In Situ Skeletonized Right Internal Mammary Artery Bypass Grafting to Left Anterior Descending Artery

Feasibility, Mid-Term Efficacy, and Risk Factors for Graft Failure

Qiang Ji,¹ MD, LiMin Xia,² MD, YunQing Shi,¹ MD, RunHua Ma,¹ JinQiang Shen,¹,
Hao Lai,¹ MD, WenJun Ding,² MD and ChunSheng Wang,¹ MD

Summary

This study aimed to evaluate the feasibility and the mid-term efficacy of an in situ skeletonized right internal mammary artery (IMA) bypass grafting to a left anterior descending artery (LAD), and to determine risk factors for IMA graft failure in a single-center study.

From January 2012 to December 2015, 189 patients (173 males, 50.6 ± 6.0 years old) undergoing first isolated coronary artery bypass grafting surgery with the in situ skeletonized right IMA grafting to the LAD were included in this study. Baseline characteristics, perioperative data, and follow-up outcomes were investigated and analyzed.

The length of the in situ skeletonized right IMA grafts was 18.6 ± 1.2 cm (17.0-22.0 cm). Intraoperative graft flow of the in situ skeletonized right IMA grafting to LAD was 42 ± 9 mL/minute (18-72 mL/minute) associated with measured pulsatility index of 0.8-4.3. In-hospital mortality was 0.5%. Postoperative morbidity included acute myocardial infarction (0.5%), stroke (0.5%), and deep sternal wound infections (1.1%). The mid-term survival was 97.2% and the incidence of repeat revascularization was 0.6%. The patency rate of the in situ skeletonized right IMA grafting to the LAD was 97.1% by computed tomography angiography examination during the follow-up period of 23.2 ± 9.7 months. Additionally, logistic regression analysis showed that intraoperative graft flow had an independent influence on the risk of the mid-term right IMA graft failure.

The strategy of the in situ skeletonized right IMA grafting to the LAD is feasible and effective. Intraoperative graft flow was an independent risk factor for the mid-term right IMA graft failure.

(Int Heart J 2018; 59: 35-42)

Key words: Coronary artery bypass grafting, Artery skeletonization, Intraoperative graft flow, Graft patency

Coronary artery bypass grafting surgery (CABG) remains one of the most common cardiac surgical procedures today.¹⁻⁵ It has been demonstrated to provide symptomatic relief and increase the long-term survival for patients with coronary artery disease, which is mainly attributed to a complete revascularization and a left internal mammary artery (IMA) bypass grafting to a left anterior descending artery (LAD).¹⁻⁵ Following the publication of the landmark study by Loop in 1986, which validated positive impacts of the IMA graft on 10-year survival and other cardiac events, the strategy of the left IMA grafting to the LAD is considered as the “gold standard” of coronary revascularization.⁶ Given the fact that patients who received CABG surgery often require more than one graft, the prospect of bilateral IMA grafting becomes very appealing to cardiac surgeons after recognition of the long-term benefits of left IMA graft.⁷

However, the use of bilateral IMA grafting is

scarcely diffused.^{8,9} Concerns regarding a higher probability of deep sternal wound infections and its ensuing complications, an increased operation time, and technical challenges including utilizing and teaching the technique, have limited the widespread use of bilateral IMA grafting.¹⁰ Lack of standardization for the appropriate use of a right IMA graft is another important reason for reluctance to adopt bilateral IMA grafting. In utilizing the right IMA graft, the rationales behind how to harvest it (skeletonized versus pedicled), how to place it (in situ versus free versus ‘Y’ graft), and where to place it (left versus right coronary system) are not as clearly delineated.¹¹ The advantages of skeletonized IMA grafting include minimizing chest wall trauma, achieving maximal length, and facilitating the ease of sequential grafting.⁷ A skeletonized IMA graft compared to a pedicled IMA graft preserves collateral circulation to the sternum and drainage of the internal mammary veins, and has been shown to reduce the risk of

From the ¹Department of Cardiovascular Surgery, Zhongshan Hospital Fudan University, Shanghai, P.R. China and ²Shanghai Institute of Cardiovascular Disease, Shanghai, P.R. China.

Address for correspondence: WenJun Ding, MD, Shanghai Institute of Cardiovascular Disease, 180 Fenglin Rd., Shanghai, 200032, P.R.China. E-mail: dwj12191@163.com or ChunSheng Wang, MD, Department of Cardiovascular Surgery, Zhongshan Hospital Fudan University, 180 Fenglin Rd., Shanghai, 200032, P.R.China. E-mail: wang.chunsheng@zs-hospital.sh.cn

Received for publication November 2, 2016. Revised and accepted March 21, 2017.

Released in advance online on J-STAGE December 27, 2017.

doi: 10.1536/ihj.16-554

All rights reserved by the International Heart Journal Association.

Table I. Baseline and Procedure Characteristics of the Cohort

Variable	
Demographics	
Age (years)	50.6 ± 6.0 (32-73)
Gender (Females/Males)	16/173
Obesity (Body mass index > 30 kg/m ²)	21 (11.1%)
Recent smoking	76 (40.2%)
Concomitant diseases	
Diabetes mellitus	66 (34.9%)
Hypertension	105 (55.6%)
Cerebrovascular disease	6 (3.2%)
Dyslipidemia	23 (12.2%)
Renal dysfunction [#]	5 (2.6%)
Hepatic dysfunction [*]	1 (0.5%)
COPD	2 (1.1%)
Sleep apnea syndrome	1 (0.5%)
Hypothyroidism	3 (1.6%)
Gout	2 (1.1%)
Varicosis of great saphenous vein	2 (1.1%)
History of carotid endarterectomy	1 (0.5%)
Preoperative cardiac status	
Remote MI	19 (10.1%)
Recent MI [†]	22 (11.6%)
Congestive heart failure (NYHA class III and IV)	26 (13.8%)
Atrial fibrillation	4 (2.1%)
Left ventricular aneurysm	2 (1.1%)
Triple vessel disease	168 (88.9%)
Left main trunk disease	43 (22.8%)
History of PCI	23 (12.2%)
LVEF (%)	58.9 ± 6.7 (40-75)
LVEDD (mm)	51.4 ± 4.3 (38-63)
Procedure characteristics	
Off-pump CABG	171 (90.5%)
On-pump CABG	18 (9.5%)
CPB time (min)	81.7 ± 8.5
Concomitant coronary endarterectomy	4 (2.1%)
Intraoperative implantation of temporary pacemaker	1 (0.5%)
Number of distal anastomosis	3.6 ± 0.7 (2-6)
In situ skeletonized right IMA to the LAD	189 (100%)
Use of in situ skeletonized left IMA	189 (100%)
Sequential anastomosis	118 (62.4%)
Single anastomosis	71 (37.6%)
Use of SVG	62 (32.8%)
Use of RA	85 (44.9%)
Intraoperative switch to on-pump	1 (0.5%)

COPD indicates chronic obstructive pulmonary disease; MI, myocardial infarction; PCI, percutaneous cardiac intervention; LVEF, left ventricular ejection fraction; LVEDD, left ventricular endo-diastolic diameter; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; IMA, internal mammary artery; LAD, left anterior descending artery; SVG, saphenous vein graft; and RA, radial artery. [#]Renal dysfunction was defined as a serum creatinine level of 2.0 mg/dL or more or as the use of renal replacement therapy. ^{*}Hepatic dysfunction was recognized on the basis of Child-Pugh scores. [†]Recent MI was evidence of MI within the last 30 days before surgery.

sternal wound infection while maintaining the benefits of the application of IMA graft.^{12,13} Additionally, a recently published propensity score adjusted analysis investigated the impacts of the in situ right IMA grafting to the LAD on the long-term mortality and the need for repeat revascularization, and validated the safety and efficacy of the in situ right IMA grafting to the LAD.¹⁴ The latest study

conducted by Magruder JT and colleagues reported that the in situ right IMA-LAD with the in situ left IMA-left coronary circulation compared with other bilateral IMA graft configuration achieved similar benefits of long-term survival and freedom from repeat revascularization.¹⁵ Although published clinical outcomes were encouraging, an important limitation of previous studies mentioned above was the absence of delivery of more information (i.e., intraoperative graft flow and graft patency rate).

This single center, retrospective study reviewed 189 consecutive patients who received non-emergency, primary, isolated CABG surgery with the in situ skeletonized right IMA grafting to the LAD, and followed up their clinical and angiographic outcomes, in order to evaluate the feasibility and the short- and mid-term efficacy of the in situ skeletonized right IMA grafting to the LAD and to determine risk factors for in situ skeletonized right IMA graft failure.

Methods

Study population: From January 2012 to December 2015, a total of 2548 consecutive patients with coronary artery disease received CABG surgery in our center. Among them, 189 patients (173 males, 50.6 ± 6.0 years old) who received non-emergency, primary, isolated CABG surgery with the in situ skeletonized right IMA grafting to the LAD were included in the current study. Baseline characteristics and procedure data are shown in Table I. Hypertension, diabetes mellitus, and dyslipidemia were three common concomitant diseases. None of the included patients had a concomitant mild aortic valve stenosis or aortic dilatation. Among the 189 included patients, 90.5% patients ($n = 171$) received off-pump CABG surgery, and the remaining patients (including one patient who underwent urgent switching from off-pump to on-pump CABG) underwent on-pump CABG surgery. The number of grafts ranged from 2 to 6 (mean 3.6 per patient). All included patients received the in situ skeletonized right IMA grafting to the LAD and the in situ skeletonized left IMA grafting to the left coronary system with sequential (62.4%) or single anastomosis (37.6%). Eighty-five patients (44.9%) received a radial artery grafting and 62 patients (32.8%) underwent a great saphenous vein grafting.

Surgical procedures: Bilateral IMAs were harvested in a skeletonized fashion; the great saphenous vein and/or the radial artery were harvested with an open technique. Exposure of left or right IMA is usually achieved by retracting the pleura laterally via a median full-sternotomy, while leaving the pleural curtain intact. A skeletonized IMA was dissected from the adjacent veins and muscle. Care was taken to identify the correct plane of dissection in order to minimize damage to the IMA and to avoid excessive devascularization of the sternum. The dissection of skeletonized IMA was distally commenced (caudal), progressing proximally to IMA's emergence from the subclavian arteries with low settings (10-15 W) on the electrocautery. Identification and division of the proximal branches of the IMA are carried out very carefully to prevent proximal steal syndrome and phrenic nerve injury.

Figure 1. A skeletonized right IMA graft. An in situ skeletonized right IMA graft (before grafting) with a measured length of 19.0 cm was long enough to reach the apex.

Arterial branches were ligated with titanium clips from the bifurcation of the IMA to the first rib and divided with small scissors. The IMA is proximally harvested from above the subclavian vein to its bifurcation while taking care to ensure that all the major branches are divided. After systemic heparinization, the IMA is divided distally, sprayed with papaverine solution, and wrapped in warm papaverine soaked gauze.

The decision to perform on-pump beating-heart or off-pump CABG was influenced by each patient's demographic and clinical profile (i.e., age, diabetes mellitus, renal function, left ventricular endo-diastolic diameter, and estimated surgical risks), but the choice was ultimately left to the discretion of the operating surgeon. For patients undergoing on-pump CABG, cardiopulmonary bypass was instituted by cannulating the ascending aorta and right atrium after systemic heparinization (3 mg/kg) with a target activated clotting time of more than 480 seconds. Generally, cold blood cardioplegia was delivered in an antegrade fashion via aortic root after aortic cross-clamping. For patients undergoing off-pump CABG, heparin was given to reach an ACT of more than 300 seconds. The central temperature was maintained above 36°C to avoid hypothermia-induced ventricular arrhythmia. The heart was displaced using a posterior pericardial stitch, large gauze swabs (12 × 70 cm) and a tissue stabilizer (Octopus; Medtronic Corporation, Minneapolis, MN). Body position changes and gravity support (right decubitus Trendelenburg position), in combination with medical reduction of heart rate and myocardial contractility (a short-acting beta-blocker), were conducted during OPCAB surgery. A CO₂-blower/NaCl mister device and an intra-coronary shunt (Medtronic Corporation) were used during grafting when necessary. Blood loss was collected with a cell salvage device and the salvaged blood was re-infused into the patient before completion of the surgery.¹⁶⁾

Outcomes: The intra-operative outcomes included the length of the IMA graft, the IMA graft flow associated with the pulsatility index measured by a transit-time flow probe (Medistim Butterfly Flow Meter, Oslo, Norway), and intra-operative fluorescence imaging acquired using the SPYTM imaging system.¹⁷⁾

The short-term outcomes included in-hospital mortality and major postoperative morbidity. Major postoperative morbidity was listed as follows: circulatory morbidity (low cardiac output syndrome and new onset of acute myocardial infarction), pulmonary complications (pneumonia and respiratory failure), renal failure requiring hemodialysis, stroke, re-operation for bleeding, and deep sternal wound infection.

The follow-up clinical outcomes included all-cause mortality and the occurrence of major adverse cardiac events (MACEs). MACEs were defined as a composite of recurrent angina, cardiac-cause mortality, nonfatal acute myocardial infarction, and repeat myocardial revascularization.

Additionally, patients received non-invasive 64-slice, dual-source coronary CT angiography (iCT 64, Philips Healthcare, Amsterdam, Netherlands) during follow-up. The images were analyzed in off-line work stations (median effective irradiation of 7.5 mSv, interquartile range 3.76 mSv). All grafts were assigned a Fitzgibbon grade of A patency (ideal patency and impaired graft with stenosis < 50%), B patency (impaired graft with stenosis > 50%), or O patency (complete occlusion).¹⁸⁾ Graft failure was defined as impaired graft with stenosis > 50% including “string sign” and complete occlusion.

Statistical Analysis: This study protocol was approved by the ethics committee of the Fudan University and was consistent with the Declaration of Helsinki. All included patients signed an informed consent approved by the ethics committee.

Categorical variables are expressed in frequencies or percentages and continuous variables as mean ± standard deviation or median with range. Logistic regression analysis was used to analyze risk factors for the in situ skeletonized right IMA graft failure based on demographic data, concomitant diseases, preoperative cardiac status, off-pump/on-pump CABG, intraoperative graft flow, and pulsatility index.

Results

Intra-operative outcomes: Before grafting, the length of skeletonized right IMA grafts ranged from 17.0 to 22.0 cm (mean, 18.6 ± 1.2 cm; median, 19.0 cm). As shown in Figure 1, a skeletonized right IMA graft with a length of 19.0 cm was long enough to reach the apex.

After grafting, the graft flow of the in situ skeletonized right IMA grafting to the LAD ranged from 18 to 72 mL/minute (mean, 42 ± 9 mL/minute) associated with the pulsatility index of 0.8-4.3 (as shown in Figure 2). Additionally, the graft flow of the in situ skeletonized left IMA separately grafting to the left coronary system was 43 ± 8 mL/minute, and the graft flow of the in situ skeletonized left IMA sequentially grafting to the diagonal branch and then to the obtuse marginal branch were 36 ±

Figure 2. Intraoperative graft flow. The left image shows an in situ skeletonized right IMA graft (to the LAD) flow of 57 mL/minute associated with measured pulsatility index of 0.8, and the right image shows an in situ skeletonized left IMA graft (to the obtuse marginal branch) flow of 32 mL/minute associated with measured pulsatility index of 2.5.

Figure 3. Intraoperative fluorescence imaging. The upper image shows fluorescence imaging of complete occlusion in the proximal and middle part of the LAD before grafting, and the lower image shows fluorescence imaging after the in situ skeletonized right IMA grafting to the LAD, validating an excellent blood flow from the in situ skeletonized right IMA to the LAD and an improvement of myocardial blood supply.

8 and 28 ± 6 mL/minute, respectively.

Twenty-six patients out of 189 included patients that received intra-operative fluorescence imaging using the SPY™ imaging system. Excellent quality SPY images were obtained for all 26 anastomoses of the in situ skeletonized right IMA grafting to the LAD. Excellent flow without defects was observed in the SPY images (as shown in Figure 3).

Short-term outcomes: The in-hospital mortality and major postoperative morbidity were listed in Table II. Only one patient died of gastrointestinal hemorrhage on the 7th day postoperatively, and the in-hospital mortality was 0.5%. Only one patient suffered from acute inferior myo-

cardial infarction on the second day after CABG surgery. Three patients developed postoperative low cardiac output within 3 days after surgery and received an IABP support. It is noteworthy that only two patients developed postoperative deep sternal wound infection, with an incidence of 1.1%. Among those two patients, one suffered from diabetes requiring insulin injections and the other suffered from prolonged mechanical ventilation due to chronic obstructive pulmonary disease with pulmonary infection.

Follow-up outcomes: Among 188 discharged patients, 176 patients (accounting for 93.6%) were followed up for 9 to 47 months consecutively (mean, 23.9 ± 9.3 months; median, 22.5 months). As shown in Table II, five patients

Table II. Clinical Outcomes

Variable	
Intra-operative outcomes	
Number of patients	189
Length of skeletonized right IMA graft (cm)	18.6 ± 1.2 (17-22)
Right IMA grafts flow (mL/minute)	42 ± 9 (18-72)
Pulsatility index of right IMA grafts	2.8 (0.8-4.3)
In-hospital outcomes	
Number of patients	189
In-hospital deaths	1 (0.5%)
Low cardiac output	3 (1.6%)
New onset of MI	1 (0.5%)
Pulmonary complications	6 (3.2%)
Hemodialysis	2 (1.1%)
Stroke	1 (0.5%)
Deep sternal wound infection	2 (1.1%)
Redo for bleeding	3 (1.6%)
Blood transfusion	21 (11.1%)
Follow-up outcomes	
Number of patients	176
Duration of follow up (months)	23.9 ± 9.3 (9-47)
Survival	171 (97.2%)
MACEs	7 (4.0%)
Recurrent angina	5
Non-fatal myocardial infarction	1
Cardiac-cause death	0
Repeat revascularization	1

IMA indicates internal mammary artery; MI, myocardial infarction; and MACEs, major adverse cardiac events.

died during follow-up and the mid-term survival rate was 97.2%. The cause of death was listed as follows: sudden death in one patient, cerebral hemorrhage in one patient, carcinoma in one patient, traffic accident in one patient, and hepatic failure in one patient.

MACEs emerged in seven patients with an incidence of 4.0%. One patient, who received off-pump CABG surgery using the in situ skeletonized right IMA grafting to the LAD with the in situ skeletonized left IMA sequentially grafting to the first diagonal branch and then to the second marginal branch, required readmission because of serious angina pectoris 3 years postoperatively. Non-invasive coronary CT angiography and then invasive coronary angiography showed patency of all grafts, as well as two serious lesions in the right coronary artery territory. That patient preferred to percutaneous coronary intervention, received coronary stent implantation, and then discharged from hospital. The other 6 patients developed recurrent angina and received medication without repeat revascularization.

A total of 169 patients underwent non-invasive coronary CT angiography examination during the follow-up period of 9-45 months (mean, 23.2 ± 9.7 months; median, 21.0 months), as presented in Figure 4. As shown in Table III, 97.1% of right IMA grafts emerged Fitzgibbon grade A patency, and the remaining emerged Fitzgibbon grade B patency.

Risk factors for right IMA graft failure: The in situ skeletonized right IMA graft failure emerged in five patients by coronary CT angiography examination during the follow-up period of 23.2 ± 9.7 months, and the mid-term

right IMA graft failure was 3.0%. Data including demographic characteristics, concomitant diseases, preoperative cardiac status, off-pump/on-pump CABG, and intraoperative graft flow and pulsatility index entered into logistic regression analysis. After adjustment for potential confounders (age, gender, obesity, smoking status, diabetes, and hyperlipaemia), intraoperative graft flow had an independent influence on the risk of the mid-term right IMA graft failure (OR = 0.95, 95%CI 0.92-0.98, *P* = 0.015). Intraoperative right IMA graft flow ranged from 18-24 mL/minute in patients with the mid-term right IMA graft failure, and 21-72 mL/minute in patients without mid-term right IMA graft failure, respectively. In detail, intraoperative right IMA graft flow in five patients with mid-term right IMA graft failure were listed as follows: 18, 18, 19, 21, and 24 mL/minute.

Discussion

This single center study validated the feasibility and the short- and mid-term efficacy of the strategy of the in situ skeletonized right IMA grafting to the LAD, and found that intraoperative graft flow had an independent influence on the risk of the mid-term in situ right IMA graft failure.

Firstly, the study validated the feasibility of this strategy of the in situ skeletonized right IMA grafting to the LAD. Some surgeons may not agree this strategy for the following reasons: 1) skeletonized IMA graft harvesting is technically more demanding than the conventional pedicled IMA harvesting; 2) in situ right IMA graft reaches target sites only with the bifurcated distal part of the artery; and 3) in situ right IMA grafting to the LAD increases the complexity of redo operation.¹⁹⁾ In our practice, with a precise understanding of the local anatomy and a delicate technique, injury to the arterial trunk can be avoided, especially at branch points with complete skeletonization of the whole length of the IMA. The technique of skeletonized IMA grafting was carried out in our center since 2011, and was performed routinely without injury to the IMA after the launch of the trial. The length of the in situ skeletonized right IMA grafts was long enough to reach the LAD territory, including the distal LAD, and even the apex. In the cohort, none of the patients faced redo operation during 23.9 ± 9.3 months follow-up period. A study from Cleveland Clinic reported that in 11 patients undergoing reoperation with a patent retrosternal right IMA crossing the midline, two grafts were damaged and eventually repaired successfully.²⁰⁾ Thus, the danger of reoperation in patients with patent crossover right IMA grafts may be overstated and the benefits outweigh any theoretical objection.

In addition, transit time flow measurement, a quantitative volume flow technique, was used for all included patients to evaluate the quality of the anastomosis. Leong and colleague assessed the quality of the anastomosis of 116 patients with a total of 322 grafts (125 arterial and 197 venous) by transit time flow measurement, and concluded that transit time flow measurement provided important and reliable information about the patency of graft individually.²¹⁾ In the cohort, flow of all right IMA grafts

Figure 4. Follow-up coronary CT angiographic outcomes. Two images show ideal patency of the in situ skeletonized right IMA graft (to the LAD) and ideal patency of the in situ skeletonized left IMA graft (to the diagonal branch and then to the obtuse marginal branch, sequential grafting) at 28 months after CABG surgery.

Table III. Follow-Up Coronary CT Angiographic Outcomes

Variable	
In situ skeletonized right IMA to LAD	<i>n</i> = 169
Duration between surgery and remote CTA (months)	23.2 ± 9.7 (9-45)
Fitzgibbon grade of A	164 (97.0%)
Fitzgibbon grade of B	5 (3.0%)
Fitzgibbon grade of O	0
In situ skeletonized left IMA to left coronary system	<i>n</i> = 169
Duration between surgery and remote CTA (months)	23.2 ± 9.7 (9-45)
Single grafting	<i>n</i> = 64
Fitzgibbon grade of A	62 (96.9%)
Fitzgibbon grade of B	2 (3.1%)
Fitzgibbon grade of O	0
Sequential grafting	<i>n</i> = 105
Graft prior to the first anastomosis	
Fitzgibbon grade of A	104 (99.1%)
Fitzgibbon grade of B	1 (0.9%)
Fitzgibbon grade of O	0
Graft between the 2 anastomoses	
Fitzgibbon grade of A	101 (96.2%)
Fitzgibbon grade of B	4 (3.8%)
Fitzgibbon grade of O	0
Radial artery conduits	<i>n</i> = 85
Duration between surgery and remote CTA (months)	23.2 ± 9.7 (9-45)
Fitzgibbon grade of A	78 (91.8%)
Fitzgibbon grade of B	5 (5.9%)
Fitzgibbon grade of O	2 (2.3%)
Great saphenous vein grafts	<i>n</i> = 62
Duration between surgery and remote CTA (months)	23.2 ± 9.7 (9-45)
Fitzgibbon grade of A	52 (83.9%)
Fitzgibbon grade of B	5 (8.1%)
Fitzgibbon grade of O	5 (8.0%)

CTA indicates computed tomography angiography; IMA, internal mammary artery; and LAD, left anterior descending artery.

was higher than 15 mL/minute and associated with measured pulsatility index below 5, suggesting high-quality anastomoses of the in situ skeletonized right IMA grafting to the LAD.

Additionally, intraoperative fluorescence imaging, based on the fluorescent properties of indocyanine green, provides a “semi-quantitative” assessment of the graft

patency with images that provide some details about the quality of coronary anastomoses. The intraoperative fluorescence imaging can define the degree of graft stenosis and discriminate between the influence of the graft conduit and the coronary arteriolar bed on the mean graft flow, which may become the gold standard for intraoperative graft validation in the near future.¹⁷⁾ In the cohort, 26

patients received intraoperative fluorescence imaging using the SPY™ imaging system. Excellent flow without defects from right IMA grafts to the LAD was detected in all 26 patients, validating the in situ skeletonized right IMA graft integrity.

Secondly, this study confirmed the short- and mid-term efficacy of the in situ skeletonized right IMA grafting to the LAD. In the cohort, the incidence of sternal wound infection was as low as 1.1%, which may be attributed to skeletonization of the IMA preserving sternal vascularization.²²⁾ Follow-up of 93.6% of hospital survivors showed that the mid-term survival was 97.2%, the incidence of repeat revascularization was 0.6%, and the mid-term graft patency rate of the in situ skeletonized right IMA grafting to the LAD was 97.1%. Therefore, the strategy of the in situ skeletonized right IMA grafting to the LAD achieved similar short- and mid-term outcomes with the “gold standard” of revascularization of LAD (left IMA grafting to the LAD) reported by previous studies.^{23,24)} Lev-Ran *et al.* investigated early and late clinical outcomes for 365 consecutive patients that underwent revascularization with bilateral in situ IMAs (the in situ right IMA grafting to the LAD with the in situ left IMA grafting to circumflex branches), and reported recurrent angina of 3% and both IMA grafts patency rate of 95% during a follow-up period of 6-49 months, and 4-year survival rates of 92.4%.²⁵⁾ A recently published propensity score adjusted analysis investigated the impact of the in situ right IMA to the LAD on the late mortality and the need for repeat revascularization, and concluded that the in situ right IMA to the LAD did not increase either the risk for the late death or the need for repeat revascularization.¹³⁾ For these two previous studies, follow-up outcomes were consistent with the findings of the current study.

Thirdly, this study found that intraoperative graft flow was an independent risk factor for the mid-term right IMA graft failure. Walker *et al.* found a significant difference in the measured graft flow between patent and non-patent left IMA-LAD grafts.²⁶⁾ Six left IMA-LAD grafts with peroperative reduced graft flow of < 15 mL/minute were found to be non-patent at follow-up by Handa *et al.*²⁷⁾ Lehnert *et al.* found that the graft flow was directly correlated with the follow-up outcomes, with an observed 4% decreased risk of the graft failure for every 1 mL/minute increase in the graft flow.²⁸⁾ These evidences were in line with the outcomes of the current study.

It is also important to keep in mind that the strategy of the in situ skeletonized right IMA grafting to the LAD is not indicated for all patients. Patients who have an anticipated life expectancy of less than a decade or patients with excessive obesity, advanced age with serious chronic obstructive pulmonary disease, and previous chest-wall irradiation may not be suitable candidates. There may also exist anatomical scenarios where right IMA grafting to the LAD may prove to be too technically challenging with the risks outweighing the benefits. Also, this strategy should be cautiously applied in patients with enlarged right ventricles. And the strategy of in situ right IMA grafting to the LAD may increase the complexity of redo surgery, especially for aortic root or aortic valve operation. Patients with a concomitant mild aortic stenosis or a mild aortic

dilatation may not be suitable candidates. In addition, hemodialysis patients with arteriovenous shunt in their right arm may not be suitable candidates due to the potential for vascular steal from the right IMA into the juxtaposed upper extremity arteriovenous fistula.²⁹⁾

The present study had some potential limitations. First, it was a single center study, which may have influenced the generalizability of the results. A final determination would need a multi-center study involving a larger sample size. Second, a control group was not set up and the number of patients is relatively small, implying some weakness of results. Third, although the vast majority of patients underwent non-invasive coronary CT angiography, only a very small number of patients received invasive coronary angiography. Non-invasive coronary CT angiography compared to invasive coronary angiography may be less accurate to assess the graft patency, but it was easily accepted by patients undergoing CABG surgery. In recent decades, noninvasive imaging techniques have allowed direct visualization of atherosclerotic disease of the coronary arteries and arterial as well as venous grafts, and have shown an excellent correlation with invasive angiography.³⁰⁾ Finally, the duration of the follow-up was relatively short, which may lead to the overestimation of net clinical benefits from the strategy of the in situ skeletonized right IMA grafting to the LAD.

Conclusion

The strategy of in situ skeletonized right IMA grafting to the LAD is feasible and effective. And intraoperative graft flow was an independent risk factor for the mid-term right IMA graft failure.

Disclosures

Conflicts of interest: None.

References

1. Puskas JD, Williams WH, Mahoney EM, *et al.* Off-pump vs conventional coronary artery bypass grafting: early and 1-year graft patency, cost, and quality-of-life outcomes: a randomized trial. *JAMA* 2004; 291: 1841-9.
2. Cho KR, Jeong DS, Kim KB. Influence of vein graft use on postoperative 1-year results after off-pump coronary artery bypass surgery. *Eur J Cardiothorac Surg* 2007; 32: 718-23.
3. Desai ND, Naylor CD, Kiss A, *et al.* Impact of patient and target-vessel characteristics on arterial and venous bypass graft patency: insight from a randomized trial. *Circulation* 2007; 115: 684-91.
4. Farkouh ME, Dargas G, Leon MB, *et al.* Design of the future revascularization evaluation in patients with diabetes mellitus: optimal management of multivessel disease (FREEDOM) trial. *Am Heart J* 2008; 155: 215-23.
5. Yu X, He J, Luo Y, *et al.* Influence of diabetes mellitus on long-term outcomes of patients with unprotected left main coronary artery disease treated with either drug-eluting stents or coronary artery bypass grafting. *Int Heart J* 2015; 56: 43-8.
6. Benedetto U, Amrani M, Gaer J, *et al.* The influence of bilateral internal mammary arteries on short- and long-term outcomes: a propensity score matching in accordance with current recommendations. *J Thorac Cardiovasc Surg* 2014; 148: 2699-705.

7. Umakanthan J, Jeyakumar P, Umakanthan B, *et al.* Barriers to the universal adoption of bilateral internal mammary artery grafting. *Int J Surg* 2015; 16(Pt B): 179-82.
8. ElBardissi AW, Aranki SF, Sheng S, O'Brien SM, Greenberg CC, Gammie JS. Trends in isolated coronary artery bypass grafting: an analysis of the Society of Thoracic Surgeons adult cardiac surgery database. *J Thorac Cardiovasc Surg* 2012; 143: 273-81.
9. LaPar DJ, Crosby IK, Rich JB, *et al.* Bilateral internal mammary artery use for coronary artery bypass grafting remains underutilized: a propensity-matched multi-institution analysis. *Ann Thorac Surg* 2015; 100: 8-15.
10. Tatoulis J, Buxton BF, Fuller JA. The right internal thoracic artery: is it underutilized? *Curr Opin Cardiol* 2011; 26: 528-35.
11. Di Mauro M, Iacò AL, Allam A, *et al.* Bilateral internal mammary artery grafting: in situ versus Y-graft. Similar 20-year outcome. *Eur J Cardiothorac Surg* 2016; 50: 729-34.
12. Kamiya H, Akhyari P, Martens A, Karck M, Haverich A, Lichtenberg A. Sternal microcirculation after skeletonized versus pedicled harvesting of the internal thoracic artery: a randomized study. *J Thorac Cardiovasc Surg* 2008; 135: 32-7.
13. Kinoshita T, Asai T, Nishimura O, Suzuki T, Kambara A, Matsubayashi K. Off-pump bilateral versus single skeletonized internal thoracic artery grafting in patients with diabetes. *Ann Thorac Surg* 2010; 90: 1173-9.
14. Raja SG, Benedetto U, Husain M, *et al.* Does grafting of the left anterior descending artery with the in situ right internal thoracic artery have an impact on late outcomes in the context of bilateral internal thoracic artery usage? *J Thorac Cardiovasc Surg* 2014; 148: 1275-81.
15. Magruder JT, Young A, Grimm JC, *et al.* Bilateral internal thoracic artery grafting: Does graft configuration affect outcome? *J Thorac Cardiovasc Surg* 2016; 152: 120-7.
16. Ding W, Ji Q, Shi Y, Ma R. Predictors of low cardiac output syndrome after isolated coronary artery bypass grafting. *Int Heart J* 2015; 56: 144-9.
17. Takahashi M, Ishikawa T, Higashidani K, Katoh H. SPY™: an innovative intra-operative imaging system to evaluate graft patency during off-pump coronary artery bypass grafting. *Interact Cardiovasc Thorac Surg* 2004; 3: 479-83.
18. Fitzgibbon GM, Kafka HP, Leach AJ, Keon WJ, Hooper GD, Burton JR. Coronary bypass graft fate and patient outcome: angiographic follow-up of 5,065 grafts related to survival and reoperation in 1,388 patients during 25 years. *J Am Coll Cardiol* 1996; 28: 616-26.
19. Kinoshita T, Asai T, Suzuki T, Kuroyanagi S, Hosoba S, Takashima N. Off-pump bilateral skeletonized internal thoracic artery grafting in elderly patients. *Ann Thorac Surg* 2012; 93: 531-6.
20. Joyce FS, McCarthy PM, Taylor PC, Cosgrove DM 3rd, Lytle BW. Cardiac reoperation in patients with bilateral internal thoracic artery grafts. *Ann Thorac Surg* 1994; 58: 80-5.
21. Leong DK, Ashok V, Nishkantha A, Shan YH, Sim EK. Transit-time flow measurement is essential in coronary artery bypass grafting. *Ann Thorac Surg* 2005; 79: 854-7.
22. Fouquet O, Tariel F, Desulauze P, Mevel G. Does a skeletonized internal thoracic artery give fewer postoperative complications than a pedicled artery for patients undergoing coronary artery bypass grafting? *Interact CardioVasc Thorac Surg* 2015; 20: 663-8.
23. Locker C, Schaff HV, Dearani JA, *et al.* Multiple arterial grafts improve late survival of patients undergoing coronary artery bypass graft surgery: analysis of 8622 patients with multivessel disease. *Circulation* 2012; 126: 1023-30.
24. Weiss AJ, Zhao S, Tian DH, Taggart DP, Yan TD. A meta-analysis comparing bilateral internal mammary artery with left internal mammary artery for coronary artery bypass grafting. *Ann Cardiothorac Surg* 2013; 2: 390-400.
25. Lev-Ran O, Pevni D, Matsa M, Paz Y, Kramer A, Mohr R. Arterial myocardial revascularization with in situ crossover right internal thoracic artery to left anterior descending artery. *Ann Thorac Surg* 2001; 72: 798-803.
26. Walker PF, Daniel WT, Moss E, *et al.* The accuracy of transit time flow measurement in predicting graft patency after coronary artery bypass grafting. *Innovations (Phila)* 2013; 8: 416-9.
27. Handa T, Orihashi K, Nishimori H, *et al.* Maximal blood flow acceleration analysis in the early diastolic phase for in situ internal thoracic artery bypass grafts: a new transit-time flow measurement predictor of graft failure following coronary artery bypass grafting. *Interact CardioVasc Thorac Surg* 2015; 20: 449-57.
28. Lehnert P, Møller CH, Damgaard S, Gerds TA, Steinbrüchel DA. Transit-time flow measurement as a predictor of coronary bypass graft failure at one year angiographic follow-up. *J Card Surg* 2015; 30: 47-52.
29. Crowley SD, Butterly DW, Peter RH, Schwab SJ. Coronary steal from a left internal mammary artery coronary bypass graft by a left upper extremity arteriovenous hemodialysis fistula. *Am J Kidney Dis* 2002; 40: 852-5.
30. Weustink AC, Nieman K, Pugliese F, *et al.* Diagnostic accuracy of computed tomography angiography in patients after bypass grafting: comparison with invasive coronary angiography. *JACC Cardiovasc Imaging* 2009; 2: 816-24.