Revascularization of Left Coronary System Using a Skeletonized Left Internal Mammary Artery
—Sequential vs. Separate Grafting—

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Background: To evaluate in-hospital and mid-term outcomes of sequential vs. separate grafting of in situ skeletonized left internal mammary artery (LIMA) to the left coronary system in a single-center, propensity-matched study.

Methods and Results: After propensity score-matching, 120 pairs of patients undergoing first scheduled isolated coronary artery bypass grafting (CABG) with in situ skeletonized LIMA grafting to the left anterior descending artery (LAD) territory were entered into a sequential group (sequential grafting of LIMA to the diagonal artery and then to the LAD) or a control group (separate grafting of LIMA to the LAD). The in-hospital and follow-up clinical outcomes and follow-up LIMA graft patency were compared. Both propensity score-matched groups had similar in-hospital and follow-up clinical outcomes. Sequential LIMA grafting was not found to be an independent predictor of adverse events. During a follow-up period of 27.0±7.3 months, 99.1% patency for the diagonal site and 98.3% for the LAD site were determined by coronary computed tomographic angiography after sequential LIMA grafting, both of which were similar with graft patency of separate grafting of in situ skeletonized LIMA to the LAD.

Conclusions: Revascularization of the left coronary system using a skeletonized LIMA resulted in excellent in-hospital and mid-term clinical outcomes and graft patency using sequential grafting.

Key Words: Coronary artery bypass grafting; In situ left internal mammary artery grafting; Sequential grafting; Skeletonized graft
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from this study on the basis of the following criteria: patients with any concomitant diseases including renal insufficiency (preoperative creatinine >2 mg/dL or need of renal replacement therapy), malignant tumor, and chronic obstructive pulmonary disease; and patients undergoing in situ skeletonized LIMA grafting to the left coronary system other than the LAD. Thus, 155 patients (concomitant renal insufficiency in 121, concomitant malignant tumor in 13, concomitant chronic obstructive pulmonary disease in 21 patients) were excluded, and 115 patients who had undergone in situ skeletonized LIMA grafting to the left coronary system other than the LAD were also excluded, leaving 1,597 eligible patients for data analysis. Among them, 123 patients who underwent sequential grafting of in situ skeletonized LIMA to the diagonal artery and then to the LAD with additional conduits grafting were entered into the sequential group, and the remaining 1,474 patients who received separate grafting of in situ skeletonized LIMA to the LAD with additional conduits grafting were included in the control group. As shown in Table 1, there were no significant differences between the 2 groups in their baseline characteristics, including age and the ratios of older age, sex, smoking history, diabetes, hypertension, hyperlipidemia, impaired left ventricular function, enlarged left ventricle, recent myocardial infarction (MI), history of cerebrovascular disease (CVD), extent of coronary artery disease (CAD), and left main CAD. No significant differences were found between the 2 groups in the number of

### Methods

#### Study Population

After approval by the Ethics Committee of Zhongshan Hospital Fudan University, in accordance with the Declaration of Helsinki, a total of 1,867 consecutive patients undergoing first scheduled isolated CABG surgery with in situ skeletonized LIMA grafting to the left coronary system between July 2012 and June 2015 were reviewed and followed, to provide a present-day assessment of the effects of this technique compared with separate grafting of in situ skeletonized LIMA to the left coronary system.

In the current study, using propensity score-matching, 120 pairs of patients undergoing first scheduled isolated CABG surgery with in situ skeletonized LIMA grafting to the left coronary system between July 2012 and June 2015 were reviewed and followed, to provide a present-day assessment of the effects of this technique compared with separate grafting of in situ skeletonized LIMA to the left coronary system and mid-term LIMA graft patency rate.

#### Table 1. Characteristics of the Entire Study Cohort Before Propensity Score-Matching

|                          | Sequential group (n=123) | Control group (n=1,474) | P value |
|--------------------------|-------------------------|-------------------------|---------|
| Preoperative data        |                         |                         |         |
| Age (years)              | 62.4±9.1                | 65.5±8.4                | 0.138   |
| Older age (>65 years)    | 55 (44.7%)              | 750 (50.9%)             | 0.189   |
| Female                   | 13 (10.6%)              | 177 (12.0%)             | 0.636   |
| Smoking history          | 52 (42.3%)              | 617 (41.9%)             | 0.928   |
| Diabetes mellitus        | 46 (37.4%)              | 579 (39.3%)             | 0.681   |
| Hypertension             | 66 (53.7%)              | 844 (57.3%)             | 0.438   |
| Hyperlipidemia           | 24 (19.5%)              | 366 (24.8%)             | 0.187   |
| LVEF <40%                | 15 (12.2%)              | 220 (14.9%)             | 0.412   |
| LVEDD >65mm              | 5 (4.1%)                | 102 (6.9%)              | 0.224   |
| Recent MI                | 37 (30.1%)              | 487 (33.0%)             | 0.502   |
| History of CVD           | 9 (7.3%)                | 152 (10.3%)             | 0.289   |
| Coronary artery lesion   |                         |                         |         |
| 2-vessel                 | 9 (7.3%)                | 117 (7.9%)              | 0.806   |
| 3-vessel                 | 114 (92.7%)             | 1,357 (92.1%)           |         |
| Left main                | 37 (30.1%)              | 427 (29.0%)             | 0.794   |
| Intraoperative data      |                         |                         |         |
| No. of grafts            | 3.5±0.7                 | 3.4±0.6                 | 0.08    |
| Off-pump CABG            | 110 (89.4%)             | 1,269 (86.1%)           | 0.300   |
| On-pump CABG             | 13 (10.6%)              | 205 (13.9%)             |         |
| Use of right IMA         | 6 (4.9%)                | 34 (2.3%)               | 0.120   |
| Use of radial artery     | 6 (4.9%)                | 70 (4.7%)               | 0.948   |
| Use of SVG               | 117 (95.1%)             | 1,418 (96.2%)           | 0.552   |
| IABP support             | 7 (5.7%)                | 89 (6.0%)               | 0.876   |

Sequential group, patients receiving sequential grafting of in situ skeletonized LIMA to the diagonal artery and then to the LAD with other conduits grafting; Control group, patients undergoing separate grafting of in situ skeletonized LIMA to the LAD with other conduits grafting. CABG, coronary artery bypass grafting; CVD, cerebrovascular disease; IABP, intra-aortic balloon pump; IMA, internal mammary artery; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; MI, myocardial infarction; SVG, saphenous vein graft.
yses were conducted to examine differences in baseline characteristics between patients in the sequential group (n=123) and patients in the control group (n=1,474). Propensity scores were then calculated using a multivariate logistic regression model based on the following characteristics: age, sex, smoking history, diabetes mellitus, hypertension, hyperlipidemia, history of CVD, recent MI, impaired left ventricular function, enlarged left ventricle, double-/triple-vessel disease, and number of grafts. The area under the receiver-operating characteristic curve was 0.81 (95% confidence interval CI) 0.70–0.88, P=0.013. The Hosmer-Lemeshow goodness for this model was 6.45 (P=0.831). Every patient in the sequential group was matched with a patient in the control group with the closest propensity score (within 0.030). Finally, by matching propensity scores, 120 pairs were successfully established in a 1:1 manner (sequential group, n=120; control group, n=120). The in-hospital clinical outcomes, follow-up clinical outcomes, and follow-up LIMA graft patency determined by noninvasive coronary computed tomographic angiography were investigated and compared.

Surgical Techniques and Postoperative Medications

The aim of surgery is to achieve complete revascularization, which is defined as bypass grafting to all epicardial coronary arteries ≥1.0 mm with a diameter reduction ≥50% in at least 1 angiographic view. The decision to perform on-pump or off-pump CABG was influenced by each patient’s demographic and clinical profiles, but finally 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 (ACT) ≥480 s. Generally, cold blood cardioplegia was delivered in an antegrade fashion via the aortic root after aortic cross-clamping. For patients undergoing off-pump CABG, heparin was given to reach an ACT ≥300 s. The body temperature was maintained >36°C. An Octopus stabilizer (Medtronic Inc., Minneapolis, MN, USA) was routinely used for distal anastomoses.

Each surgeon decided whether to harvest the IMA conduit in a skeletonized fashion. As additional conduits, the great saphenous vein and/or radial artery were harvested with an open technique. In addition, surgeons were at liberty to choose sequential or separate LIMA grafting in each case. Factors influencing surgeons’ preference for sequential or separate LIMA grafting may have included the length of available LIMA conduit; desire to increase manipulation of the LIMA graft; and preconceptions regarding the safety and efficacy of sequential LIMA grafting. All anastomoses of LIMA-native coronary artery were conducted with a double-armed 8-0 polypropylene suture and a continuous suturing technique. Separate anastomosis of the in situ skeletonized LIMA graft to the LAD was conducted in an end-to-side fashion. Sequential anastomoses of the in situ skeletonized LIMA graft to the diagonal artery and then to the LAD were conducted in a side-to-side fashion and an end-to-side fashion, respectively. When planning sequential anastomoses of the in situ skeletonized LIMA graft to the left coronary system, the size of the former anastomosis (a parallel-shaped anastomosis of the LIMA-diagonal artery) should be less than that of the latter anastomosis (anastomosis of LIMA-LAD), and was not more than 3 mm.

The quality of anastomosis was assessed after grafting with a transit time flow probe (Medistim Butterfly Flow Meter, Oslo, Norway) during the operation. Systolic blood pressure was maintained around 110–120 mmHg and a heart rate around 80 beats/min. The probe size was selected to fit the graft tightly without compressing it. The graft flow associated with the measured pulsatility index was obtained under the conditions of apnea for approximately 10 s.

Statin medication, aspirin, and clopidogrel were routinely prescribed to all included patients starting from postoperative day 1 or 2. Statin medication and aspirin were continued indefinitely, whereas clopidogrel was discontinued after 1 year.

Clinical Data Collection and Definitions of Variables

Preoperative data were obtained from the institutional database and were reviewed using a standard data collection form. Follow-up data were obtained by telephone and/or clinic visit. Data collection was performed by trained staff (2 people) who did not know the purpose of the current study.

The following baseline demographic and clinical variables were considered: age, older age (>65 years), sex (male or female), smoking history, diabetes, hypertension, hyperlipidemia, history of CVD, impaired left ventricular function (left ventricular ejection fraction (LVEF) <40%), enlarged left ventricle (left ventricular end-diastolic diameter >65 mm), recent MI (within the last 30 days before surgery), and coronary artery lesion (double- or triple-vessel disease, left main CAD). Intraoperative variables of interest included the number of distal anastomoses, off-pump or on-pump CABG, use of right IMA and radial artery as well as great saphenous vein grafts, and application of IABP support.

The in-hospital outcomes of interest included in-hospital death and major postoperative morbidity (including MI, prolonged ventilation (>48 h), peroperative stroke, re-operation prior to discharge from hospital, and deep sternal wound infection). In-hospital death was defined as death that occurred during the same hospitalization or within 30 days of the operation. MI associated with CABG was arbitrarily defined by elevation of cardiac biomarker values >10×99th percentile upper reference limit in patients with normal baseline cardiac troponin values (<99th percentile upper reference limit). In addition, MI associated with CABG was defined by either (1) new pathological Q waves or new left bundle branch block, or (2) angiographic documented new graft or new native coronary artery occlusion, or (3) imaging evidence of new loss of viable myocardium or new regional wall motion abnormality. Peroperative stroke was defined as any new temporary or permanent focal or global neurological deficit, in accordance with the published guidelines, within 30 days from operation or later than 30 days if still in hospital. The incidence of deep sternal wound infection (bone related; any drainage of purulent material from the sternotomy wound and instability of the sternum) was recorded.

The follow-up outcomes among patients discharged alive from hospital included all-cause death and repeat revascularization. All-cause death rather than cardiac-cause death was chosen because it is the most robust and unbiased index that exempted us from misreading the
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ous variables using the Mann-Whitney U test, and categorical variables were compared by $\chi^2$ test or Fisher’s exact test, where appropriate. Multiple logistic regression analysis was also conducted to assess the effects of LIMA grafting technique (sequential LIMA grafting vs. separate LIMA grafting) as an independent predictor on the in-hospital and follow-up clinical outcomes. All statistical tests were two-sided. Results were considered statistically significant at a level of P<0.05. All analyses were performed with the SPSS statistical package version 17.0 (SPSS Inc., Chicago, IL, USA).

Results

Study Population

As shown in Table 2, the 2 propensity score-matched groups had similar baseline characteristics, including age and the ratios of older age, sex, smoking history, diabetes, hypertension, hyperlipidemia, impaired LV function, enlarged left ventricle, recent MI, history of CVD, extent of CAD, and left main CAD.

The number of bypass conduits ranged from 3 to 6 (mean 3.5 per patient); 91.3% of the included patients received off-pump CABG surgery. In the sequential group, all patients had sequential grafting of the in situ skeletonized LIMA to the diagonal artery and then to the LAD. Additionally, 115 patients had sequential or separate grafting of the great saphenous vein to the left circumflex territory and/or to the right coronary artery territory, and the remaining 5 patients underwent in situ skeletonized right IMA grafting to the obtuse marginal artery with radial artery grafting to the posterior descending artery. In the

Table 2. Baseline and Surgical Data After Propensity Score-Matching

| Preoperative data       | Sequential group (n=120) | Control group (n=120) | P value |
|-------------------------|-------------------------|-----------------------|---------|
| Age (years)             | 62.9±9.4                | 63.6±8.5              | 0.517   |
| Older age (>65 years)   | 55 (45.8%)              | 57 (47.5%)            | 0.796   |
| Female                  | 12 (10.0%)              | 15 (12.5%)            | 0.540   |
| Smoking history         | 51 (42.5%)              | 50 (41.7%)            | 0.896   |
| Diabetes mellitus       | 45 (37.5%)              | 47 (39.2%)            | 0.791   |
| Hypertension            | 65 (54.2%)              | 68 (56.7%)            | 0.697   |
| Hyperlipidemia          | 23 (19.2%)              | 26 (21.7%)            | 0.631   |
| LVEF <40%               | 14 (11.7%)              | 16 (13.3%)            | 0.696   |
| LVEDD >65mm             | 5 (4.2%)                | 7 (5.8%)              | 0.554   |
| Recent MI               | 36 (30.0%)              | 39 (32.5%)            | 0.676   |
| History of CVD          | 9 (7.5%)                | 11 (9.2%)             | 0.640   |
| Coronary artery lesion  |                         |                       |         |
| 2-vessel                | 8 (6.7%)                | 9 (7.5%)              | 0.801   |
| 3-vessel                | 112 (93.3%)             | 111 (92.5%)           |         |
| Left main               | 36 (30.0%)              | 35 (29.2%)            | 0.888   |
| Intraoperative data     |                         |                       |         |
| Number of grafts        | 3.5±0.7                 | 3.5±0.6               | 0.823   |
| Off-pump CABG           | 110 (91.7%)             | 109 (90.8%)           | 0.819   |
| On-pump CABG            | 10 (8.3%)               | 11 (9.2%)             |         |
| Use of right IMA        | 5 (4.2%)                | 4 (3.3%)              | 1.000   |
| Use of radial artery    | 5 (4.2%)                | 6 (5.0%)              | 0.758   |
| Use of SVG              | 115 (95.8%)             | 116 (96.7%)           | 0.734   |
| IABP support            | 6 (5.0%)                | 7 (5.8%)              | 0.776   |

Abbreviations as in Table 1.

cause of death with the subjective and sometimes inaccurate medical records. Repeat revascularization was defined as a second percutaneous coronary intervention or redo CABG surgery to deal with graft failure or new high-grade native coronary artery stenosis.

LIMA Graft Patency

The LIMA graft patency was determined by noninvasive coronary computed tomographic (CT) angiography. Coronary CT angiography were performed with a 64-slice, dual-source CT (iCT 64, Philips Healthcare, Amsterdam, The Netherlands). The images were analyzed in off-line work stations (median effective irradiation of 7.5mSv, interquartile range 3.76mSv). Sequential segments of grafts were considered as separate grafts. All coronary CT angiograms were reviewed by 2 experienced radiologists.

All angiograms were evaluated by the FitzGibbon grading system: grade A patency (excellent graft with unlimited runoff), B patency (stenosis reducing caliber of proximal or distal anastomosis or trunk to <50% of LIMA graft), or O patency (complete occlusion).14 In this study, LIMA graft patency included ideal patency and impaired graft with stenosis <50% (grade A patency). LIMA graft failure included impaired graft with stenosis >50% (grade B patency) and complete occlusion (grade O patency).

Statistical Analysis

Categorical variables are presented as frequency distributions and single percentages. Values of continuous variables are expressed as a mean±standard deviation. Normally distributed continuous variables were compared using a Student t-test, non-normally distributed continu-
control group, all patients had separate grafting of the in situ skeletonized LIMA to the LAD. In addition, 107 patients had sequential grafting of the great saphenous vein to the diagonal artery and/or to the obtuse marginal artery and/or to the right coronary artery territory. 4 patients had in situ skeletonized right IMA grafting to the obtuse marginal artery with radial artery grafting to the posterior descending artery, and the remaining 9 patients had sequential grafting of the great saphenous vein to the diagonal artery and to the obtuse marginal artery and then to the posterior branch of the left ventricle with separate grafting of the great saphenous vein (7 patients) or radial artery (2 patients) to the posterior descending artery. Revascularization of the LAD territory was as follows: the LAD was revascularized using LIMA conduits in all patients in the 2 groups, and the diagonal artery was revascularized using LIMA conduits in all patients in the sequential group and was revascularized using great saphenous vein grafts in 116 patients in the control group (100% vs. 96.7%, P>0.05). As shown in Table 2, procedural characteristics (including the number of distal anastomosis, the ratios of use of off-pump technique and preoperative IABP support as well as arterial and venous conduits) were also balanced between the 2 groups after matching.

**Intraoperative LIMA Graft Flow**

As shown in Figure 1, graft flow after separate grafting of the in situ skeletonized LIMA to the LAD was $37\pm9\,\text{mL/min}$ associated with a measured pulsatility index of 1.1–4.2, and graft flow after sequential grafting of the in situ skeletonized LIMA to the diagonal artery and then to the LAD was $47\pm10\,\text{mL/min}$ with a measured pulsatility index of 0.7–3.8 and $32\pm8\,\text{mL/min}$ with a measured pulsatility index of 1.0–4.1, respectively. Graft flow of all LIMA grafts or segments, including the trunk of sequential skeletonized LIMA grafts, skeletonized LIMA grafts between the diagonal artery and the LAD, and skeletonized LIMA-LAD grafts (separate LIMA grafting), were higher than 15 mL/min, associated with measured pulsatility index <5, suggesting high-quality anastomoses. The trunk flow of sequential LIMA grafts was significantly higher than that of separate LIMA grafts ($47\pm10\,\text{mL/min}$ vs. $37\pm9\,\text{mL/min}$, P<0.05). Graft flow of skeletonized LIMA grafts between the diagonal artery and the LAD was lower than that of skeletonized LIMA-LAD grafts (separate LIMA grafting), but no significant difference was found ($32\pm8\,\text{mL/min}$ vs. $37\pm9\,\text{mL/min}$, P>0.05).

**Clinical Outcomes**

As shown in Table 3, no significant differences were found between the 2 propensity score-matched groups in the in-hospital outcomes, including in-hospital death and the incidences of MI associated with CABG, prolonged ventilation, peroperative stroke, re-operation before discharge, and deep sternal wound infection. Furthermore, both 2 groups had similar composite in-hospital outcomes. A total of 231 patients (116 patients for the sequential group and 115 patients for the control group), accounting for 96.3% of included patients, were followed up for

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**Table 3. Clinical Outcomes After CABG Surgery**

|                          | Sequential group | Control group | P value |
|--------------------------|------------------|---------------|---------|
| **In-hospital outcomes** |                  |               |         |
| No. of patients          | 120              | 120           |         |
| In-hospital death        | 2 (1.7%)         | 2 (1.7%)      | 1.000   |
| Myocardial infarction    | 1 (0.8%)         | 2 (1.7%)      | 1.000   |
| Prolonged ventilation    | 2 (1.7%)         | 3 (2.5%)      | 1.000   |
| Stroke                   | 2 (1.7%)         | 2 (1.7%)      | 1.000   |
| Re-operation before discharge | 1 (0.8%) | 2 (1.7%) | 1.000 |
| Deep sternal wound infection | 1 (0.8%) | 1 (0.8%) | 1.000 |
| Composite in-hospital outcome | 6 (5.0%) | 7 (5.8%) | 0.776 |
| **Follow-up outcomes**   |                  |               |         |
| No. of patients          | 116              | 115           |         |
| All-cause death          | 4 (3.4%)         | 5 (4.3%)      | 0.748   |
| Repeat revascularization | 2 (1.7%)         | 3 (2.6%)      | 0.683   |
| Repeat revascularization from LAD territory | 0 | 2 (1.7%) | 0.154 |

CABG, coronary artery bypass grafting; LAD, left anterior descending.
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28.4±8.6 months. During follow-up, 9 patients (4 patients from the sequential group and 5 patients from the control group) died, and the follow-up all-cause mortality rate was 3.9%. No significant difference was found in the follow-up all-cause mortality rate between the 2 groups (3.4% vs. 4.4%, P=0.748). Cardiac-cause death occurred in 3 patients (1 patient from the sequential vs. 2 patients from the control group, P=0.622).

During follow-up, 5 patients underwent repeat revascularization (2 patients from the sequential group vs. 3 patients from the control group, P=0.683). Only 1 patient (in the control group) underwent repeat on-pump CABG surgery because of LIMA graft occlusion, and the remaining 4 patients (2 patients from the sequential group and 2 patients from the control group) preferred percutaneous coronary intervention. In the sequential group, intervention was conducted on 1 radial artery graft (grafting from the aorta to the posterior descending artery) and 1 great saphenous vein graft (grafting from the aorta to the obtuse marginal artery). In the control group, intervention was performed on 1 great saphenous vein graft (grafting from the aorta to the diagonal artery) and 1 native posterior descending artery distal to the insertion of great saphenous vein graft (grafting from the aorta to the posterior descending artery). The sequential group compared with the control group was associated with a trend towards a lower incidence of repeat revascularization from the LAD territory (0% vs. 1.7%, P=0.154).

The effects of LIMA grafting techniques (sequential LIMA grafting vs. separate LIMA grafting) on the in-hospital and follow-up clinical outcomes analyzed using multiple logistic regression are shown in Table 4. Results from the multiple logistic regression analysis showed that sequential LIMA grafting was not found to be an independent predictor of adverse events.

LIMA Graft Patency Rate

Detailed noninvasive coronary CT angiographic results are shown in Figure 2. In the sequential group, 116 of 118 patients discharged alive from hospital underwent coronary CT angiographic examination during a follow-up period of 27.0±7.3 months. The follow-up LIMA graft patency rate (FitzGibbon grade A patency) was 99.1% for the diagonal site and 98.3% for the LAD site. FitzGibbon grade B patency was observed in 1 LIMA graft for the diagonal site and in 2 LIMA grafts for the LAD site. No cases of FitzGibbon grade O patency were observed in the sequential group. In the control group, 113 of 118 patients discharged alive from hospital underwent noninvasive coronary CT angiographic examination during a follow-up period of 27.2±7.2 months. CT scan demonstrated FitzGibbon grade A patency in 111 LIMA grafts, and the follow-up LIMA graft patency rate was 98.2%. FitzGibbon grade B patency was observed in 1 LIMA graft, and grade O patency was observed in 1 LIMA graft. No significant differences were found in the follow-up LIMA graft patency rates of the 2 groups.

Discussion

The main finding of this study was that the mid-term LIMA graft patency rate of sequential grafting of in situ skeletonized LIMA to the left coronary system was not inferior to that of separate grafting of in situ skeletonized LIMA to the LAD. During a follow-up period of 27.0±7.3 months, this study demonstrated 99.1% LIMA graft patency rate for the diagonal artery site and 98.3% LIMA graft patency rate for the LAD site after following up 116 patients who had sequential grafting of in situ skeletonized LIMA to the diagonal artery and then to the LAD, both...
rates being similar to the LIMA graft patency rate after separate grafting of in situ skeletonized LIMA to the LAD, which is considered as the “gold standard” of coronary revascularization. Previously, Wendt et al reported 100% patency rate of the diagonal artery anastomosis and 97% patency rate of the LAD anastomosis after sequential grafting of LIMA to the diagonal artery and then to the LAD at 3-year follow-up, and concluded that with regard to the anterolateral wall of the left ventricle, there was an advantage to sequential LIMA grafting compared with separate LIMA and venous grafting. However, Wendt’s study only included 29 patients undergoing sequential LIMA grafting. A small sample size may result in weak and insufficient evidence. Another previous study reviewed 57 patients who had sequential grafting of LIMA to the LAD area, and found that the 2-year LIMA graft patency rates were 100% for the diagonal artery site and 98% for the LAD site. They concluded that revascularization of the LAD area using a single LIMA resulted in excellent graft patency using sequential grafting. That evidence is in line with the outcomes of the current study.

It is accepted that graft patency of the IMA is closely related to intraoperative graft flow. In this study, the LIMA graft flow for either sequential LIMA grafting or separate LIMA grafting was higher than 15 mL/min and associated with a measured pulsatility index <5, validating sequential and separate LIMA graft integrity and high-quality anastomoses. This study demonstrated that the trunk flow after sequential LIMA grafting was higher than that of separate LIMA grafting to the LAD, which may have contributed to the mid-term LIMA graft patency rate of sequential LIMA grafting not being inferior to that of separate LIMA grafting. Although the trunk flow after sequential LIMA grafting was superior to that of separate LIMA grafting, LIMA graft flow between the diagonal artery and the LAD may be reduced when planning sequential LIMA grafting compared with separate LIMA grafting (i.e., reduction of blood flow through LIMA grafts to the LAD) did not translate into more adverse events and an inferior LIMA graft patency rate. It remains to be determined by long-term outcomes.

Another important finding was that patients who had sequential grafting of in situ skeletonized LIMA to the left coronary system shared similar in-hospital clinical outcomes, and follow-up rates of all-cause mortality and repeat revascularization with patients who underwent separate grafting of in situ skeletonized LIMA to the LAD with additional conduit grafting. These clinical outcomes supported the strategy of sequential grafting of in situ skeletonized LIMA to the left coronary system and were in line with the outcomes of previous studies.

It is crucial to avoid the risk of LIMA graft kinking when planning sequential LIMA grafting. The LIMA length and the geometric relationship between the targeted diagonal artery and the LAD should be considered when planning sequential anastomosis of the in situ skeletonized LIMA to the diagonal artery and then to the LAD. If the angle between the LAD and targeted diagonal artery is acute (<60°), LIMA sequential anastomosis is feasible. However, if the lateral distance between the proposed diagonal artery and the LAD is greater than 4 cm, or the angle between the 2 arteries is greater than 60°, sequential anastomosis is generally avoided because of a risk of graft kinking just proximal to the sequential anastomosis. Intraoperative measurement of graft flow contributes to reducing the risk of kinking with sequential LIMA grafting.

Sequential grafting of in situ skeletonized LIMA to the left coronary system may be an attractive alternative strategy. However, it does not translate into sequential LIMA grafting as the preferred strategy relative to separate grafting of the LIMA to the LAD. The strategy of sequential LIMA grafting may be a relatively favorable choice when planning complete left-sided IMA grafting or when there is a shortage of available conduits. Additionally, it is important to keep in mind that the strategy is not indicated for all patients. Patients who have an anticipated life expectancy of less than a decade, excessively obese patients, and those with advanced age with serious chronic obstructive pulmonary disease, and previous chest radiotherapy may not be suitable candidates. Also, hemodialysis patients with an arteriovenous shunt in their left arm may not be suitable candidates because of the potential for vascular steal from the LIMA into the juxtaposed upper extremity arteriovenous fistula. Additionally, when planning sequential grafting of in situ skeletonized LIMA to the diagonal artery and then to the LAD the strategy is best avoided when the distal IMA bifurcation cannot reach the LAD. In this category are patients with a short LIMA, an enlarged right or left ventricle, or a second anastomotic site that is too distal or unpredictable.

**Study Limitations**

First, although using propensity score-matching, this study was only a single-center, clinical observational trial with a small sample size, which may influence its generalizability. Unobserved confounds and selection biases among the 2 groups cannot be eliminated. A final determination would need a prospective, multicenter study involving a larger sample size. Second, noninvasive coronary CT angiography was used to assess LIMA graft patency. Noninvasive coronary CT angiography compared with invasive coronary angiography may be less accurate for assessing LIMA graft patency and was not suitable for assessing the function of the IMA; however, it is well accepted by patients. In recent decades, noninvasive imaging techniques have allowed direct visualization of atherosclerotic disease of the coronary arteries and of arterial as well as venous grafts, and have shown an excellent correlation with invasive angiography. Finally, the duration of follow-up was relatively short. Long-term outcomes require further observation.

**Conclusions**

This single-center, propensity score-matched study showed that revascularization of the left coronary system using sequential grafting with in situ skeletonized LIMA resulted in excellent in-hospital and mid-term clinical outcomes and graft patency.
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