graft (red line) vs a non-functional graft (green line). (**C**) The Kaplan–Meier curve of a competitive graft comparing an MLD <1 mm (black line) vs MLD >1 mm (red line). C: competitive graft; CABG: coronary artery bypass grafting; F: functional graft; MLD: minimum luminal diameter; NF: non-functional graft.

In cases with an MLD >1 mm, the >1.0-mm to 1.3-mm group had a significantly higher patency than the >1.3-mm group ($P = 0.002$) (Fig. 5).

DISCUSSION

The ideal graft for CABG has been discussed at length, especially for right coronary lesions. The SV is commonly used for the RCA globally. However, the SV is not without its disadvantages. For instance, the long-term patency of the SV is unsatisfactory due to graft disease [17]. Second, it requires proximal anastomosis mainly on the ascending aorta, even though this can cause embolism such as cerebral infarction. The RA is also used for RCA lesions [18] and is categorized as a muscular artery, like the GEA. However, the RA did not repeatedly show superior long-term patency rates compared with the SV on RCA lesion. Also occasionally, the length of the RA may be limited for bypass to the RCA system due to the relatively short arm span in Japanese patients. Furthermore, it also requires another skin incision and the proximal anastomosis such as the SV, so the advantages of using the RA seem few. A composite graft technique to an ITA graft is also used to prevent manipulation of the ascending aorta. Using the double ITA as a composite graft is technically difficult to perform, and also the concern remains when there is only 1 ITA inflow supplying multiple outflows including RCA lesion. The GEA has an advantage in that it can be used as an *in situ* graft and is particularly useful for patients with a diseased ascending aorta [19]. Especially for off-pump CABG, the complete aorta no-touch technique can be used to reduce the risk of embolism such as cerebral infarction. When we started using the GEA, there were no data indicating the long-term results. We believe, however, that total arterial bypass grafting with the GEA can help improve the outcomes of CABG, especially for relatively young patients [7, 20]. This study, therefore, investigated the long-term patency of a semiskeletonized GEA and clarified the validity of our strategy.

The semiskeletonized gastroepiploic artery

The GEA is the third branch of the coeliac artery and histologically categorized as a muscular artery with a considerable amount of smooth muscle tissue. As it can cause spasm like the RA, the optimum method of harvesting the GEA is controversial. In addition, the length and calibre of the GEA vary considerably by individual. In some cases, the size of the GEA could be too small for grafting when subjected to pedicle harvesting. A skeletonized GEA can have an increased graft length and calibre size when compared with pedicle harvesting. Furthermore, Suma *et al.* [21] reported that the long-term patency of a pedicle GEA

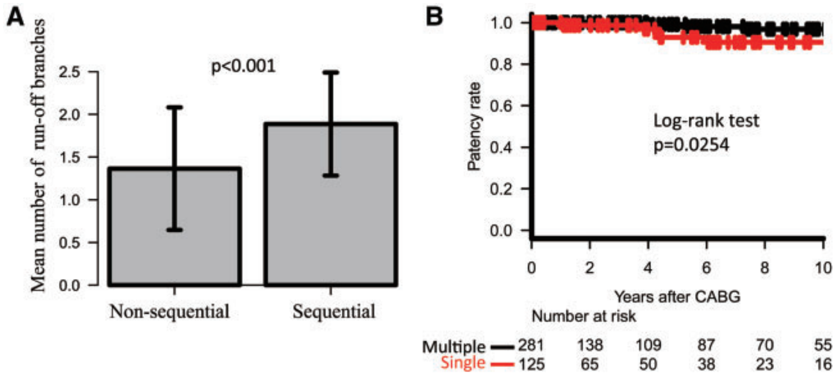


Figure 4: (**A**) The mean number of run-off branches between a sequential graft and a non-sequential graft. (**B**) The Kaplan–Meier curve comparing a multiple run-off graft (black line) vs a single run-off graft (red line). CABG: coronary artery bypass grafting.

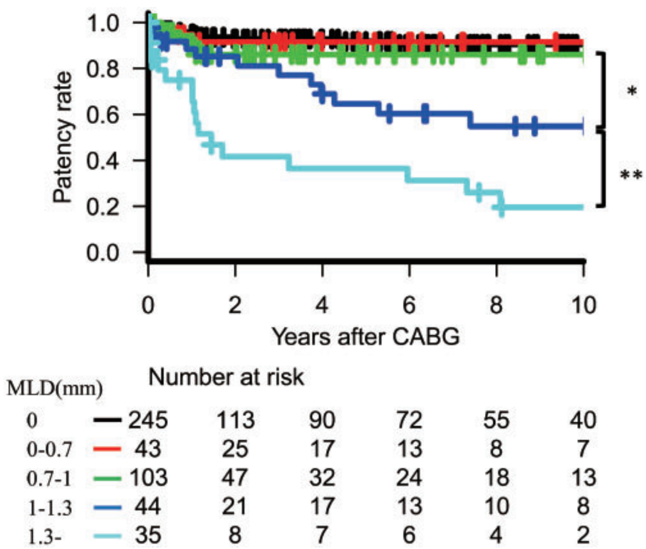


Figure 5: The Kaplan–Meier curve showing the gastroepiploic artery patency of MLD = 0 mm (black line), MLD >0 mm and <0.7 mm (red line), MLD >0.7 mm and <1 mm (green line), MLD >1 mm and <1.3 mm (blue line) and MLD >1.3 mm (light-blue line). *>0.7 mm and <1 mm vs >1 mm and <1.3 mm, $P = 0.018$; **>1 mm and <1.3 mm vs >1.3 mm, $P = 0.002$. CABG: coronary artery bypass grafting; MLD: minimum luminal diameter.

was 66.5% after 10 years, but the patency rate reportedly improved after switching to a skeletonized GEA, with further improvement in grafting to the RCA with severe stenosis in the last 5 years. Suzuki *et al.* [22] also reported a good patency rate of 90.2% in the skeletonized GEA at 8 years after surgery. However, the graft spasm or injury may occur with the harvesting in a skeletonized fashion, because the GEA has a satellite vein very closely running beside it. We, therefore, selected a semiskeletonized fashion, in which the GEA is harvested with the satellite vein by removing the artery from the serosa of the greater omentum. This helps prevent the graft spasm by reducing the touching of the GEA and also increases the calibre size of the less fatty GEA through wrapping with a papaverine-soaked gauze. This semiskeletonized GEA usually has a sufficient length and calibre to enable sequential anastomosis of the RCA system.

Minimal lumen diameter and graft function

QCA analysis has proved useful for evaluating the severity of stenosis [23]. A previous randomized study, which evaluated the postoperative angiograms at 3 years after surgery, showed that the number of the functional GEA grafts was significantly decreased compared with the number of the SV grafts when the MLD of the stenosis site of the native coronary artery was >1.1 mm on preoperative QCA [24]. In this study, we also used QCA to clarify the relationship between the precise severity of stenosis and the patency. All preoperative angiograms were reviewed to remeasure the target vessel stenosis. The analysis revealed that there was a significant difference in the long-term patency depending on the MLD, as the randomized study indicated. Sixty GEAs were occluded within a mean follow-up of 6.7 years, and a time-depending ROC analysis identified an MLD >1 mm to be a predictor of occlusion (Fig. 1).

In the previous randomized study, non-functional GEA grafts (occlusion, flow competition, string sign, etc.) were detected on the postoperative angiograms [24–26]. However, the fate of those non-functional grafts remains uncertain, as few follow-up studies have been rarely conducted. The present study confirmed that the GEA frequently became occluded in the late phase with non-functional grafts and competitive graft with an MLD >1 mm on angiograms obtained immediately after surgery, whereas the competitive graft with an MLD <1 mm showed to be as good as that of the functional graft (Fig. 3). In the subgroup analysis, the patency rate in cases with an MLD <1 mm showed no marked changes depending on the degree of stenosis, whereas the patency rate in those with an MLD >1 mm decreased over time (Fig. 5). The patency rate in cases with an MLD of >1.3 mm was particularly low, and the dysfunctionality of the graft on the angiogram immediately after CABG was identified as a cause of late occlusion (Fig. 3). In cases of an MLD >1 mm, the GEA graft patency was worse than that of the SV as reported previously.

Sequential anastomosis

Sequential anastomosis was shown to be a protective factor for long-term patency in this study. The graft flow rate basically depends on the flow demand of the target area. A sequential anastomosis technique can cover a wider covered area on the RCA system, derive a larger flow demand and obtain a higher graft flow than a non-sequential approach and can also achieve a better patency rate, even in a long-term period (Fig. 4). This study indicates that sequential anastomosis is a protective factor for GEA patency, as previously reported [27, 28]. Our results showed the inferior old myocardial infarction to be another independent risk factor for graft occlusion, which generally reduces the graft flow demand.

Limitations

There are several limitations associated with this study.

(i) this is a non-randomized and retrospective study with a small number of subjects. However, all procedures were performed by a single surgeon in the same institution with the semi-skeletonized GEA method.

(ii) the long-term patency assessments for the asymptomatic patients were mainly performed by computed tomography angiography, accordingly its low invasiveness. Computed tomography angiography can detect graft patency, but it is a weak tool for determining the functionality of a graft.

(iii) some patient selection bias may remain in the evaluation of long-term patency. Even computed tomography angiography cannot be performed on patients with a low renal function or in those who are unwilling to be subjects.

(iv) the subgroup analysis with an MLD >1 mm, the number of patients at risk for depending on an MLD >1.3 mm and the >1-mm to 1.3-mm group were lower than in the cases with an MLD <1 mm in the long-term period. This might have influenced the statistical conclusions regarding the graft occlusion.

CONCLUSION

The long-term patency of the semiskeletonized GEA was acceptable. The target vessel MLD obtained by QCA was a strong predictor of patency. Good long-term patency can be expected for an MLD ≤1 mm.

Conflict of interest: none declared.

REFERENCES

[1] Masuda M, Okumura M, Doki Y, Endo S, Hirata Y, Kobayashi J.; Committee for Scientific Affairs. Thoracic and cardiovascular surgery in Japan during 2014: annual report by The Japanese Association for Thoracic Surgery. Gen Thorac Cardiovasc Surg 2016;64:665–97.

[2] Mohr FW, Rastan AJ, Serruys PW, Kappetein AP, Holmes DR, Pomar JL. Complex coronary anatomy in coronary artery bypass graft surgery: impact of complex coronary anatomy in modern bypass surgery? Lessons learned from the SYNTAX trial after two years. J Thorac Cardiovasc Surg 2011;141:130–40.

[3] Taggart DP, D'Amico R, Altman DG. Effect of arterial revascularisation on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 2001;358:870–5.

[4] Lytle BW, Blackstone EH, Sabik JF, Houghtaling P, Loop FD, Cosgrove DM. The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. Ann Thorac Surg 2004;78:2005–12; discussion 2012–4.

[5] Kurlansky P. Thirty-year experience with bilateral internal thoracic artery grafting: where have we been and where are we going? World J Surg 2010;34:646–51.

[6] Di Mauro M, Contini M, Iacò AL, Bivona A, Gagliardi M, Varone E *et al.* Bilateral internal thoracic artery on the left side: a propensity score-matched study of impact of the third conduit on the right side. J Thorac Cardiovasc Surg 2009;137:869–74.

[7] Glineur D, D'Hoore W, Price J, Dormeus S, de Kerchove L, Dion R *et al.* Survival benefit of multiple arterial grafting in a 25-year single-institutional experience: the importance of the third arterial graft. Eur J Cardiothorac Surg 2012;42:284–90; discussion 290–1.

[8] Shi WY, Tatoulis J, Newcomb AE, Rosalion A, Fuller JA, Buxton BF. Is a third arterial conduit necessary? Comparison of the radial artery and saphenous vein in patients receiving bilateral internal thoracic arteries for triple vessel coronary disease. Eur J Cardiothorac Surg 2016;50:53–60.

[9] The Survey Committee of Japanese Association for Coronary Artery Surgery (JACAS). Coronary Artery Surgery Results. 2017. http://www.jacas.org/data/pdf/slide_2017_e.pdf (10 October 2018, date last accessed).

[10] Suma H. Spasm of the gastroepiploic artery graft. Ann Thorac Surg 1990; 49:168–9.

[11] Mills NL, Hockmuth DR, Everson CT, Robart CC. Right gastroepiploic artery used for coronary artery bypass grafting. Evaluation of flow characteristics and size. J Thorac Cardiovasc Surg 1993;106:579–85; discussion 586.

[12] Cate CM, Gitter R, Jett K. Spasm of the gastroepiploic artery used for coronary artery bypass grafting. Am J Cardiol 1996;77:1022–3.

[13] Hashimoto H, Isshiki T, Ikari Y, Hara K, Saeki F, Tamura T *et al.* Effects of competitive blood flow on arterial graft patency and diameter. Medium-term postoperative follow-up. J Thorac Cardiovasc Surg 1996;111: 399–407.

[14] Uchida N, Kawaue Y. Flow competition of the right gastroepiploic artery graft in coronary revascularization. Ann Thorac Surg 1996;62:1342–6.

[15] Asai T, Tabata S. Skeletonization of the right gastroepiploic artery using an ultrasonic scalpel. Ann Thorac Surg 2002;74:1715–7.

[16] Gronenschild E, Janssen J, Tijdens F. CAAS. II: a second generation system for off-line and on-line quantitative coronary angiography. Cathet Cardiovasc Diagn 1994;33:61–75.

[17] McKavanagh P, Yanagawa B, Zawadowski G, Cheema A. Management and prevention of saphenous vein graft failure: a review. Cardiol Ther 2017;6:203–23.

[18] Hirose H, Amano A, Takahashi A. Triple arterial coronary revascularization using the radial artery and bilateral internal mammary arteries versus the gastroepiploic artery and bilateral internal mammary arteries. Circ J 2002;66:544–8.

[19] Nakatsu T, Tamura N, Sakakibara Y, Hagio K, Ishigami M. Long-term survival after coronary arterial grafts in patients with end-stage renal disease. Ann Thorac Surg 2010;90:738–43.

[20] Nishida H, Tomizawa Y, Endo M, Koyanagi H, Kasanuki H. Coronary artery bypass with only in situ bilateral internal thoracic arteries and right gastroepiploic artery. Circulation 2001;104(12 Suppl 1):I76–80.

[21] Suma H, Tanabe H, Takahashi A, Horii T, Isomura T, Hirose H *et al.* Twenty years experience with the gastroepiploic artery graft for CABG. Circulation 2007;116: I188–91.

[22] Suzuki T, Asai T, Nota H, Kuroyanagi S, Kinoshita T, Takashima N *et al.* Early and long-term patency of in situ skeletonized gastroepiploic artery after off-pump coronary artery bypass graft surgery. Ann Thorac Surg 2013;96:90–5.

[23] Berger A, MacCarthy PA, Siebert U, Carlier S, Wijns W, Heyndrickx G. Long-term patency of internal mammary artery bypass grafts: relationship with preoperative severity of the native coronary artery stenosis. Circulation 2004;110(11 Suppl 1):II36–40.

[24] Glineur D, D'Hoore W, de Kerchove L, Noirhomme P, Price J, Hanet C *et al.* Angiographic predictors of 3-year patency of bypass grafts implanted on the right coronary artery system: a prospective randomized comparison of gastroepiploic artery, saphenous vein, and right internal thoracic artery grafts. J Thorac Cardiovasc Surg 2011;142:980–8.

[25] Glineur D, Hanet C, Poncelet A, D'hoore W, Funken JC, Rubay J *et al.* Comparison of saphenous vein graft versus right gastroepiploic artery to revascularize the right coronary artery: a prospective randomized clinical, functional, and angiographic midterm evaluation. J Thorac Cardiovasc Surg 2008;136:482–8.

[26] Glineur D, D'hoore W, El Khoury G, Sondji S, Kalscheuer G, Funken JC *et al.* Angiographic predictors of 6-month patency of bypass grafts implanted to the right coronary artery a prospective randomized comparison of gastroepiploic artery and saphenous vein grafts. J Am Coll Cardiol 2008;51:120–5.

[27] Nakano J, Okabayashi H, Noma H, Sato T, Sakata B. Early angiographic evaluation after off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg 2012;146:1119–25.

[28] Ochi M, Bessho R, Saji Y, Fujii M, Hatori N, Tanaka S. Sequential grafting of the right gastroepiploic artery in coronary artery bypass surgery. Ann Thorac Surg 2001;71:1205–9.