Surgical management of diffusely diseased coronary arteries

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Abstract

Purpose To analyze the outcomes of long segment coronary anastomoses in patients with diffusely diseased coronary arteries and compare them with medically managed patients.

Methods We retrospectively studied patients with diffusely diseased coronary arteries who underwent complete revascularization with long segment coronary reconstruction (> 2 cm in length) from February 2015 to November 2016. During the same time, patients who opted medical management for diffuse coronary artery disease were also studied.

Results Forty-one patients underwent long segment coronary anastomoses for diffuse coronary artery disease with either left internal thoracic artery (LITA) or saphenous vein conduits. In 15 (36.58%) patients, the anastomosis length was more than 4 cm. In 41 patients, left anterior descending (LAD) artery had long segment anastomosis and in four patients, posterior descending artery (PDA) had long segment anastomosis. Twenty-one patients were operated off-pump and the rest were operated on cardiopulmonary bypass. The post-operative recovery of all the patients was uneventful. There were no procedural complications. There was one mortality due to cerebrovascular accident (2.43%). During the study period, 50 patients with diffuse coronary artery disease were under medical management. In the medically managed group, there were seven death during the follow-up, with mortality rate of 14%.

Conclusion Patients with diffuse disease coronary diseases, who are surgically managed, have a better outcome when compared to the medically managed patients with acceptable morbidity and mortality.

Keywords Coronary artery bypass grafting · Diffuse coronary artery disease · Surgical management

Introduction

Management of diffuse coronary artery disease (CAD) is a surgical challenge. Routine coronary artery bypass graft (CABG) surgery in diffuse CAD may result in incomplete revascularization and there is a high chance of early graft occlusion due to poor distal flow. This may lead to high chance of peri-operative morbidity and mortality in these patients with prolonged need for pharmacological and mechanical supports. In addition, if the anastomosis compromises the native coronary flow, patient may develop acute myocardial ischemia, if occlusion of the grafts occurs in the course of time.

This category of patients with diffuse CAD was mostly considered inoperable and was being continued on medical management, until the introduction of reconstructive procedures. These reconstructive procedures include saphenous vein onlay patch followed by LITA grafting or direct anastomosis of LITA to the long segment arteriotomy of LAD with or without endarterectomy [1–4].

The advantage of long segment LAD reconstruction is to achieve flow to the majority of diagonal and most of septal branches of LAD, which is not possible with a conventional anastomosis. The conventional grafting to the distal LAD alone cannot achieve this advantage of long segment anastomosis, as it would not perfuse the diseased and/or more proximal segments of the coronary artery. We report our surgical experience in the management of diffuse CAD.

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Materials and methods

This was a retrospective observational non-randomized study. Between February 2015 and November 2016, 41 patients with

single-, double- or triple-vessel diffuse CAD, with or without left main disease, underwent long segment coronary anastomoses. These patients constituted 8.1% of all patients undergoing isolated CABG during the same period. The records of these 41 patients were reviewed to assess the pre-operative characteristics, major adverse cardiac and cerebrovascular events following long segment coronary reconstruction and bypass graft. Ethics Committee approved this study, and individual consent for the study was waived by the committee.

A conventional anastomosis is usually < 2 cm in length. Long segment reconstruction was defined as the length of the anastomosis more than 2 cm [2]. The term extensive coronary artery reconstruction was considered if the length of the anastomosis was more than 4 cm [4]. We also compared the outcomes of patients with diffuse CAD, who opted for medical management during the same study period with the surgically managed patients.

Selection of patients for surgery

The decision to operate a diffuse CAD in an otherwise anaesthetically fit patient was according to the size and morphology of coronary arteries and willingness of the patient to undergo CABG. The size and morphology of coronary arteries were based on conventional coronary angiography. Angiographic grading of diffuse CAD was according to the concept as described by Graham et al. [5]. Graham et al. weighted coronary artery segments into 6 grades (0 to 5). Coronary artery segments distal to significant obstruction were considered at risk (grades 1 to 5) as shown in (Table 1).

Our criteria for selection of patients for coronary reconstruction were those with LAD or other coronary arteries having moderate to very severe diseases (grades 3 to 5), even with multiple level lesions, but with at least 2–3 cm of patent vessel distal to the obstruction.

Surgical technique

After induction with general anesthesia and insertion of an arterial line and central venous line, patient was positioned,

prepped, and draped. Midline sternotomy was performed. Pedicled LITA was harvested using low energy electrocautery. Saphenous venous graft was also harvested. Pericardium was opened and the standard technique of CABG was carried out with systemic heparinization. When the planned reconstruction of LAD segment was 2 to 4 cm, we preferred to do it off-pump using suction stabilization device (Maquet ACROBAT-i Stabilizer System). In case the extensive reconstruction (> 4 cm) of coronary artery, it was done on-pump with the arterial cannula in the ascending aorta and a two-stage venous cannula, inserted through the right atrial appendage.

The myocardial protection was achieved using intermittent aortic cross clamp and fibrillatory arrest technique with mild hypothermia. The sequence of grafting was first to LAD followed by grafting to other diseased coronary arteries. Once the arteriotomy was done, the vessel was inspected for the atheromatous plaques. The length of the incision was extended depending upon the extent of the atheromatous plaques and skip lesions. Intra-operative assessment of the diameter of the coronary artery was done using the intracoronary shunts, which come in sizes of 1.0 mm, 1.25 mm, 1.5 mm, 1.75 mm, and 2 mm. The shunt that snugly fitted into the coronary artery was taken as the inner diameter of the coronary artery.

The arteriotomy length was measured and LITA or saphenous vein graft was opened accordingly. We routinely use 8–0 prolene suture for the anastomosis. The suture bites were fashioned in a manner such that the lateral plaques were exteriorized to anastomosis producing a smooth surface for the blood flow (Fig. 1) with decreased chance of turbulence or thrombus formation at the site of anastomosis. Figure 2 shows LAD reconstruction.

We usually do not prefer endarterectomy of LAD as it compromises the flow to the septal and diagonal branch vessels, as endarterectomy removes the intima of these exposed vessels and thus it is prone for thrombosis. The similar technique was also used to graft obtuse marginal (OM) and PDA. Proximal anastomosis of saphenous venous graft was done on ascending aorta after a portion of it was excluded after a side-biting clamp was applied. Graft de-airing was done after completing each proximal anastomosis. In case of on-pump surgery, standard decannulation technique was followed after weaning of bypass. The usual inotropes used were noradrenaline and dobutamine.

Protamine was started after checking bleeding at anastomotic sites and chest closure was done.

Post-operative course and follow-up

Post-operative parameters like duration of mechanical ventilation and inotropic and intra-aortic balloon pump (IABP) requirements were studied. Postoperative hospital stay, morbidity, and mortality were noted. For patients with coronary artery, plasty without endarterectomy, intravenous heparin,

Table 1 Weighting of segments by angiographic appearance

Grade	Description
0	Not at risk
1	> 2 mm; large normal vessel
2	1.5–2.0 mm; medium, normal, or large with mild disease
3	1.0–1.5 mm; moderate disease
4	0.5–1.0; severe disease
5	< 0.5 mm; very severe disease or totally occluded and poorly visualized or not suitable for revascularization by CABG

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Fig. 1 Exteriorization of plaque. **a** It shows a section of a diffusely diseased LAD with a septal branch. **b** Section of the LAD after a long segment arteriotomy. **c** LITA being anastomosed to the LAD. The sutures are fashioned in such a way that the plaques get exteriorized once the anastomosis is completed. **d** Completed anastomosis showing the exteriorized plaque with LITA forming the lateral walls and the roof of the newly reconstructed LAD. The native posterior wall of LAD is felt intact from which septal and diagonal branches originates from LAD

low dose aspirin (150 mg/day), and clopidogrel (75 mg/day) was started in the immediate post-operative period. The intravenous heparin was stopped on fourth post-operative day.

In patients undergoing endarterectomy, acenocoumarol was started after bridging with intravenous heparin until target international normalized ratio of 2.0 to 2.5 was reached along with aspirin. Acenocoumarol was continued till 3 months post-surgery. Follow-up was done at 1, 3, and 6 months. They were evaluated with a standard 12 lead electrocardiogram (ECG) on each visit and 2D echocardiography (Echo) on the third month follow-up. Check coronary angiography was

advised whenever there were new onset symptoms, ECG changes, or regional wall motion abnormality in the follow-up Echo.

Statistical analysis

The data obtained from the records were entered into a computerized data sheet. The data was analyzed using the IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp. The distribution of data related to clinical conditions and co-morbidities, clinical outcome, etc. was expressed

Fig. 2 LAD extensive reconstruction (> 4 cm in length). **a** It shows long 4.7 cm arteriotomy of LAD (white arrow), the blood has filled the entire length of the arteriotomy and one can also appreciate the thready LAD.

The LITA (black arrow) is also opened according to the arteriotomy length. **b** The completed anastomosis of LITA to LAD (black arrow)

as frequency and percentages. The data related to echocardiography parameters, biochemical parameters, etc. was expressed as mean with standard deviation or median with range. The comparison of surgically and medically treated groups was carried using independent sample *t* test for numeric and chi-square test for categorical variables. The statistical analysis was carried at 5% level of significance and *p* value < 0.05 was considered as significant.

Results

Patient demographics and pre-operative data

Of the 41 patients, 27 patients were male (65.85%) and 14 were female (34.14%). Eighteen patients (43.9%) had left main coronary artery disease (LMCA). Twenty-eight patients (68.29%) had triple vessel disease (TVD), six patients (14.63%) had double vessel disease (DVD), and seven patients (17.07%) had single vessel disease (SVD). The mean age was 61.69 ± 11.04 years (range was from 43 to 77 years).

Twenty-nine patients (70.73%) had diabetes mellitus, twenty-five patients (60.97%) had systemic hypertension, and one patient (2.43%) had chronic kidney disease (CKD). All of them were symptomatic and presented with Canadian Cardiovascular Society (CCS) grade III and IV angina. Seven patients (17.07%) required pre-operative IABP (Maquet CS100® IABP with IntelliSync®) in view of LM disease and left ventricular systolic dysfunction. The pre-operative mean left ventricular ejection fraction was $50.15 \pm 8.29\%$. On coronary angiogram, 21 patients (51.22%) had of grade 3 CAD, 17 patients (41.46%) had grade 4, and 3 patients (7.31%) had grade 5 CAD (Table 2). Coronary angiogram of a sample patient demonstrating the diffuse coronary artery disease is shown in (Fig. 3a).

Intra-operative data

Coronary artery bypass artery grafting was performed off-pump in 21 patients (51.22%) and on cardiopulmonary bypass (CPB) in 20 patients (48.78%). Twelve patients (29.26%) had intra-operative IABP insertion in view of hypotension in spite of maximal pharmacological manipulation.

Long segment arteriotomy was done in all of these patients and an arterial (LITA) or a saphenous vein graft was used to complete the plasty. Endarterectomy of LAD was performed in four (9.75%) patients. All the patients had LAD reconstruction. PDA reconstruction was done in four patients (9.75%) whereas OM reconstruction was done in six patients (14.63%). Long segment reconstruction of all three vessels, i.e., LAD, OM, and PDA, was done in one patient. The average number of distal anastomosis was 2.69 ± 1.03 .

Table 2 Pre-operative patient characteristics

Age	
Mean	61.69 ± 11.04 (range 43–77)
40–50 years	05 (12.19%)
51–60 years	15 (36.58%)
61–70 years	13 (31.70%)
71–80 years	08 (19.51%)
Sex	
Males	27 (77.14%)
Females	14 (22.85%)
NYHA class on presentation	
I	Nil
II	03
III	18
IV	20
Coronary artery disease	
LMCA	18 (43.90%)
SVD	07 (17.07%)
DVD	06 (14.63%)
TVD	28 (68.29%)
Recent MI	09 (21.95%)
Diabetes mellitus	29 (70.73%)
Hypertension	25 (60.97%)
CKD	01 (02.43%)
Prior CVA	NIL
Pre-operative IABP	07 (17.07%)
Pre-operative EF	50.15 ± 8.29%

DVD double vessel disease, *CKD* chronic kidney disease, *CVA* cerebrovascular accident, *EF* ejection fraction, *IABP* intra-aortic balloon pump, *LMCA* left main coronary artery, *MI* myocardial infarction, *NYHA* New York Heart Association, *SVD* single vessel disease, *TVD* triple vessel disease

Twenty-six patients (63.41%) received graft to diagonal, 32 patients (78.04%) received graft to OM, and PDA grafting was done in 36 patients (87.80%). In all the 41 patients, LITA was used as the conduit for LAD, whereas saphenous vein graft (SVG) was used for the other coronary targets. We have not used the saphenous venous patch onlay technique in any of our patients for LAD plasty.

The average diameter of LAD was 1.08 ± 0.22 mm. Among the patients who underwent LAD reconstruction 15 patients (36.58%) had extensive reconstruction. The average length of LAD anastomosis was 3.73 ± 1.06 cm (Table 3).

Post-operative and follow-up data

All patients were shifted to the post-operative intensive care unit (ICU) with inotropic supports. The mean duration of mechanical ventilation was 7.19 ± 2.05 h. IABP was removed on the first or second post-operative day. There were no

Fig. 3 Pre- and post-surgery coronary angiogram. **a** Pre-surgery angiographic image showing diffusely diseased LAD. **b** Post-surgery angiographic image shows patent long segment LITA to LAD anastomosis with good distal filling

complications due to IABP. The mean units of blood and blood components transfused were 2.77 ± 1.23 units.

Six patients (14.63%) developed acute kidney injury (AKI), of which four patients had on-pump CABG. All patients with AKI were treated conservatively and none required dialysis. New onset atrial fibrillation was noticed in five patients (12.19%). There was no incidence of peri-operative myocardial infarction in our study. There was one case of post-operative cerebrovascular accident (CVA) due to embolism of the right middle cerebral artery on the seventh post-operative day and expired on eight post-operative day. The in

hospital mortality was 2.43%. The average in hospital stay was 7 ± 0.7 days (Table 4). On the last follow-up (6 months post-surgery), none of the patients had new ECG changes but six patients had CCS grade II angina (14.63%). In these 6 symptomatic patients, check angiogram was performed. In all patients, LITA to LAD long segment reconstruction was patent with good distal run off (Fig. 3b), but it showed partial blockages of saphenous venous grafts.

Medically managed patient data

During the study period, there were 50 patients with diffuse CAD who were not willing to undergo high-risk CABG. The decision was taken after the heart team (cardiologist and cardiac surgeon) discussion with the patients in detail about the pros and cons of the surgery. These patients were not amenable for percutaneous coronary intervention due to unsuitable coronary morphology. The medical management included dual antiplatelet therapy (aspirin with clopidogrel) for at least

Table 3 Intra-operative data

Off-pump	21 (51.22%)
On CPB	20 (48.78%)
Intra-operative IABP insertion	12 (29.26%)
Grafted coronaries	
LAD	41 (100%)
Diagonal	26 (63.41%)
OM	32 (78.04%)
PDA	36 (87.8%)
Number of distal anastomosis	2.69 ± 1.03
SIZE of lumen of LAD based on angiography	
Grade 3 (1.0 to 1.5 mm)	21 (60%)
Grade 4 (0.5 to 1.0 mm)	11 (31.42%)
Grade 5 (< 0.5 mm)	03 (8.57%)
Average size of the LAD lumen	1.08 ± 0.22 mm
The length of anastomosis	
2–4cms	26 (63.41%)
> 4cms	15 (36.58%)
The average length of LAD anastomosis	3.73 ± 1.06 cm
PDA plasty	04 (9.75%)
OM plasty	06 (14.63%)

CPB cardiopulmonary bypass, IABP intra-aortic balloon pump, LAD left anterior descending, OM obtuse marginal, PDA posterior descending artery

Table 4 Post-operative characteristics

Mean duration on ventilator (in hours)	07.19 ± 2.05
Post-operative EF	$50.46 \pm 6.78\%$
Number of transfusions (mean units)	2.77 ± 1.23
Peri-operative MI	Nil
Post-operative MI	Nil
CVA	01 (2.43%)
New onset AF	05 (12.19%)
AKI	06 (14.63%)
Requirement of dialysis	Nil
Hospital stay (mean number of days)	07 ± 0.7
Deaths	01 (2.43%)
Re-explorations	Nil
Sternal wound infections	Nil

AF atrial fibrillation, AKI acute kidney injury, CVA cerebrovascular accident, EF ejection fraction, MI myocardial infarction

12 months following an acute coronary syndrome, then continue aspirin alone for their life time. Drug therapy also included lipid lowering drugs (atorvastatin), beta blockers, and anti anginal drugs (isosorbide dinitrate/ranolazine). For patients in cardiac failure in addition to above drugs, angiotensin converting enzyme inhibitors and diuretics were added. The mean age of these patients was 59.42 ± 9.57 years. While on medical management, 23 patients (46%) developed recurrence of chest pain, in that 12 patient had new ECG changes. Nine patients had recurrent hospital admissions. There were seven death during the follow-up, mortality rate of 14%. Comparison between the surgically and medically managed patients is given in (Table 5).

Discussion

The earlier understanding of diffusely diseased coronaries was to declare them inoperable, as they would not benefit from surgical revascularization. Shapira and colleagues have reported on the techniques of LITA onlay patch grafting after a long segment arteriotomy [6]. Since then, several more studies were carried out and improvising the techniques of grafting in such scenarios in a better manner. The preferred conduit for grafting LAD was invariably LITA, because of its proven long-term patency and less chances of atherosclerosis as described in various studies [7–12]. In our study also in patients in whom follow-up coronary angiogram was done, it showed patent LITA to LAD long segment anastomosis with good distal run off.

The earlier use of saphenous vein for patch reconstruction of LAD was abandoned, as it was associated with accelerated atherosclerosis, aneurysmal dilatations, and turbulence [13]. We have used LITA as the conduit to graft LAD in all of our patients. Incomplete revascularization is never advocated as the chance of

peri-operative myocardial infarction, recurrence of symptoms, and reoperations are invariably present, either in the immediate post-operative phase or later. Residual disease affects the outcomes adversely after CABG, and every step to avoid it should be the prime dictum in surgical revascularization [6].

Kato and colleagues have reported the outcomes of performing long segment LAD reconstruction with endarterectomy and without endarterectomy. They did not observe much difference in outcomes except for the longer duration of surgery in cases of endarterectomy. The overall survival rate and 10-year freedom from major adverse cardiac events were not significantly different in these two categories [14].

In our study, we have performed only 4 endarterectomies and the rest were done without an endarterectomy. We reserve endarterectomies only for severely calcific and atheromatous coronary artery without any lumen for anastomosis. We prefer not to do endarterectomy for fear of early thrombosis of septal and diagonal branches, as it removes intima from these vessels, and activates the coagulation cascade in early post-operative period and myofibrointimal proliferation in the late stages [15]. The better option would be to exteriorize the lateral plaques in the coronary artery while anastomosing the conduit. The advantage of this technique is that intima is preserved, so that there is less chance of thrombosis and intima of the conduit forms the lateral wall and roof of the anastomosed coronary artery.

We have not used the saphenous venous onlay patch in any of our patients for LAD reconstruction, as the patency of saphenous venous onlay patch is much less than when LITA itself was used to reconstruct LAD [7–9, 16–18]. A few of our patients received long segment anastomosis to the OM and PDA with good outcomes. These were on-table decisions, to do a long segment grafts in these vessels, which were found to have diffuse disease during intra-operative examination of the vessels.

Table 5 Comparison between surgically and medically treated patients with diffuse coronary artery disease

Variable	Surgically treated (<i>n</i> = 41)	Medically managed (<i>n</i> = 50)	<i>P</i> value
Mean age	61.69 ± 11.04 (range 43–77)	59.42 ± 9.57 (range 44–83)	0.29
Recurrence of symptoms (chest discomfort)	6 (14.63%)	23 (46%)	0.0015
New ECG changes	Nil	12 (24%)	0.0008
Post treatment MI	Nil	17 (34%)	<0.0001
Readmissions into hospital	Nil	9 (18%)	0.004
Pre-treatment ejection fraction (mean)	50.15 ± 8.29%	49.26 ± 7.13%	0.58
Post-treatment ejection fraction (mean)	50.46 ± 6.78%	45.47 ± 9.54%	0.006
Stroke	1 (2.43%)	Nil	0.27
Kidney dysfunction	6 (14.63%)	14 (28%)	0.12
New onset arrhythmias	05 (12.19%)	08 (16%)	0.60
Deaths	01 (2.43%)	07 (14%)	0.05

Off-pump technique was used in 51.22% in this study with good results to perform LAD reconstruction. There is a common notion that long segment anastomosis requires CPB for safer anastomosis with good myocardial protection. However, in patients with diffuse coronary disease, there are good collateral circulations, so that off-pump can be safely performed by the surgeon with good surgical experience in off-pump surgery. Fukui et al. also showed that off-pump technique could be safely used for long segment coronary anastomosis [19].

Multiple sequential anastomoses to LAD have been described as an alternative procedure for treating multilevel LAD lesions [20–22]. LITA was anastomosed side to side for the proximal part of LAD and anastomosed end to side for the distal part of LAD. This ensures adequate revascularization of the septal branches as well as the apical left ventricular myocardium. In case LITA length was insufficient, the authors have also used right internal thoracic for the sequential anastomosis. This sequential technique is possible only if the LAD has multiple short segments lesions with good run-off.

The main advantage of this study was that it had a control group to compare the outcomes of diffuse CAD, managed surgically and medically. It was clear from the study that during the course of medical management, patient had increased incidence of recurrence of symptoms, new ECG changes, and readmission to hospital when compared to patients treated surgically and it was statistically significant. Also in medically managed patients, the left ventricular function deteriorated with time. The surgical patients had improvement of left ventricular function during the follow-up. Mortality rate was 14% in medically managed patients, which is much higher when compared to the surgically treated patients (2.43%). Therefore, the outcome of patients with diffuse CAD treated surgically was better than the medically treated patients.

In addition, the outcome of long segment coronary artery bypass in this study was comparable to the outcome of conventional CABG without diffuse CAD as reported in the literature [16]. The limitations of the study were the following: small study population; short follow-up period; it was a retrospective, non-randomized study; and the lack of angiographic assessment of all the patients. As angiography was performed in only 6 out of 41 (14.63%) patients, it is difficult to comment with certainty on patency of all the grafts in the setting of diffuse CAD. However, lack of symptoms has been used as a surrogate marker for patency in our study which suggests satisfactory outcomes.

Conclusion

We conclude that patients with diffuse CAD can undergo CABG with long segment coronary reconstruction with acceptable morbidity and mortality, similar to the conventional CABG. Surgically managed patients also have a better

outcome when compared to the medically treated patient with diffuse CAD, but it requires further validation from a large propensity matched study.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Individual consent for the study was waived by the committee as it was a retrospective study. All the patients provided informed written consent for the surgery.

Conflict of interest The authors declare that they have no conflict of interest.

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References

1. Santini F, Casali G, Lusini M, et al. Mid-term results after extensive vein patch reconstruction and internal mammary grafting of the diffusely diseased left anterior descending coronary artery. *Eur J Cardiothorac Surg*. 2002;21:1020–5.
2. Kato Y, Takanashi S, Fukui T, Naruko T, Shibata T, Shimizu Y. Does the complexity of coronary artery disease affect outcomes after complete revascularization with long segmental reconstruction of the left anterior descending artery using the left internal thoracic artery? *Interact Cardiovasc Thorac Surg*. 2015;21:308–14.
3. Myers PO, Tabata M, Shekar PS, Couper GS, Khalpey ZI, Aranki SF. Extensive endarterectomy and reconstruction of the left anterior descending artery: early and late outcomes. *J Thorac Cardiovasc Surg*. 2012;143:1336–40.
4. Fukui T, Tabata M, Taguri M, Manabe S, Morita S, Takanashi S. Extensive reconstruction of the left anterior descending coronary artery with an internal thoracic artery graft. *Ann Thorac Surg*. 2011;91:445–51.
5. Graham MM, Chambers RJ, Davies RF. Angiographic quantification of diffuse coronary artery disease: reliability and prognostic value for bypass operations. *J Thorac Cardiovasc Surg*. 1999;118: 618–27.
6. Shapira N, Lumia FJ, Gottdiener JS, Germon P, Lemole GM. Adjunct endarterectomy of the left anterior descending coronary artery. *Ann Thorac Surg*. 1988;46:289–96.
7. Barner HB, Standeven JW, Reese J. Twelve-year experience with internal mammary artery for coronary artery bypass. *J Thorac Cardiovasc Surg*. 1985;90:668–75.
8. Edwards FH, Clark RE, Schwartz M. Impact of internal mammary artery conduits on operative mortality in coronary revascularization. *Ann Thorac Surg*. 1994;57:27–32.
9. Loop FD, Lytle BW, Cosgrove DM, et al. Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. *N Engl J Med*. 1986;314:1–6.
10. Schwann TA, Zacharias A, Riordan CJ, Durham SJ, Shah AS, Habib RH. Survival and graft patency after coronary artery bypass grafting with coronary endarterectomy: role of arterial versus vein conduits. *Ann Thorac Surg*. 2007;84:25–31.
11. Cameron A, Davis KB, Green G, Schaff HV. Coronary bypass surgery with internal thoracic-artery grafts—effects on survival over a 15-year period. *N Engl J Med*. 1996;334:216–9.

12. Cameron AA, Green GE, Brogno DA, Thornton J. Internal thoracic artery grafts: 20-year clinical follow-up. *J Am Coll Cardiol*. 1995;25:188–92.
13. Taşdemir O, Kiziltepe U, Karagöz HY, Yamak B, Korkmaz S, Bayazit K. Long-term results of reconstructions of the left anterior descending coronary artery in diffuse atherosclerotic lesions. *J Thorac Cardiovasc Surg*. 1996;112:745–54.
14. Kato Y, Shibata T, Takanashi S, Fukui T, Ito A, Shimizu Y. Results of long segmental reconstruction of left anterior descending artery using left internal thoracic artery. *Ann Thorac Surg*. 2012;93:1195–200.
15. Soyulu E, Harling L, Ashrafian H, Casula R, Kokotsakis J, Athanasiou T. Adjunct coronary endarterectomy increases myocardial infarction and early mortality after coronary artery bypass grafting: a meta-analysis. *Interact Cardiovasc Thorac Surg*. 2014;19:462–73.
16. Sergeant P, Blackstone E, Meyns B. Validation and interdependence with patient-variables of the influence of procedural variables on early and late survival after CABG. K.U. Leuven Coronary Surgery Program. *Eur J Cardiothorac Surg*. 1997;12:1–19.
17. Cooper GJ, Underwood MJ, Deverall PB. Arterial and venous conduits for coronary artery bypass. A current review. *Eur J Cardiothorac Surg*. 1996;10:129–40.
18. Tyras DH, Barner HB, Kaiser GC, Codd JE, Pennington DG, Willman VL. Bypass grafts to the left anterior descending coronary artery: saphenous vein versus internal mammary artery. *J Thorac Cardiovasc Surg*. 1980;80:327–33.
19. Fukui T, Takanashi S, Hosoda Y. Long segmental reconstruction of diffusely diseased left anterior descending coronary artery with left internal thoracic artery with or without endarterectomy. *Ann Thorac Surg*. 2005;80:2098–105.
20. Alamanni F, Parolari A, Agrifoglio M, et al. Myocardial revascularization procedures on multisegment diseased left anterior descending artery: endarterectomy or multiple sequential anastomoses (jumping)? *Minerva Cardioangiol*. 1996;44:471–7.
21. Nežić D, Knežević A, Milojević P, Jović M, Šagić D, Djukanović B. Tandem pedicled internal thoracic artery conduit for sequential grafting of multiple left anterior descending coronary artery lesions. *Tex Heart Inst J*. 2006;33:469–72.
22. Mert M, Cetin G, Yildiz CE, et al. Long term follow up results of sequential left internal thoracic artery grafts on severe left anterior descending artery disease. *J Cardiothorac Surg*. 2010;5:87.