Surgical anterior ventricular endocardial restoration performed with total arterial revascularization: Serial 5-year follow-up

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Objective: We evaluated the changes in left ventricular (LV) function and volumes after surgical anterior ventricular endocardial restoration.

Methods: A total of 63 patients who had undergone surgical anterior ventricular endocardial restoration and total arterial revascularization were included. Echocardiography and myocardial single photon emission computed tomography were performed to examine LV function and volumes preoperatively, early postoperatively, and annually thereafter to 5 years after surgery. Coronary angiography was performed at 5 years postoperatively.

Results: Operative mortality was 7.9% (5 of 63). Echocardiograms performed before discharge demonstrated a significantly improved LV ejection fraction that was maintained at 5 years, significantly decreased early postoperative LV end-diastolic and end-systolic volume indexes that were slightly increased at 1 year and then maintained at 5 years, and early postoperative decrement of the stroke volume index that had disappeared at 1 year and had not reappeared by 5 years. Postoperative myocardial single photon emission computed tomography showed an LV ejection fraction that had gradually improved until 2 years and was maintained at 5 years, significantly decreased LV end-diastolic and end-systolic volume indexes that were maintained at 5 years, and a stroke volume index that was unchanged until 2 years and slightly increased at 3 to 4 years. The arterial graft patency rate in the left coronary territory was 95.7% (67 of 70) at 5 years. The 10-year overall survival and adverse event-free rate were 59.2% and 61.2%, respectively.

Conclusions: Improved LV ejection fraction and reduced volume indexes were maintained and the stroke volume index had not decreased at 5 years after the procedure. Preserved patency of the arterial grafts might have an important role in maintaining improved LV function. (J Thorac Cardiovasc Surg 2014;148:529-35)

Surgical anterior ventricular endocardial restoration (SAVER), initially described by Dor and associates¹ as endoventricular circular patch plasty, has been a surgical treatment option for the failing ischemic myocardium. The midterm clinical outcomes demonstrated relatively good midterm survival and a high degree of freedom from readmission for heart failure up to 5 years postoperatively in patients with advanced ischemic cardiomyopathy.^{2,3} Several studies using echocardiography, magnetic resonance imaging, and gated single photon emission computed tomography (SPECT) have demonstrated postoperative changes in left ventricular (LV) function.⁴⁻⁶ However, most of these studies were cross-sectional investigations performed at a defined point after SAVER.

The aim of the present study was to demonstrate the serial changes in LV function and volume indexes using echocardiography and myocardial SPECT for ≤ 5 years after SAVER performed concomitant with total arterial coronary artery bypass grafting (CABG).

METHODS

Patient Characteristics

The institutional review board reviewed the study protocol and approved it as a minimal-risk retrospective study (approval no. H-1201-006-392) that did not require individual patient consent according to the institutional guidelines for waiving consent.

From 1999 to 2005, 63 patients (44 men and 19 women) who had undergone SAVER with concomitant total arterial CABG were studied. The mean patient age at surgery was 62.7 ± 9.0 years. Hypertension ($n = 38$, 60.3%) and diabetes mellitus ($n = 27$, 42.9%) were common comorbidities (Table 1).

Operative Strategy

SAVER was performed using cardiopulmonary bypass and cold blood cardioplegic arrest ($n = 48$, 76.2%) or ventricular fibrillation ($n = 15$, 23.8%) with moderate hypothermia (25° - 28° C). The mean cardiopulmonary bypass time was 153 ± 66 minutes, and the mean aortic crossclamp time in 48 patients was 66 ± 25 minutes. The left ventricle was opened parallel to the left anterior descending coronary artery. An endoventricular circular pursestring suture using a 2-0 monofilament suture was placed circumferentially in the transitional zone between the normal and diseased myocardium. A balloon was inserted into the ventricular base, and the LV diastolic volume was adjusted to 50-70 mL/m² by

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Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication March 27, 2013; revisions received Sept 20, 2013; accepted for publication Oct 13, 2013; available ahead of print Nov 26, 2013.

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0022-5223/\$36.00

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<http://dx.doi.org/10.1016/j.jtcvs.2013.10.022>

Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
ITA	= internal thoracic artery
LV	= left ventricular
LVEDVI	= LV end-diastolic volume index
LVEF	= LV ejection fraction
LVESVI	= LV end-systolic volume index
SAVER	= surgical anterior ventricular endocardial restoration
SPECT	= single photon emission computed tomography
STICH	= Surgical Treatment for Ischemic Heart Failure
SVI	= stroke volume index

tightening the pursestring suture. A commercially available woven vascular patch, with the size determined by the circumference of the circular suture after balloon removal, was used to close the defect. Coronary revascularization was performed after SAVER, and most revascularizations were performed under an on-pump beating heart after releasing the aortic crossclamping. The left internal thoracic artery (ITA) was used in all patients. It was commonly anastomosed to the left anterior descending coronary artery territory ($n = 52$, 82.5%). The additional arterial conduits used for total arterial revascularization were the right ITA ($n = 38$) and right gastroepiploic artery ($n = 33$; Table 2). When bilateral ITAs were used as in situ grafts, the right ITA was anastomosed to the left anterior descending coronary artery ($n = 7$, 11.5%). The mean number of distal anastomoses was 2.5 ± 0.9 . Mitral annuloplasty was performed when preoperative echocardiography revealed mitral regurgitation of moderate or greater degree ($n = 11$, 17.5%). Partial flexible rings were inserted in all 11 patients (Duran AnCore ring, Medtronic, Inc, Minneapolis, Minn, in 6, and Cosgrove-Edwards ring, Edwards Lifesciences, Irvine, Calif, in 5). One patient underwent mitral valve replacement because of combined rheumatic mitral pathologic features.

Evaluation of Clinical Outcomes

The patients underwent regular postoperative follow-up examinations at the outpatient clinic at 3- or 4-month intervals and were interviewed by telephone for confirmation of their condition if the last clinic visit had not occurred at the scheduled time. The clinical follow-up period for all patients was completed on December 31, 2012. The follow-up data were complete for 52 of the 57 survivors (91.2%), with a median follow-up duration of 103 months (range, 6-160). Operative mortality was defined as any death within 30 days, including death after hospital discharge. Cardiac death was defined as any death related to cardiac events, including sudden death during the follow-up period. Major adverse cardiac or cerebrovascular events included cardiac death (including sudden death during follow-up); acute myocardial infarction; heart failure needing readmission; reoperation or coronary intervention; and cerebrovascular accident.

Evaluation of LV Function

The LV ejection fraction (LVEF), LV end-diastolic and end-systolic volume index (LVEDVI and LVESVI, respectively), and stroke volume index (SVI) were measured preoperatively using transthoracic echocardiography and myocardial SPECT. For echocardiographic evaluation, the modified biplane Simpson method was used to calculate the LVEF and LV volumes. Myocardial SPECT images were obtained using dual-head gamma cameras (Vertex EPIC, ADAC Laboratories, Milpitas,

Calif). The images were reconstructed into 16-frame gated images using a filtered back-projection technique. The LV volumes were automatically calculated using a software package (QGS, Cedars-Sinai, Los Angeles, Calif) in which an automatic myocardial border detection algorithm was implemented.⁷ Postoperative echocardiographic evaluations were performed before discharge and annually thereafter to 5 years. Postoperative myocardial SPECT was performed at 3 months and annually thereafter to 5 years.

Angiographic Evaluation of Graft Patency

Early (10 ± 13 days), 1-year (12.2 ± 1.1 months), and 5-year (61.1 ± 7.2 months) follow-up coronary angiography was performed regardless of the patients' angina symptoms in 92% (58 of 63), 98.1% (52 of 53), and 80.5% (33 of 41) of the patients available for follow-up for each period, respectively. Graft patency was graded as described by FitzGibbon and colleagues.⁸ Steno-occlusion was defined as occluded or stenosis of $\geq 75\%$ diameter.⁸

Statistical Analysis

Statistical analysis was performed using the IBM SPSS, version 19 (IBM, Armonk, NY) and Statistical Analysis Systems, version 9.1 (SAS Institute, Cary, NC), software packages. Data are presented as mean $\pm$ standard deviation, median and range, or proportions. $P < .05$ was considered statistically significant. Angiographic patency rates were compared using a generalized estimating equation. Serial changes in LVEF, LVEDVI, LVESVI, and SVI were also analyzed using generalized estimating equations. All pairwise comparisons on time were performed using the Sidak method. Survival rates were estimated using the Kaplan-Meier method.

RESULTS**Clinical Outcomes**

The operative mortality was 7.9% (5 of 63 patients). The postoperative complications included atrial fibrillation ($n = 17$, 27.0%), low cardiac output syndrome ($n = 13$, 7.9%), reoperation for bleeding ($n = 8$, 12.7%), acute renal failure ($n = 5$, 7.9%), perioperative myocardial infarction ($n = 5$, 7.9%), and mediastinitis ($n = 1$, 1.6%). Late deaths during the follow-up period occurred in 19 patients, including 8 cardiac deaths. The 5- and 10-year overall survival rates were 72.4% and 59.2%, respectively. During the follow-up period, 5 patients underwent percutaneous coronary intervention because of progression of native coronary artery disease in 3 patients and occlusion of the right gastroepiploic artery conduit anastomosed to the posterior descending coronary artery in 2 patients. None of patients underwent redo-CABG. Eight patients required readmission for management of aggravated congestive heart failure. Another 3 patients experienced cerebrovascular events during the follow-up period. The 5- and 10-year freedom from major adverse cardiac or cerebrovascular event rates were 73.8% and 61.2%, respectively (Figure 1).

Echocardiographic Results

The serial echocardiographic examinations demonstrated that the LVEF had improved significantly early after surgery (preoperative vs early postoperative,

TABLE 1. Preoperative characteristics and risk factors (n = 63)

Variable	Value
Age (y)	62.7 ± 9.0
Gender	
Male	44
Female	19
Risk factor	
Smoking	29 (46.0)
Hypertension	38 (60.3)
Diabetes mellitus	27 (42.9)
Dyslipidemia	15 (23.8)
History of stroke	7 (11.1)
Chronic renal failure	6 (9.5)
Diagnosis	
Left main disease	8 (12.7)
Three-vessel disease	37 (58.7)

Data presented as mean ± standard deviation or n (%).

32.4% ± 9.0% vs 37.5% ± 10.3%; $P < .001$). Although the LVEF had improved further at 4 and 5 years after surgery, the difference was not statistically significant compared with the early postoperative value. The early postoperative LVEDVI and LVESVI had decreased significantly. Both volume indexes were slightly increased at 1 year postoperatively compared with the early postoperative values and were then maintained for 5 years. Early postoperative SVI decreased significantly; however, the decrement had disappeared at 1 year and had not reappeared by 5 years (Table 3 and Figure 2).

None of the 11 patients who had undergone concomitant posterior mitral annuloplasty demonstrated residual mitral regurgitation of moderate or greater degree early after surgery. Follow-up echocardiography was performed in 9 patients at a median of 51 months (range, 6-123) after surgery, and recurrent mitral regurgitation of moderate or greater degree was found in only 1 patient.

Myocardial SPECT Results

The results of myocardial SPECT were similar to those of echocardiography. Serial myocardial SPECT demonstrated that the LVEF had improved significantly at 3 months postoperatively (preoperative vs 3 months, 26.6% ± 8.4% vs 36.3% ± 11.3%, $P < .001$) and had improved further at 2 years postoperatively (3 months vs 2 years, 36.3% ± 11.3% vs 41.0% ± 10.6%, $P = .008$). The changes in LVEF >2 years postoperatively were not statistically

TABLE 2. Arterial grafts used in coronary artery bypass grafting

Graft	In situ	Composite	Free	Total
Left ITA	62	1	0	63 (100)
Right ITA	7	31	0	38 (60.3)
RGEA	17	15	1	33 (52.4)

Data presented as n (%). ITA, Internal thoracic artery; RGEA, right gastroepiploic artery.

FIGURE 1. Kaplan-Meier curves of (A) overall survival and (B) freedom from major adverse cardiac or cerebrovascular events. The 5- and 10-year overall survival and freedom from major adverse cardiac or cerebrovascular event rates were 72.4% and 59.2%, and 73.8% and 61.2%, respectively.

significant compared with the LVEF at 2 years. The LVEDVI and LVESVI had both decreased significantly at 3 months postoperatively (LVEDVI, 129.5 ± 42.4 vs 93.4 ± 31.1 mL/m², $P < .001$; LVESVI, 97.2 ± 40.4 vs 61.4 ± 27.9 mL/m², $P < .001$). After 3 months, no statistically significant changes were found in the LVEDVI and LVESVI during the 5 postoperative years. The SVI did not change until 2 years postoperatively and had increased slightly at 3 to 4 years (Table 4 and Figure 3).

Angiographic Patency Rates

The overall graft patency rates at early, 1 year, and 5 years postoperatively were 99.3% (148 of 149),

TABLE 3. Changes in left ventricular function and volumes after surgical anterior ventricular endocardial restoration with concomitant total arterial revascularization measured using transthoracic echocardiography

Variable	Preoperative data (n = 58)	Postoperative data					
		Early (n = 58)	1 y (n = 53)	2 y (n = 47)	3 y (n = 41)	4 y (n = 39)	5 y (n = 33)
LVEF (%)	32.4 ± 9.0	37.5 ± 10.3*	41.0 ± 0.7*	40.5 ± 9.8*	40.6 ± 9.3*	43.1 ± 10.6*	44.7 ± 11.5*
LVEDVI (mL/m ²)	91.1 ± 8.6	59.4 ± 22.0*	75.5 ± 24.0*,†	75.0 ± 23.2*,†	78.1 ± 21.9†	74.3 ± 19.5†	74.0 ± 21.3†
LVESVI (mL/m ²)	62.5 ± 34.3	38.4 ± 17.0*	45.8 ± 21.9*,‡	45.5 ± 21.3*	47.9 ± 20.0§,	41.6 ± 15.4*	42.9 ± 17.7§
SVI (mL/m ²)	28.6 ± 8.7	21.4 ± 9.1*	30.0 ± 7.7†	30.7 ± 10.2†	29.6 ± 7.6†	30.8 ± 10.7¶	29.1 ± 10.9#

LVEF, Left ventricular ejection fraction; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; SVI, stroke volume index.
 * $P < .001$ compared with preoperative value. † $P < .001$ compared with early postoperative value. ‡ $P = .027$ compared with early postoperative value. § $P = .004$ compared with preoperative value. || $P = .004$ compared with early postoperative value. ¶ $P = .005$ compared with early postoperative value. # $P = .016$ compared with early postoperative value.

97.0% (129 of 133), and 92.0% (81 of 88), respectively (Table 5). When the graft patency rates were compared according to the target coronary territories, the graft patency rates in the left coronary artery territory were significantly greater than those in the right coronary artery territory at 5 years postoperatively (95.7%

[67 of 70] vs 77.8% [14 of 18], $P = .026$). The patency rate of the right gastroepiploic artery conduit was 92% (81 of 88) at 5 years postoperatively and was significantly greater in the left coronary artery territory than in the right coronary artery territory (95.7% [67 of 70] vs 77.8% [14 of 18], $P = .03$).

FIGURE 2. Changes in the (A) left ventricular ejection fraction (LVEF), (B and C) left ventricular end-diastolic and end-systolic volume indexes (LVEDVI and LVESVI), and (D) stroke volume index (SVI) before surgery (*pre*), early after surgery (*post*), and 1 to 5 years postoperatively, measured on the transthoracic echocardiograms. (The central box represents the values from the lower to upper quartile and the middle line, the median; a line extends from the minimum to the maximum value.)

TABLE 4. Changes in left ventricular function and volumes after surgical anterior ventricular endocardial restoration with concomitant total arterial revascularization measured using myocardial single photon emission computed tomography

Variable	Preoperative data (n = 57)	Postoperative data					
		3 mo (n = 55)	1 y (n = 52)	2 y (n = 44)	3 y (n = 43)	4 y (n = 39)	5 y (n = 30)
LVEF (%)	26.6 ± 8.4	36.3 ± 11.3*	39.7 ± 12.1*	41.0 ± 10.6*,†	42.7 ± 12.0*,‡	43.9 ± 10.0*,‡	45.5 ± 12.3*,‡
LVEDVI (mL/m ²)	129.5 ± 42.4	93.4 ± 31.1*	88.6 ± 35.5*	89.3 ± 35.6*	94.3 ± 36.2*	91.0 ± 33.6*	87.4 ± 36.1*
LVESVI (mL/m ²)	97.2 ± 40.4	61.4 ± 27.9*	56.5 ± 32.0*	55.7 ± 31.2*	57.3 ± 33.0*	53.6 ± 28.4*	50.9 ± 30.2*
SVI (mL/m ²)	31.9 ± 8.1	32.1 ± 7.4	32.0 ± 6.9	32.8 ± 8.6	37.0 ± 7.9§	37.4 ± 7.3	36.5 ± 8.7

LVEF, Left ventricular ejection fraction; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; SVI, stroke volume index. **P* < .001 compared with preoperative value. †*P* = .008 compared with 3-month postoperative value. ‡*P* < .001 compared with 3-month postoperative value. §*P* = .028, *P* = .021, and *P* = .011 compared with preoperative, 3-month postoperative, and 1-year postoperative value, respectively. ||*P* = .005, *P* = .001, and *P* < .001 compared with preoperative, 3-month postoperative, and 1-year postoperative value, respectively.

DISCUSSION

The present study has revealed 2 main findings. First, improved LV function and volume indexes were maintained for 5 years after SAVER. Second, the 5-year graft patency rate in the left coronary artery territory was >95% after

total arterial revascularization, which might have positively affected the maintenance of the LV function and volumes after SAVER.

SAVER, initially described by Dor and associates,¹ has been performed to reshape the dilated left ventricle caused

FIGURE 3. Changes in the (A) left ventricular ejection fraction (LVEF), (B and C) left ventricular end-diastolic and end-systolic volume indexes (LVEDVI and LVESVI), and (D) stroke volume index (SVI) before surgery (pre), 3 months after surgery, and 1 to 5 years postoperatively, measured on myocardial single photon emission computed tomography scans. (The central box represents the values from the lower to upper quartile, and the middle line, the median; a line extends from the minimum to the maximum value.)

TABLE 5. Early, 1-year, and 5-year angiographic patency rates

Patency	Graft	LCA	LAD	LCx	RCA	Total
Early (n = 58)						
	LITA	68/68	59/59	9/9	0/0	68/68 (100)
	RITA	38/38	14/14	24/24	6/6	44/44 (100)
	RGEA	15/15	4/4	11/11	21/22	36/37 (97.3)
	Total	121/121 (100)			27/28 (96.4)	148/149 (99.3)
1 y (n = 52)						
	LITA	59/60	50/51	9/9	0/0	59/60 (98.3)
	RITA	33/33	13/13	20/20	3/4	36/37 (97.3)
	RGEA	14/15	3/3	11/12	20/21	34/36 (94.4)
	Total	106/108 (98.1)			23/25 (92.0)	129/133 (97.0)
5 y (n = 33)						
	LITA	38/39	31/32	7/7	0/0	38/39 (97.4)
	RITA	23/24	10/10	13/14	2/3	25/27 (92.6)
	RGEA	6/7	1/1	5/6	12/15	18/22 (81.8)
	Total	67/70 (95.7)			14/18 (77.8)	81/88 (92.0)

Data presented as n (%). LCA, Left coronary artery; LAD, left anterior descending artery; LCx, left circumflex artery; RCA, right coronary artery; LITA, left internal thoracic artery; RITA, right internal thoracic artery; RGEA, right gastroepiploic artery.

by ischemic cardiomyopathy. Previous studies have demonstrated improved LVEF and reduced LV volume indexes after SAVER.⁴⁻⁶ However, most of these studies were cross-sectional investigations performed at a defined point after SAVER. One previous study using myocardial SPECT evaluated the midterm changes in LV function after SAVER.⁴ The early and midterm postoperative LV volumes and LVEF were measured in 14 patients. Decreased LVEDVI and LVESVI and improved LVEF were demonstrated early postoperatively. An additionally decreased LVESVI and improved LVEF were observed at the midterm postoperative follow-up point. Another study using echocardiography demonstrated that the reduced LV volumes early after surgery increased again at the midterm follow-up point (≥ 6 months after surgery).⁹ They suggested that progressive LV sphericity after surgery subsequently increased wall tension and redilatation of the LV volumes. Those studies, however, included only a small number of patients and the ventricular volumes were measured at 2 postoperative periods. Another previous study, including 234 patients, demonstrated that the SVI had frequently decreased early postoperatively and had recovered at midterm follow-up after surgical ventricular restoration despite uniformly decreased LV volume indexes and improved LVEF.¹⁰ Those investigators suggested that the ventricle had regained its preload reserve, allowing the stroke volume to increase during exercise, independent of the baseline value of the stroke volume at rest, in accordance with the well-demonstrated clinical improvement after surgery.¹¹ In the present study, we evaluated the LVEF, LV volume indexes, and SVI preoperatively, early postoperatively, and annually thereafter to 5 years postoperatively using transthoracic echocardiography and myocardial SPECT. Serial examinations of both studies demonstrated similar findings: the LVEF had improved

and the LVEDVI and LVESVI had decreased postoperatively and were maintained during the 5-year study period. Our results have suggested that the LV volume was significantly reduced in the immediate postoperative period, had slightly increased during the early postoperative period, and was then maintained during the 5-year study period. Echocardiography demonstrated that the SVI had decreased early postoperatively but had recovered by 1 year, with the recovery maintained throughout the 5-year study period. However, myocardial SPECT demonstrated slightly increased SVI during postoperative years 3 to 4.

Previous studies have demonstrated 5-year overall and heart failure-free survival rates of 68% to 82% and 58% to 78%, respectively, after SAVER.^{2,3} In the present study, the 5- and 10-year overall survival rates were 72.4% and 59.2%, and the 5- and 10-year freedom from major adverse cardiac or cerebrovascular event rates were 73.8% and 61.2%, respectively. Although a recent multicenter trial comparing CABG with and without surgical ventricular reconstruction (Surgical Treatment for Ischemic Heart Failure [STICH] trial) failed to demonstrate any advantages to adding surgical ventricular restoration to CABG,¹² the flaws indicated in the STICH trial should be addressed; SAVER could be a valid surgical option to improve the clinical outcomes in patients with a failing ischemic heart.^{13,14} The present study has demonstrated that the LVESVI was reduced 40% in the early postoperative period when evaluated echocardiographically and 39% at 3 months postoperatively when evaluated using SPECT. This is in agreement with the suggestion of Suma and Anyanwu¹⁵ that most surgeons can achieve a volume reduction of $>30\%$ after SAVER with appropriate training and good technique. In the STICH trial, however, the LVESVI was reduced only 19% at 4 months after surgery.¹²

Those findings also suggested that volume reduction surgery in the STICH trial might have been suboptimal, and the conclusions reached might have been misguided.^{13,15}

Our operative strategy for ischemic cardiomyopathy during the study period was to perform SAVER concomitant with total arterial graft revascularization. Most patients with ischemic cardiomyopathy will have a mixture of stunned, hibernating, remodeled, and nonviable myocardium and will, therefore, show varying degrees and timing of functional improvement after revascularization depending on the preoperative ratios of these components.^{16,17} Because total arterial revascularization has demonstrated excellent graft patency rates and good clinical results,^{18,19} we have presumed that long-term maintenance of graft patency will be even more important for recovery of the dilated failing ischemic myocardium. In the present study, the overall and left coronary artery territory graft patency rates at 5 years postoperatively were 92.0% and 95.7%, respectively. The preserved midterm patency of arterial grafts, particularly in the left coronary territory, might have an important role in maintaining improved LV function up to 5 years postoperatively.

Study Limitations

The present study had limitations that must be recognized. First, the present study was a retrospective observational study at a single institution, although all consecutive patients were enrolled. Second, follow-up echocardiography and myocardial SPECT were not performed in all patients. Although we adopted a generalized estimating equation to overcome this limitation, selection bias could have affected our results. Third, cardiac magnetic resonance imaging, which has been recognized as the reference standard for the assessment of ventricular volumes, was not performed in the early postoperative period of our study and cardiac magnetic resonance imaging data were not included. However, previous studies have demonstrated a good correlation in the measured volumes between magnetic resonance imaging and myocardial SPECT.²⁰ Therefore, observation of the serial changes in the LV volumes measured using myocardial SPECT seemed to be sufficient. Finally, we did not compare our results with those of SAVER performed with CABG using ≥ 1 vein grafts, because almost all SAVER operations at our institution were performed with total arterial revascularization during the study period.

We wish to thank the Medical Research Collaborating Center of Seoul National University Hospital for their efforts in statistical assistance.

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