SURGERY FOR ACQUIRED HEART DISEASE

LATE HEMODYNAMIC RESULTS AFTER LEFT VENTRICULAR PATCH REPAIR ASSOCIATED WITH CORONARY GRAFTING IN PATIENTS WITH POSTINFARCTION AKINETIC OR DYSKINETIC ANEURYSM OF THE LEFT VENTRICLE

This study reports hemodynamic, electrophysiologic, and clinical results in 171 patients (157 men and 14 women, mean age 57 ± 8 years) 1 year after endoventricular circular patch repair and coronary grafting for postinfarction left ventricular dyskinetic or akinetic aneurysm. All patients had hemodynamic and electrophysiologic study before the operation and early and 1 year after the operation. The vast majority of aneurysms were anterior ($n = 166$), with a mean delay from infarction of 43 ± 50 months. Fifty-two percent of patients were in New York Heart Association class III or IV, and preoperative ejection fraction was less than 40% in the majority of them (75%). Preoperative clinical ventricular tachycardia was present in 25 patients and was inducible in 59 patients. All patients had endoventricular circular patch repair with a synthetic ($n = 99$) or autologous patch ($n = 72$); 96% had associated coronary grafting with a mean number of bypass grafts of 1.9 ± 0.9 . Results at 1 year demonstrated a significant increase in ejection fraction (from $36\% \pm 13\%$ to $46\% \pm 12\%$ ($p < 0.0001$)) and a significant reduction in ventricular volumes (end-diastolic volume index from 116 ± 5 to 94 ± 29 ml/m² and end-systolic volume index from 77 ± 45 to 53 ± 25 ml/m², $p < 0.0001$). New York Heart Association functional classification was significantly improved (2.6 ± 0.9 vs 1.4 ± 0.6 , $p < 0.0001$) and ventricular tachycardias were almost suppressed (no documented clinical ventricular tachycardias and 8% incidence of inducible ventricular tachycardias after 1 year, $\chi^2 < 0.001$). Patients who benefit most from the operation are those with more severe preoperative left ventricular dysfunction (i.e., ejection fraction $< 30\%$), more frequent ventricular arrhythmias, and larger ventricular volumes. At regression analysis, critical disease of the right coronary artery was the only independent predictor of unsatisfactory pump improvement (as evaluated by postoperative increase of ejection fraction < 10 absolute points). In conclusion, in our large series of patients operated on by one surgical team between 1988 and 1993, who were studied hemodynamically both before and after the operation, endoventricular circular patch repair of left ventricular aneurysm associated with coronary grafting definitely improves left ventricular pump function and clinical status 1 year after the operation. (J THORAC CARDIOVASC SURG 1995;110:1291-301)

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Endoventricular circular patch repair of left ventricular (LV) aneurysm is an innovative technique that improves LV function mainly by improving LV geometry, which is markedly abnormal in LV aneurysm.^{1, 4, 7, 8, 10} We^{5, 11} had previously reported early hemodynamic results after this operative technique and demonstrated that the technique, associated with nonguided subtotal endocardial resection and cryotherapy, is highly effective in suppressing clinical and inducible ventricular tachycardia (VT).³

Limited data concerning late functional and hemodynamic status after this kind of operation are available in the medical literature,^{6, 9} and we know that these are important criteria for evaluation because these outcomes should strongly influence a clinical decision for operative technique.

The aim of the current study was to evaluate late hemodynamic, clinical, and electrophysiologic results after patch repair of LV aneurysm of either the akinetic or the dyskinetic type in patients who had been operated on and who gave their consent to a second hemodynamic study.

Patients and methods

Patients. Among 600 patients who were subjected to LV patch repair for postinfarction LV aneurysm by the same surgical team since 1984, we analyzed 171 patients (operated on between 1988 and 1993) who gave their consent to second hemodynamic and electrophysiologic studies 1 year after the operation. All patients had right and left heart catheterization, ventricular angiography, coronary arteriography, and electrophysiologic study (unless contraindicated) before and early after the operation.

After 1 year all these patients were studied with an identical protocol. Cardiac output was measured by means of the thermodilution method. LV volumes and ejection fraction (EF) were calculated angiographically, and coronary bypass grafts were evaluated in each case. The stimulation protocol at preoperative and early and late postoperative studies included (1) ventricular pacing up to a rate of 200 beats/min and (2) single and double extra-stimuli delivered after an eight-beat ventricular drive at two basic cycle lengths of 600 and 500 msec from the right ventricular apex. Inducible sustained VT was defined as a monomorphic VT that lasted more than 15 seconds with a heart rate less than 250 beats/min.

Single indications for operation were angina in 66 patients, congestive cardiac failure in 19, and clinical VT in 7. A combination of angina, congestive cardiac failure, and VT constituted the indication for operation in the remaining patients (41%).

Twenty-one patients were operated on on an emergency basis (11 for cardiac failure, 2 for intractable angina, 5 for intractable VT, 2 for postinfarction ventricular septal defect, and 1 for cardiac rupture). Twenty-three patients required preoperative intraaortic balloon pumping (12 having emergency operations and 11 elective operations).

Table I. Clinical characteristics of the study groups (*n* = 171)

Age (yr)	57 ± 8
Sex	
Male	157
Female	14
Delay from MI (mo)	43 ± 50
Site of aneurysm	
Anterior	166
Posterior	5
Type of aneurysm	
Dyskinetic	117
Akinetic	54
NYHA functional class	
Class I	19
Class II	63
Class III	63
Class IV	26
EF (%)	36 ± 13
EFc (%)	44 ± 11
EDVI (ml/m ²)	117 ± 51
PAP (mm Hg)	20 ± 8
CWP (mm Hg)	14 ± 6
Coronary lesions	
One vessel	62
Two vessels	67
Three vessels	42
Left main	9
Mitral insufficiency	16
Grade I	5
Grade II	10
Grade III	1
Clinical VT	25
Inducible VT	59

MI, Myocardial infarction; NYHA, New York Heart Association; EF, ejection fraction; EFc, contractile ejection fraction; EDVI, end-diastolic volume index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure; VT, ventricular tachycardia.

Clinical characteristics of the study group are given in Table I. Preoperative renal failure was present in 9 patients and respiratory insufficiency in 3.

Surgical technique. The technique has been described in detail in previous articles^{1, 5}. The procedure (Fig. 1) is performed during total cardiac arrest with cold crystalloid or blood cardioplegia and local cooling. Coronary revascularization is first performed with one or two internal thoracic arteries and vein grafting, or both. Then the LV is opened in the middle of the akinetic or dyskinetic zone. Clots are removed and endocardial resection is accomplished in patients with spontaneous or inducible ventricular arrhythmias. The endocardial resection is conducted to the border of the scarred area of the septum (one third or two thirds) and the papillary muscle root. A portion of the scarred endocardium is left to allow the suture to be anchored. Cryotherapy is then applied to the edge of resection in patients with clinical or inducible VT (or both). A 2-0 monofilament suture is then sutured circumferentially approximately 1 cm above the border between normal and diseased muscle to reestablish a normal LV shape. This "Fontan maneuver" facilitates the sizing of

Fig. 1. Technique of endoventricular circular patch repair. **A**, Lesions exposed under total cardiac arrest after implantation of left internal mammary artery. **B**, Mobilization of the endocardial scar on the septum and up to contractile muscle. **C**, Cryotherapy probe on the limit of resection (in case of ventricular aneurysm). Dacron patch inside the LV on contractile muscle with 2-0 monofilament on pericardial strip. **D**, Autologous endocardial patch is cut in the mobilized septal scar and sutured on contractile muscle.

the circular patch, which is built with autologous (endocardium or pericardium) or synthetic tissue. This patch is fixed by the same 2-0 suture inside the LV cavity on the border marked by the circular suture.

Excluded areas can be resected (in case of great excess), folded, or sutured above the patch, so that damage to the bypassed left anterior descending artery with this suture can be avoided.

Table II. Variables used for analysis

<i>Historical</i>	
Renal failure (preoperative creatinine level > 1.8 mg/dl)	
Spontaneous arrhythmias	
Congestive heart failure	
Myocardial infarction	
Interval between first infarction and operation	
Functional class dyspnea (New York Heart Association)	
<i>Clinical</i>	
Gender	
Age	
Indication for operation	
Angina	
Congestive heart failure	
Spontaneous ventricular arrhythmias	
Emergency or elective operation	
<i>Angiographic</i>	
Left ventricular end-diastolic and end-systolic volume indexes	
Ejection fraction	
Mean pulmonary artery pressure	
End-diastolic left ventricular pressure	
Cardiac index	
Type of aneurysm (akinetic or dyskinetic)	
Site of the aneurysm (anterior or posterior)	
Associated valvular dysfunction	
Coronary artery lesions (degree and extent)	
<i>Electrophysiologic data</i>	
Inducible arrhythmias	
<i>Surgical technique</i>	
Type of cardioplegia	
Degree of hypothermia	
Time duration of cardiopulmonary bypass	
Time duration of aortic crossclamping	
Number of venous grafts	
Internal thoracic artery implantation	
Aneurysm revascularization	
Type of patch (synthetic or autologous)	
Associated procedures	
Subtotal endocardectomy	
Cryotherapy	
Mitral valve replacement or repair	
Support pump (intraaortic balloon pump or other mechanical assistance)	

Statistical analysis. All data are expressed as mean $\pm$ standard deviation. The significance of the difference of means of continuous variables (*t* test) or the distribution of dichotomous variables (χ^2 test or Fisher's exact test) was used when appropriate. A *p* value less than 0.05 was considered significant. To analyze predictors of functional outcome, we divided patients according to postoperative EF; that is, an increase in EF of more than 10 absolute points at 1 year was considered a good outcome. To this purpose we analyzed several clinical, demographic, and hemodynamic variables collected in the study (Table II). These variables were then screened by means of univariate statistical methods, in which variables identified as univariately predictive of outcome (*p* value at most 0.05)

Table III. Perioperative complications

	No. of patients
Low cardiac output necessitating:	
Intraaortic balloon pumping	20
Inotropic support	24
Renal insufficiency	8
Ventricular arrhythmias	8
Supraventricular arrhythmias	14
Conduction defects necessitating temporary pacing	41
Bleeding	20
Bleeding necessitating blood transfusion	13
Infections	4

were entered into backward stepwise logistic regression analysis.

Results

All patients had LV aneurysm repair with synthetic or autologous patch (99 and 72 patients, respectively). Associated procedures included subtotal endocardial resection and cryotherapy in 71 patients with clinical or inducible VT (or both), ventricular septal defect closure in 2, mitral valve replacement in 2, mitral valve repair in 8 patients, aortic valve replacement in 1 patient, and aortic valve repair in another patient. A total of 164 patients had associated coronary grafting (96%): one vessel in 62 patients, two vessels in 63, three vessels in 34, four vessels in 4, and five vessels in 1 patient. The internal thoracic artery was grafted in 145 patients (85%), almost always to the left anterior descending coronary artery (92%). The mean number of bypass grafts was 1.9 ± 0.9 . Perioperative complications are reported in Table III. Hemodynamic data in the overall group are reported in Table IV.

Table V reports New York Heart Association functional class before and 1 year after the operation. Mean functional class was significantly improved in these patients, although 12 patients still had angina. After 1 year 19 patients had angiographic evidence of mitral insufficiency (grade I to II in 15 patients and grade III to IV in 4 patients).

Tables VI and VII report electrophysiologic results in patients with inducible and clinical ventricular arrhythmias, respectively. Angiography at 1 year showed that 16 of 102 vein grafts were occluded and 10 internal thoracic artery grafts were either occluded or patent but with poor flow to the grafted vessel. Thus 93% of internal thoracic arteries im-

Table IV. Hemodynamic data before and early and 1 year after operation

	Preop.	Early postop.	One year postop.
EF (%)	36 ± 13	49 ± 11*	46 ± 12*†
EDVI (ml/m ²)	116 ± 51	79 ± 23*	94 ± 29*†
ESVI (ml/m ²)	77 ± 45	41 ± 19*	53 ± 25*†
CI (ml/min/m ²)	2.67 ± 0.68	2.61 ± 0.56	2.64 ± 0.61
PAP (mm Hg)	20 ± 8	18 ± 7*	25 ± 14*†
CWP (mm Hg)	14 ± 7	11 ± 5*	16 ± 10*†

EF, Ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; CI, cardiac index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure.

*Versus basal value ($p < 0.05$).

†Versus early postoperative value ($p < 0.05$).

planted in the aneurysmal territory were patent after 1 year.

Table VIII gives 1-year hemodynamic results in patients divided according to preoperative EF at preoperative and early and late postoperative studies. Angina and critical disease of the right coronary artery are more prevalent in patients with an EF greater than 40% ($p < 0.02$); the internal thoracic artery is more often used in this group (96% vs 87% in the group with an EF of 30% to 40% and 81% in patients with an EF of less than 30%; $p < 0.002$). Predominant symptoms were angina in patients whose major indication for surgical treatment was an EF less than 40% and cardiac insufficiency in patients whose major indication was an EF less than 30% ($p < 0.002$).

Table IX reports hemodynamic data in patients whose EF did not improve more than 10 absolute points by 1 year after the operation. Patients whose EF improved more than 10 points were older (59 ± 9 vs 55 ± 7 years, $p < 0.01$), had multivessel disease, and had a greater number of vein grafts (1.1 ± 0.8 vs 0.77 ± 0.88 , $p < 0.03$). In patients whose EF did not improve more than 10 points, preoperative critical stenosis of the right coronary artery was present in a significantly higher rate; mean pulmonary artery pressure after 1 year was significantly higher (30 ± 16 vs 22 ± 12 mm Hg, $p < 0.02$).

Patients who had a postoperative increase in EF of more than 10 points (Table X) had a lower basal EF ($30\% \pm 11\%$ vs $41\% \pm 11\%$, $p < 0.001$), were more likely to have inducible or spontaneous VT before the operation, and consequently were more likely to have had cryotherapy. They had a greater basal end-systolic volume index (87 ± 47 vs 68 ± 43 ml/m², $p < 0.01$), and the use of intraaortic balloon pumping was more common in these patients. At 1 year end-systolic volume index was smaller (48 ± 23 vs 58 ± 25 ml/m², $p < 0.02$) and cardiac index was greater (2.8 ± 0.6 vs 2.5 ± 0.5 , $p < 0.001$). Only 4%

Table V. NYHA functional class before and 1 year after operation

	Preop. (No. of patients)	One-year postop. (No. of patients)
NYHA I	19	97
NYHA II	63	59
NYHA III	63	11
NYHA IV	26	4
Mean	2.6 ± 0.9	1.4 ± 0.6 ($p < 0.0001$)

NYHA, New York Heart Association.

of these patients were in New York Heart Association class III or IV compared with 13% of patients whose EF did not increase after the operation (χ^2 , $p < 0.01$).

On logistic regression analysis, critical involvement of the right coronary artery was an independent predictor of unsatisfactory outcome. Table XI shows hemodynamic data in patients divided according to basal pulmonary pressure. At 1 year after the operation, pulmonary artery pressure and capillary wedge pressure increased substantially. This increase is related to preoperative pulmonary artery pressures and, accordingly, to LV dysfunction.

No significant differences in hemodynamic results were found when the type of repair (synthetic or autologous patch) was considered. There is a tendency to greater postoperative increase in end-diastolic volume index in patients with an autologous rather than a synthetic patch (from 73 ± 21 to 92 ± 21 to 92 ± 26 ml/m² and from 81 ± 22 to 92 ± 25 ml/m²); however, the difference is not significant.

Discussion

This study was prospectively designed to evaluate clinical, hemodynamic, and electrophysiologic results after LV patch repair associated with coronary grafting and cryotherapy (when indicated) in patients with postinfarction akinetic or dyskinetic aneurysm.

Table VI. Electrophysiologic results

	Postop. PVS (n = 131)			One year PVS (n = 132)		
	Ind	Non-Ind	NA	Ind	Non-Ind	NA
Preop. PVS (n = 126)						
Ind VT (n = 59)	5	54	—	5	50	4
Non-Ind VT (n = 67)	2	59	6	2	64	1
CI (n = 12)	3	8	1	3	8	1

PVS, Programmed ventricular stimulation; VT, ventricular tachycardia; Ind, inducible; Non-ind, noninducible; CI, contraindicated; NA, not available.

Table VII. Electrophysiologic results in patients with preoperative clinical ventricular tachycardia

	Postop. PVS (n = 24)			One year PVS (n = 24)		
	Ind	Non-Ind	NA	Ind	Non-Ind	NA
SVT (n = 25)						
Ind VT (n = 12)	2	10	—	—	12	—
Non-Ind VT (n = 1)	—	1	—	—	1	—
CI (n = 12)	3	8	1	3	8	1

PVS, Programmed ventricular stimulation; SVT, supraventricular tachycardia; VT, ventricular tachycardia; Ind, inducible; Non-ind, noninducible; CI, contraindicated; NA, not available.

Table VIII. Hemodynamic data in patients divided according to basal EF

	EF < 30% (n = 62)			EF > 30% to ≤ 40% (n = 51)			EF > 40% (n = 58)		
	Preop.	Postop.	1 year	Preop.	Postop.	1 year	Preop.	Postop.	1 year
EF (%)	23 ± 6	41 ± 10	40 ± 11*	36 ± 2	49 ± 10	44 ± 10*†	50 ± 7	58 ± 7	54 ± 11*†
EFc (%)	36 ± 8			43 ± 6			55 ± 8		
EDVI (ml/m ²)	143 ± 67	89 ± 24	105 ± 28*†	108 ± 28	78 ± 23	94 ± 30†	96 ± 29	67 ± 17	84 ± 25†
ESVI (ml/m ²)	111 ± 54	52 ± 19	63 ± 23*†	68 ± 19	40 ± 18	54 ± 26*†	47 ± 17	28 ± 8	41 ± 21†
CI (ml/min/m ²)	2.6 ± 0.6	2.6 ± 0.5	2.7 ± 0.6	2.7 ± 0.8	2.5 ± 0.5	2.6 ± 0.5	2.7 ± 0.7	2.6 ± 0.7	2.6 ± 0.6
PAP (mm Hg)	21 ± 8	18 ± 6	28 ± 14*†	21 ± 11	18 ± 8	28 ± 15*†	17 ± 6	16 ± 7	21 ± 12*†
CWP (mm Hg)	15 ± 6	12 ± 5	18 ± 10*†	14 ± 8	11 ± 6	18 ± 10*†	12 ± 6	10 ± 5	13 ± 8

EF, Ejection fraction; EFc, contractile ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; CI, cardiac index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure.

*Versus basal value ($p < 0.05$).

†Versus postoperative value.

Clinical results. After 1 year patients do well clinically, mean functional class significantly decreases, and only 15 patients are still in New York Heart Association class III or IV. This observation is even more relevant than the improvement in EF, because functional class reflects not only pump function at rest but also the ability for cardiac output to increase during physical activity.

Hemodynamic results. The study demonstrates a significant increase in EF both at early and at late follow-up. The patients who benefit more from the operation are those with more severely depressed pump function (EF < 30%). LV volumes were higher at 1 year in all subsets of patients. This can depend, in part, on loading conditions that can be

altered shortly after the operation, as evidenced by right pulmonary artery pressures that are also lowered at the early follow-up examination. However, a remodeling of the LV after patch repair cannot yet be excluded.

The dramatic improvement in pump function, especially in patients with severe preoperative LV dysfunction, is certainly related both to the more physiologic chamber geometry and to the associated complete myocardial revascularization. Moreover, circular patch repair, in which the border zone of the aneurysm is actually sutured over a stiff synthetic patch, allows a more synchronized contraction by improving contraction and relaxation abnormalities that are present even in zones remote from the

Table IX. Hemodynamic data in patients with an increase of postoperative EF < 10 absolute points

	Preop.	Postop.	One year
EF (%)	41 ± 10	49 ± 11	42 ± 11
EDVI (ml/m ²)	112 ± 54	76 ± 21	95 ± 28
ESVI (ml/m ²)	68 ± 43	39 ± 17	58 ± 25
CI (ml/min/m ²)	2.7 ± 0.6	2.6 ± 0.6	2.5 ± 0.5
PAP (mm Hg)	20 ± 10	18 ± 8	30 ± 15
CWP (mm Hg)	13 ± 7	12 ± 5	18 ± 10

EF, Ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; CI, cardiac index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure.

Table X. Hemodynamic data in patients with an increase of postoperative EF > 10 absolute points

	Preop.	Postop.	One year
EF (%)	30 ± 12	49 ± 12	50 ± 12
EDVI (ml/m ²)	121 ± 49	79 ± 23	94 ± 29
ESVI (ml/m ²)	87 ± 47	41 ± 18	48 ± 23
CI (ml/min/m ²)	2.6 ± 0.7	2.6 ± 0.5	2.8 ± 0.6
PAP (mm Hg)	20 ± 7	17 ± 5	22 ± 12
CWP (mm Hg)	14 ± 6	10 ± 4	15 ± 9

EF, Ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; CI, cardiac index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure.

Table XI. Hemodynamic data in patients divided according to basal pulmonary pressure

	PAP ≤ 22 mm Hg			PAP > 22 to < 28 mm Hg			PAP ≥ 28 mm Hg		
	Preop.	Postop.	1 year	Preop.	Postop.	1 year	Preop.	Postop.	1 year
EF (%)	38 ± 12	50 ± 12*	47 ± 13†‡	31 ± 12	44 ± 11*	40 ± 10†	31 ± 14	45 ± 10*	41 ± 9†‡
EFc (%)	46 ± 11			41 ± 10			38 ± 11		
EDVI (ml/m ²)	111 ± 52	75 ± 22*	91 ± 25†‡	138 ± 71	84 ± 22*	98 ± 26†	131 ± 34	87 ± 25*	102 ± 36†‡
ESVI (ml/m ²)	71 ± 43	38 ± 17*	50 ± 23†‡	103 ± 69	49 ± 23*	60 ± 21†‡	91 ± 34	47 ± 17*	64 ± 30†‡
CI (ml/min/m ²)	2.7 ± 0.7	2.6 ± 0.6	2.6 ± 0.6	2.7 ± 0.4	2.7 ± 0.5	2.6 ± 0.5	2.7 ± 0.7	2.4 ± 0.5	2.9 ± 0.7
PAP (mm Hg)	16 ± 4	16 ± 7	24 ± 14†‡	24 ± 1	20 ± 6*	28 ± 13‡	35 ± 8	22 ± 8*	34 ± 14‡
CWP (mm Hg)	11 ± 4	10 ± 5	15 ± 9†‡	16 ± 1	13 ± 6*	17 ± 8‡	25 ± 5	13 ± 6*	22 ± 10‡

EF, Ejection fraction; EFc, contractile ejection fraction; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; CI, cardiac index; PAP, mean pulmonary artery pressure; CWP, capillary wedge pressure.

*Postoperative versus preoperative.

†One year versus preoperative.

‡One year versus postoperative.

aneurysm and next to the border zone, as demonstrated in our previous articles.¹²⁻¹⁴ Nevertheless, some patients do not have a satisfactory improvement of EF either early or late after the operation; therefore, we attempted to define variables that can predict functional outcome by dividing patients according to the EF 1 year after the operation. We defined an improvement in EF of less than 10 absolute points as indicative of an unsatisfactory result. Univariate analysis of these two groups showed that patients with a “bad” outcome were significantly more likely to have multivessel disease and, in particular, critical involvement of the right coronary artery. Consequently, the mean number of bypass grafts is significantly higher in these patients

(2.0 ± 0.75 vs 1.5 ± 0.9, $p < 0.03$), and in particular they have a greater number of vein grafts (1.1 ± 0.8 vs 0.77 ± 0.88, $p < 0.03$). The fact that patients with a “bad” functional outcome have multivessel disease and a greater number of coronary grafts seems in disagreement with data from the medical literature, which reports a beneficial effect of surgical treatment primarily in patients with multivessel disease.¹⁵⁻²¹ However, the majority of those studies deal with survival, mortality, and morbidity and not with improvement in global pump function. The great majority of our patients do well clinically; therefore the discordance is only apparent, in our opinion. One-year hemodynamic parameters are concordant in these patients: EF is lower (41% ±

11% vs 50% $\pm$ 11%, $p < 0.0001$), capillary wedge and pulmonary artery pressures are higher (18 ± 11 vs 22 ± 11 mm Hg and 30 ± 16 vs 22 ± 11 mm Hg, $p < 0.004$, respectively), and cardiac index is significantly lower (2.5 ± 0.05 vs 2.8 ± 0.06 , $p < 0.001$).

Patients who benefit most from this operation are those with more severe preoperative LV dysfunction, more frequent spontaneous and inducible VT, and higher end-systolic volumes. Most of these patients had a subtotal nonguided endocardial resection and cryotherapy, and this indicates that the procedure does not adversely affect pump function. It has been reported that the function of the non-aneurysmal portion of the ventricle is predictive of outcome^{2, 21-24} and affects survival, yet it does not influence postoperative pump function. In fact, in our patients contractile EF does not relate to postoperative global function when all variables are considered. Neither type of aneurysm (akinetic vs dyskinetic) in our patients relates to postoperative pump function, an observation that is in disagreement with data in the medical literature that report more favorable results in patients with dyskinetic LV aneurysm.^{25, 26} This observation comes from studies that most often adopted other techniques of ventricular repair,²⁷⁻³² and we think that endoventricular circular patch repair of LV aneurysm, by resecting or excluding all the myocardial scar and by circularly reconstructing the cavity, should overcome these differences.

Conclusion

To our knowledge, our study is the only one that prospectively evaluates a large series of patients subjected to patch repair of an LV aneurysm in whom preoperative and postoperative hemodynamic studies have been performed. Important observations from this study are as follows:

LV global pump function is objectively improved after the operation, and patients who benefit most are those with more severe preoperative LV dysfunction. Akinetic or dyskinetic aneurysms do not relate to postoperative pump changes, nor does the type of patch (synthetic or autologous). The improvement in pump function is certainly the result of the more physiologic LV shape, which reduces afterload (by reducing volumes and wall tension) and to the myocardial revascularization that allows an increase in contraction of the muscle. Revascularization of the aneurysmal portion of the ventricle with the internal thoracic artery has been beneficial in our

patients. Therefore we strongly recommend the use of the thoracic artery for grafting of the left anterior descending artery in patients with an anterior aneurysm.

Functional status is improved in the vast majority of patients after 1 year; only 8% of patients were still in New York Heart Association class III or IV, and only 12 patients had angina.

VTs, either spontaneous or inducible, are almost nonexistent in our patients; only 8% of patients had inducible VT 1 year after the operation, and no cases of spontaneous VT were documented. Thus associated nonguided endocardectomy and cryotherapy are highly effective in preventing recurrent arrhythmias and do not affect pump function.

The critical involvement of the right coronary artery is the only significant predictor of unsatisfactory pump function, as evaluated by a postoperative increase in EF of less than 10 absolute points. Thus our experience with LV patch repair, as well as the experience of others, allows us to state that, at present, the guidelines of LV aneurysmectomy reported by Froehlich,³³ Cohen,²⁶ and their associates should at least be rewritten.

Limitation of the study. Patients were not receiving medications at the time of the preoperative and the early and late postoperative studies; however, precise data on specific therapy before the operation and during the 1-year postoperative interval are not available, and absence of medical therapeutic management could potentially influence the results. Moreover, this is a nonrandomized series of patients, and a comparison with medically treated patients or with patients undergoing other surgical techniques is not available.

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Discussion

Dr. Delos M. Cosgrove (*Cleveland, Ohio*). Dr. Dor, I congratulate you and your colleagues on having achieved excellent results and further for defining the reasons for hemodynamic improvement after ventricular aneurysm resection. I believe this is the best and the most complete study ever done of the hemodynamic changes that have been achieved after surgery for ventricular aneurysms. It further confirms the fact that the prognosis is not as good after resection of a ventricular aneurysm in patients who have right coronary artery disease. Have you any idea why that is true? Have you any observations on the handful of patients with aneurysms in the distribution of the right coronary artery in your series? What were the results in those patients and the predictive improvement that was achieved there?

Your approach to operating on ventricular aneurysms has clearly affected our surgical approach at the Cleveland Clinic.

Dr. Dor. When a patient has a posterior scar from a previous aneurysm in addition to anteroseptal apical akinesia, the situation is grave. We agree to try to improve the LV cavity, but we know that often the late result will not be satisfactory. We are sure that the scar on the posterior wall is one of the reasons for the poor late result. Apart from this particular localization, we have no other means to predict which patients will have poor results, even in the case of extremely low EF.

Dr. Michael K. Pasque (*St. Louis, Mo.*). Dr. Dor's contributions to the surgical repair of LV aneurysms are widely known. The results from his current large group of patients suggest that his method of repair has had a significant impact in eliminating postoperative residual LV aneurysm. In this regard, the primary surgical decision involves the approach to the transition or border zone, which lies between the scar tissue and the normal ventricular myocardium.

We can now characterize the functional status of the border zone by using radiofrequency tissue tagging techniques that place small crosshatched tracking grids across the border zone areas. The deformation of these grids, and therefore the myocardium itself, can be defined and tracked with a high degree of accuracy. The computer-generated tracking lines consistently and reproducibly demonstrate abnormal strain patterns in the border zone areas during the isovolumic contraction period. Specifically, instead of circumferential shortening and wall thickening as seen in normal myocardium, the border zone strains demonstrate longitudinal stretching and myocardial thinning. Although there is some return toward normal strain patterns during late ejection, the border zone contractile mechanics are not normal.

Dr. Dor's patch repair takes advantage of the excellent suturing characteristics of the border zone while at the same time essentially excluding the border zone from the LV cavity. The abnormal LV remodeling and subsequent regional impairment of LV contractile function, especially in the area of the septum, is therefore eliminated by this patch technique. Our studies would also suggest that if the border zone can be protected by the patch from abnormal deformation during isovolumic systole, the border zone may actually contribute to late systolic ejection mechanics

if it is closed over the patch. In this regard, Dr. Dor's autologous patch technique may be optimal, because it would resist distention during isovolumic systole but may allow more late ejection contribution by the border zone than a less malleable Dacron patch.

With these thoughts in mind, I would like to ask Dr. Dor whether he prefers the autologous patch technique over synthetic patch material and whether there is anything to be gained in regard to optimizing border zone contribution, especially in the area of the septum, by closing the border zones over the top of the patch. Finally, what are the most important technical aspects of the repair in regard to optimal recovery of ventricular function?

Dr. Dor. Dr. Pasque, I congratulate you for this interesting experimental work with radiofrequency tissue tagging. As soon as your manuscript is printed, we will mention it in our list of references.

I think that improvement of contraction of the remote segment is due to the circular reorganization or restriction of the opening of the collar at the mouth of the aneurysm. This can be achieved by external reduction as in the Jatene technique or by internal reduction as with the patch.

The second reason for improvement of this border zone is the exclusion of all akinetic areas by the patch inside the ventricle. Insertion of the patch inside the ventricle is the only way to achieve complete reorganization, probably because of endoventricular patch repair with septal exclusion, which is the type of operation we described 10 years ago.

Dr. Denton A. Cooley (*Houston, Tex.*). Although a few reports of repair of postinfarction aneurysm were available before the availability of cardiopulmonary bypass, since the middle 1950s surgeons have been increasingly aggressive. The earliest repairs followed the methods used in repair of sacciform aneurysms of the aorta with a linear or tangential repair of the ventricular incision. With availability of synthetic or biologic prostheses, repairs have been performed in a more anatomic and physiologic manner.

In their original reports, Dor and Jatene described techniques that provide better functional results and a more complete repair. In my opinion their techniques are somewhat complex and subject to certain disadvantages, on which I will not elaborate. At about the time of their reports, I devised a simpler and I believe more satisfactory technique of intracavitary repair or endoaneurysmorrhaphy.

After the aneurysm is opened, a transition zone between scarred and normal myocardium is identified and the estimated defect is restored with a patch of Dacron fabric or pericardium. This does not disturb the external configuration of the heart surface in any way.

Dr. Dor has shown the effect on LV ejection fraction by the sculptured repair, revealing what has been known since the earliest reports 40 years ago, namely, that the more extensive the lesion, the more impressive the results physiologically.

A more difficult task has been to compare the now popular contoured repair with the old conventional techniques. Among the 296 patients in my experience with

intracavitary repair, results in EF in 67 patients were compared with those in 103 patients with conventional linear repair. The mean increase in EF in the current cases was 13% and in the conventional repairs 8%, not a very significant or striking improvement or difference.

Nevertheless, the contoured repairs are logically more effective in restoring the geometry of the ventricular cavity and increasing the surgeon's ability to restore ventricular function in the diffusely involved ventricle, sometimes obviating cardiac transplantation. Similar techniques are useful for postinfarction ventricular septal defects.

Dr. Dor, have you modified the technique of repair from your original report?

Dr. Dor. Dr. Cooley, we are aware of all of your pioneering activity in the 1950s for the treatment of such aneurysms, and your publications are mentioned in all bibliographies. We were happy to see that in 1989 you used a technique with a patch inside the ventricle, similar to the technique we presented in 1985. The small difference consists in the attitude toward the excluded area, simply sutured or resected.

We have no basic modification of the technique described in 1989, apart from one change. Following the advice of Francis Fontan, we use a continuous suture inside the LV after resection of the endocardial scar when it is diseased or at the limit of the diseased scar, so that the cavity is restricted. With this continuous suture (in the Jatene technique this suture is passed externally), the patch can be sized easily. The patch is tailored to the dimension obtained after this continuous suture is tied.

Dr. Lynda L. Mickleborough (*Toronto, Ontario, Canada*). I would like to give Dr. Dor full credit for having the most extensive and comprehensive hemodynamic assessment of patients after ventricular aneurysm resection. He has demonstrated not only that symptoms are improved after aneurysm resection, but that LV function is improved and that the long-term outlook regarding ventricular arrhythmias is probably favorably affected by the intervention.

We and many other groups have shown similar results with LV aneurysm repair. In our previously reported series, in which we used a modified linear repair technique in patients with an average EF of 27%, the operative mortality was 3%. Survival at 5 years was 8%. No deaths resulting from arrhythmias occurred in this series.

I have several questions for Dr. Dor. First, what was the operative mortality in the entire series, not in just the selected patients presented in this report?

Second, can you explain how you determined which patients require septal cryoablation and scar excision, which is thought to influence long-term survival as far as arrhythmias are concerned? Is your decision based on preoperative electrophysiologic studies or preoperative symptoms?

Finally, how do you determine in patients with akinesia (not dyskinesia) who is going to benefit from this kind of procedure versus those who would benefit from revascularization of hyperbating myocardium? Do you rely on thallium or positron emission tomographic scanning? Do

you depend on judgment at the time of the intervention—looking at the heart, assessing thickness of the wall? How do you decide whether to resect an akinetic area or to revascularize it?

Dr. Dor. Thank you, Dr. Mickleborough. The overall mortality of the global series of 600 cases, including patients with myocardial rupture, acute infarct, and EF below 15%, is 7.4%. This mortality is higher than 15% for severe or emergency cases and lower than 1.5% for standard cases.

We do not use cryoablation. We use cryotherapy on the edge of the endocardium to complete the resection when there is a spontaneous or inducible VT.

Regarding the limited akinetic septal areas, positron emission tomography is not available, but we do use thallium scanning before the operation in the majority of cases. Perioperative checking is important. We make sure that we do not increase the operative risk by excluding this scar in such patients. Inasmuch as we now have 1-year and 5-year follow-up data on many patients, I can state that it is safe and beneficial to exclude this area during coronary revascularization.

Dr. Robert Replogle (*Chicago, Ill.*). My views on aneurysm resection were tempered by Dr. Cooley's pioneering work in the 1950s. As the years went by, it became clear to me that the clinical improvement in aneurysm resection was well documented but the functional improvement was not. I kind of stopped my thinking in 1980 when Dr. Doty presented a prospective study of 15 patients in whom there was excellent improvement in clinical activity and no improvement in ventricular function after aneurysm resection.

When I became aware of Dr. Dor's work and his impressive results in functional activity were reported, I used a technique that I have employed over the years: I went to the source to see it with my own eyes. Frequently we find that the difference between the published and the real results may be occasionally, on at least a daily basis, not true. So I went to Monaco to watch Dr. Dor do these operations, and I was stunned by the improvement in the patients after the operations. I observed them for a few weeks and was also impressed by Dr. Dor's compulsive comprehensive study of these patients.

Some of the improvement in the functional activity comes from the environment to which his patients are exposed. The delights of Monaco are widely known. But Dr. Dor's meticulous technique and care deserve most of the credit.

Dr. Dor, with the volume reduction culture that is now upon us, have you tried to actively reduce LV volume beyond that of the scar? Do you use a smaller patch to reduce volume or do you simply follow the outlines of the ventricle as evidenced by the scar?

Dr. Dor. Thank you, Dr. Replogle, for your comments about our activity. I cannot answer your last question, because we have never tried volume reduction of a dyskinetic heart. And we would need more information about the patient with regard to contraction of the septum, pulmonary pressure, and end-diastolic pressure.