# Predictors of Improved Left Ventricular Systolic Function After Surgical Revascularization in Patients With Ischemic Cardiomyopathy

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Introduction and objectives. Although it is known that the presence of myocardial viability predicts an increase in ejection fraction after revascularization in patients with ischemic cardiomyopathy, little is known about other predictive factors. The aim of this study was to identify variables that can predict an increase in ejection fraction after coronary revascularization surgery in patients with ischemic cardiomyopathy and a viable myocardium.

**Methods.** The study included 30 patients (mean age, 61.6 [11] years, 1 female) with ischemic cardiomyopathy (ejection fraction  $\leq$ 40%) who fulfilled criteria for myocardial viability. All underwent ECG-gated single-photon emission computed tomography before and after surgery.

**Results.** An increase in ejection fraction  $\geq$ 5% occurred after surgery in 17 of the 30 patients (56.6%). These patients were characterized by the presence of left main coronary artery disease (*P*<.004), a large number of grafts (*P*<.03), a high perfusion summed difference score (*P*<.012), a low end-diastolic volume (*P*<.013), and a low end-systolic volume (*P*<.01). An end-systolic volume <148 mL and a summed difference score  $\geq$ 4 gave the best predictive model (*P*=.001, *R*<sup>2</sup>=0.73) for an increase in ejection fraction.

**Conclusions.** In patients with ischemic cardiomyopathy and a viable myocardium, the main determinants of an increase in ejection fraction after revascularization surgery were low levels of left ventricular remodeling and myocardial ischemia.

**Key words:** *Surgery. Scintigraphy. Cardiomyopathy. Remodeling. Hibernation.* 

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# Variables predictoras de mejoría de la función sistólica ventricular izquierda después de la cirugía de revascularización coronaria en pacientes con miocardiopatía isquémica

Introducción y objetivos. Aunque se sabe que la presencia de viabilidad miocárdica es predictora de mejoría de la fracción de eyección poscirugía de revascularización en los pacientes con miocardiopatía isquémica, es menos conocido si hay otros factores predictores. El objetivo de este estudio ha sido analizar las variables predictoras de mejoría de la fracción de eyección después de la revascularización coronaria quirúrgica en los pacientes con miocardiopatía isquémica y presencia de miocardio viable.

**Métodos.** Se estudió a 30 pacientes (edad media, 61,6  $\pm$  11 años, una mujer), con miocardiopatía isquémica (fracción de eyección  $\leq$  40%) y criterios de viabilidad, mediante tomografía computarizada por emisión de fotón único sincronizada con el electrocardiograma, antes y después de la cirugía.

**Resultados.** En 17 de los 30 pacientes (56,6%) hubo un aumento  $\geq$  5% de la fracción de eyección poscirugía. Estos pacientes se caracterizaron por tener más enfermedad del tronco común (p < 0,004), mayor número de injertos (p < 0,03), mayor suma diferencial de puntuación perfusión (p < 0,012), menor volumen telediastólico (p < 0,013) y menor volumen telesistólico (p < 0,01). El mejor modelo predictor (p = 0,001; R<sup>2</sup> = 0,73) del aumento de la fracción de eyección poscirugía  $\geq$  5% fue un volumen telesistólico < 148 ml y una suma diferencial de puntuación de perfusión  $\geq$  4.

**Conclusiones.** El menor remodelado ventricular izquierdo y la isquemia miocárdica en los pacientes con miocardiopatía isquémica y viabilidad miocárdica son los principales determinantes en la mejoría de la fracción de eyección poscirugía revascularizadora.

Palabras clave: Cirugía. Gammagrafía. Miocardiopatía. Remodelado. Hibernación.

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## ABBREVIATIONS

EDV: end-diastolic volume EF: ejection fraction ESV: end-systolic volume ICM: ischemic cardiomyopathy SDS: summed difference score SPECT: single-photon emission computed tomography

# INTRODUCTION

An improvement in the ejection fraction (EF) is observed in 21% to 65% of the patients with ischemic heart disease after undergoing a coronary revascularization procedure.<sup>1-8</sup> The presence of myocardial viability is one of the predictive factors of this improvement.9-12 Although some studies have demonstrated that ischemia and ventricular remodeling can also play an important role,<sup>13-16</sup> when all the clinical, ergometric, scintigraphic, coronary angiographic, and surgical parameters are assessed together in patients with ischemic cardiomyopathy (ICM), it is not sufficiently clear which are the major predictors of improvement in left ventricular systolic function following surgery. For this reason, the authors undertook this study, which involved the use of gated myocardial perfusion single-photon emission computed tomography (gated SPECT) as a noninvasive technique that enables the evaluation of the perfusion and left ventricular systolic function before and after myocardial revascularization.

# **METHODS**

# Patients

We performed a retrospective, observational study involving individuals with ICM (EF of 40% or less) who were referred to the Nuclear Cardiology Unit of Hospital Universitario Vall d'Hebron over a 6-year period for risk stratification, on the basis of the criteria of the attending cardiologist. There had been no selection process. Among this population of patients with ICM, we analyzed all the viable patients who had undergone gated SPECT before and after coronary revascularization (n=30).

The study included 30 patients (mean age plus or minus the standard deviation [SD]: 61.6 [11] years; 1 woman) with an EF of 40% or less in whom myocardial viability was detected in gated SPECT carried out before and after (more than 2 months) coronary revascularization surgery. The mean interval between the gated SPECT study and coronary revascularization was 2.8 (2) months and the mean interval between revascularization and postoperative gated SPECT was 20.2 (13) months. None of the patients developed cardiovascular complications during the period between the 2 SPECT studies. For the present report, this population was divided into 2 groups: patients with an increase in EF of 5% or greater following surgery (n=17) and patients in whom the EF did not increase (n=13).

We compared the clinical and ergometric features, the gated SPECT and coronary angiographic findings, and the surgical protocol in the patients with and without an increase of 5% or more in the EF following surgery.

# **Gated Myocardial Perfusion SPECT**

Preoperative gated SPECT was performed at rest in 11 patients, whereas 19 patients underwent stress-rest SPECT. The latter group of patients also underwent symptom-limited cycle ergometry at an initial load of 50 watts, with successive 25-watt increments every 3 minutes until exhaustion, the onset of symptoms, ST segment depression greater than or equal to 2 mm, the development of ventricular or supraventricular arrhythmias, and the absence of an increase in systemic arterial pressure. The duration of the test, maximum oxygen consumption estimated in metabolic equivalents (MET), maximum heart rate, percentage of the predicted maximum heart rate for the age of the patient (220 minus age) attained, peak systolic arterial pressure (SAP), the maximum heart rate-peak SAP product, angina, and a downsloping or upsloping of the ST segment greater than or equal to 1 mm, 0.08 seconds after the J point were assessed.

In these patients, gated SPECT was performed according to a short (1-day) protocol with technetiumlabeled compounds (methoxyisobutyl isonitrile or tetrofosmin). The first dose of 8 mCi was administered 30 to 60 seconds before the end of the stress portion of the test and the second, of 24 mCi, during the resting study, with an interval of more than 45 minutes between the 2. A Siemens E. CAM 90-degree dual head gamma camera equipped with a high-resolution collimator, with a semicircular rotation of 180°, was employed in "stepand-shoot" mode, starting in 45° right anterior oblique projection, with acquisitions every 3 degrees (25 seconds per frame). The acquisition was synchronized with the R wave of the electrocardiogram, and the cardiac cycle was divided into 8 phases. The reconstruction system utilized involved filtered back-projection (fifth-order Butterworth filter with a cutoff frequency of 0.4). Corrections for attenuation and dispersion were not carried out.

Ventricle was divided into 17 segments and, for the assessment of the perfusion and wall thickening, a score of 0 to IV was assigned (perfusion: 0 = normal perfusion, I = slight hypoperfusion, II = moderate hypoperfusion, III = severe hypoperfusion, and IV = absence of uptake; wall thickening: 0 = normal, I = slight decrease, II = moderate decrease, III = severe decrease, and IV = absence). The summed rest score, the summed stress score and the summed difference score (SDS) were

calculated, as was the summed wall thickening score at rest.<sup>17-19</sup>

All the patients fulfilled the criteria for viability accepted in our Nuclear Cardiology Unit for rest gated SPECT: less than 3 myocardial segments with perfusion and/or wall thickening scores of III-IV in regions with akinesia or dyskinesia.<sup>20</sup> A patient was considered to present exercise-induced ischemia when gamma scintigraphy revealed a SDS greater than or equal to II in 2 or more myocardial segments.

The calculation of the EF and ventricular volumes was performed automatically in rest gated SPECT by means of the automatic delineation of the endocardial and epicardial borders using the quantitative QGS® software package (Cedars-Sinai Medical Center, Los Angeles, CA).<sup>21</sup>

# **Coronary Angiography**

Coronary angiography was performed using 1 of the 2 Philips systems, Optimus M200 (biplane) or Integris (monoplane). A field of view of 17.8 cm was employed in every case. In agreement with routine practice in our center, coronary stenosis was assessed visually by the examiner, who then discussed the findings with another interventional cardiologist in order to reach an agreement on the status of the patient. Significant coronary artery disease was considered to be present when coronary stenosis was greater than 50%, and multivessel disease when there was a significant lesion in left main coronary artery or significant lesions in 2 or 3 vessels.<sup>22</sup>

## **Coronary Revascularization Surgery**

Coronary revascularization was performed with hypothermia (31°C) and a cardioplegic solution with a hematocrit value of 32% in every case. The use of cardiopulmonary bypass, the number of aortocoronary bypass grafts, the ischemia time, the total operative time, complete revascularization in relation to the coronary anatomy, and the postoperative complications were assessed.

#### **Statistical Analysis**

All the continuous variables were expressed as the mean plus or minus the standard deviation (SD) and all the categorical variables were expressed as percentages. The continuous variables were compared using unpaired Student's *t* test. The differences between the percentages were compared by means of the  $\chi^2$  test; when the number of expected values was less than 5, Fisher's exact test was employed. The optimal cutoff value for the qualitative variables related to the postoperative EF that were found to be significant in univariate analysis was determined by means of the analysis of the receiver operating characteristic (ROC) curves. Logistic regression analysis

was utilized to calculate the odds ratio (OR) for the values shown to be significant in univariate analysis, categorized according to the cutoff value obtained in the ROC curves. To estimate the different models, the variables found to be significant (P<.05) in the univariate analysis were included, and the method employed was backward stepwise logistic regression, with probabilities of entry and removal of 0.05 and 0.10, respectively. For the choice of the final model, the sensitivity, specificity, percentage of correct classifications, and the area under the ROC curve for each was assessed.

For the linear regression analysis, the independent variables employed, with the exception of the left main coronary artery lesion, were qualitative. The significance of the effect of the end-systolic volume (ESV) on the postoperative EF was adjusted for the end-diastolic volume (EDV), the left main coronary artery lesion, the number of bypass grafts, and the SDS. In addition, the linear and quadratic components were analyzed by means of the generation of dummy variables with the coefficients of the corresponding orthogonal polynomials, introduced into the regression equation. A *P*-value less than .05 was considered significant. All the data were analyzed using the SPSS version 13.0 (SPSS Inc, Chicago, IL) and Medcalc® statistical software packages for Windows.

#### RESULTS

#### Clinical, Angiographic, and Surgical Variables

Prior to surgery, there were no significant differences between the patients with and without an increase in EF of 5% or more following coronary revascularization in terms of the clinical variables. The involvement of the left main coronary artery was greater among the patients with an increase in EF (P=.004). The number of coronary bypass grafts per patient was also greater in this group of patients (P=.03) (Table 1).

#### Gated Myocardial Perfusion SPECT

In patients with an increased EF following revascularization, the EDV and ESV were significantly smaller (Table 2). Using the ROC curves (Figure 1), cutoff values for the preoperative EDV, ESV, and SDS that best enabled the prediction of a postoperative improvement in the EF were obtained. The optimal cutoff value for the ESV was 148 mL (area under the ROC curve [AUC], 0.73; 95% confidence interval [CI], 0.53-0.87), with a sensitivity of 94.1% (95% CI, 79-99.4), a specificity of 53.8% (95% CI, 34.8-72.1), a positive predictive value of 72.7%, a negative predictive value of 87.5%, and a diagnostic efficacy of 76.6%. The optimal cutoff value for the EDV was 190 mL (AUC, 0.73; 95% CI, 0.54-0.88), with a sensitivity of 70.5% (95% CI, 51.2-85.7), a specificity of 69.2% (95% CI, 49.8-84.6), a positive predictive value of 75%, a negative predictive

# TABLE 1. Characteristics of the Patients Who Experienced an Improvement in the Ejection Fraction ≥5% Following Surgery and Those Who Did Not

| Clinical Variables                     | Patients Without ↑<br>EF≥5% (n=13) | Patients with ↑<br>EF≥5% (n=17) | Р    |
|--|------------------------------------|---------------------------------|------|
| Age, mean (SD), years                  | 58 (13.7)                          | 63 (9.5)                        | .325 |
| Hypertension, n (%)                    | 3 (23.1%)                          | 9 (52.9%)                       | .141 |
| Diabetes, n (%)                        | 4 (30.8%)                          | 4 (23.5%)                       | .698 |
| Dyslipidemia, n (%)                    | 8 (69.2%)                          | 8 (47.1%)                       | .936 |
| Smoking habit, n (%)                   | 9 (69.2%)                          | 12 (70.6%)                      | .936 |
| Prior myocardial infarction, n (%)     | 12 (92.3%)                         | 12 (76%)                        | .196 |
| NYHA functional class, n (%)           | 6 (46.2%)                          | 4 (23.5%)                       | .255 |
| I                                      | 0                                  | 0                               |      |
| II                                     | 1                                  | 3                               |      |
| III                                    | 1                                  | 1                               |      |
| IV                                     | 4                                  | 0                               |      |
| Angina (CCS), n (%)                    | 6 (46.2%)                          | 10 (58.8%)                      | .491 |
| I                                      | 0                                  | 0                               |      |
| II                                     | 2                                  | 4                               |      |
| III                                    | 2                                  | 2                               |      |
| IV                                     | 2                                  | 4                               |      |
| Coronary angiography, n (%)            |                                    |                                 |      |
| 1 vessel                               | 2 (15.4%)                          | 1 (5.9%)                        | .565 |
| 2 vessels                              | 3 (23.1%)                          | 2 (11.8%)                       | .628 |
| 3 vessels                              | 8 (61.5%)                          | 14 (82.4%)                      | .242 |
| Anterior descending, n (%)             | 13 (100%)                          | 16 (94.1%)                      | .374 |
| Circumflex, n (%)                      | 8 (67.5%)                          | 14 (82.4%)                      | .242 |
| Right coronary, n (%)                  | 11 (84.6%)                         | 15 (88.2%)                      | .773 |
| Left main coronary, n (%)              | 0                                  | 8 (47.1%)                       | .004 |
| Patients with occluded arteries, n (%) | 8 (61.5%)                          | 7 (41.2%)                       | .269 |
| Occluded arteries/patient, mean (SD),  | n 1.25 (0.46)                      | 1.28 (0.48)                     | .882 |
| Stenoses ≥50%/patient, mean (SD), n    | 2.4 (0.7)                          | 2.7 (0.5)                       | .225 |
| Surgery                                |                                    |                                 |      |
| Without CPB, n (%)                     | 4 (30.7%)                          | 7 (41.1%)                       | .708 |
| Grafts/patient, mean (SD), n           | 2.1 (1.1)                          | 3 (0.8)                         | .03  |
| Ischemia time, mean (SD), min          | 49 (19)                            | 53 (16)                         | .726 |
| Operative time, mean (SD), min         | 92.3 (27)                          | 98.2 (21)                       | .640 |
| Complete revascularization, n (%)      | 8 (61.5%)                          | 13 (76.5%)                      | .376 |

CCS indicates Canadian Cardiovascular Society; CPB, cardiopulmonary bypass; EF, ejection fraction; NYHA, New York Heart Association; SD, standard deviation.

value of 64%, and a diagnostic efficacy of 70%. The optimal cutoff value for the SDS was 4 (AUC, 0.79; 95% CI, 0.59-0.99), with a sensitivity of 88.8% (95% CI, 66-98), a specificity of 60% (95% CI, 35.4-81.3), a positive predictive value of 64.2%, a negative predictive value of 100%, and a diagnostic efficacy of 73.6%.

Among the 19 patients who underwent a stress test, no statistically significant differences were observed between those who experienced a postoperative increase in the EF and those who did not in terms of the ergometric variables. The SDS was significantly higher in the patients with a postoperative improvement in the EF (Table 3).

## **Regression Analysis**

In the logistic regression analysis, the OR of the significant qualitative variables, categorized according to the cutoff value of the ROC curves was: ESV greater than 148 mL, OR=12 (95% CI, 1.9-76; P=.009); EDV greater than 190 mL, OR=5.4 (95% CI, 1.1-26; P=.036); and SDS greater than or equal to 4, OR=1.7 (95% CI, 1.7-2.6; *P*=.04). For left main coronary artery stenosis, the OR was 9.8 (95% CI, 1.1-7.2; P=.024), and for the number of bypass grafts, it was 2.4 (95% CI, 1.1-5,7; P=.041). The best predictive model ( $\chi^2=15.004$ ; P=.001; Nagelkerke's  $R^2 = 0.73$ ) for an increase in the EF $\geq 5\%$ following surgery consisted of an ESV of less than 148 mL and an SDS ≥4 (-23 932+3466×ESV<148+22 546  $\times$ SDS $\geq$ 4), with a specificity, sensitivity, and percentage of correct classification of 90%, 88%, and 89.5%, respectively. The predictive power of this model, assessed by means of the area under the ROC curve, was acceptable (AUC=0.92; 95% CI, 0.79-1; P=.002). In the multivariate analysis, the most significant variable was an ESV of less than 148 mL (OR=32; 95% CI, 1.6-65; P=.025).

In the linear regression analysis, the association of the adjusted ESV was more significant ( $\beta$ =-0.66; *P*=.003;

. . ..

| ABLA 2. Characteristics of Resting Gated SPECT in the Patients who Experienced an Improvement in the |  |
|--|--|
| Ejection Fraction ≥5% Following Surgery and Those Who Did Not  |  |
|  |  |

|  | Patients Without $\uparrow$ EF $\ge$ 5% (n=13) | Patients With ↑EF≥5% (n=17) | Р    |
|--|--|-----------------------------|------|
| Gated SPECT  |  |                             |      |
| STSR, mean (SD)                                    | 17.3 (7.6)                                     | 16.6 (9.9)                  | .844 |
| Segments with a thickening score of IV, mean (SD)  | 7.2 (6)  | 7.6 (6)                     | .918 |
| EF, mean (SD), %                                   | 28 (6.4)                                       | 31 (6.8)                    | .234 |
| ESV, mean (SD), mL                                 | 147.6 (51.2)                                   | 105.5 (37.7)                | .01  |
| EDV, mean (SD), mL                                 | 202.6 (57.7)                                   | 149.5 (50.8)                | .013 |
| SV, mean (SD), mL                                  | 54.9 (14.5)                                    | 44 (20)                     | .113 |
| Perfusion  |  |                             |      |
| SRS, mean (SD)                                     | 22.2 (8.3)                                     | 21 (10.6)                   | .733 |
| Necrotic myocardium, mean (SD), %                  | 9.2 (5.7)                                      | 14.2 (6.6)                  | .155 |
| Segments with grade III-IV perfusion, mean (SD), n | 26.6 (14.7)                                    | 22.8 (18)                   | .549 |

EF indicates ejection fraction; EDV, end-diastolic volume; ESV, end-systolic volume; SD, standard deviation; SRS, summed rest score; STSR, summed thickening score at rest; SV, stroke volume.

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Figure 1. Optimal cutoff values in the receiver operating characteristic (ROC) curves for (A) the end-systolic volume (ESV), (B) the end-diastolic volume (EDV), and (C) the summed difference score (SDS) for stress and resting perfusion.

95% CI, -1.1 to -0.27) than that of the EDV (β=-0.38; P=.02; 95% CI, -0.072 to -0.69). The left main coronary artery lesion was significant (β=14; P=.036; 95% CI, 1.14-28.6), whereas no significance was observed in the number of bypass grafts (β=-1.89; P=.37; 95% CI, -6.28 to 2.5) or in the SDS (β=-0.527; P=.423; 95% CI, -0.851 to 1.9).



As the ventricular volumes increase, the probability of a significant improvement in the EF following surgery is reduced, whereas an increment in the SDS increases the probability of a significant improvement in the postoperative EF (Figure 2). In the analysis of the linear relationship ( $\beta$ =-10.115; P=.001) and quadratic relationship ( $\beta$ =-1897; P=.184) (Figure 3A), a significant linear trend was observed between the different preoperative ESV values (grade 1: <101 mL; grade 2: 101-147 mL; grade 3 >147 mL) and the postoperative EF: as the ESV increased the EF decreased. In Figure 3B, the y-axis corresponds to the increase in the EF (postoperative EF minus the preoperative EF), and it shows that 80% of the patients with an ESV less than 148 mL presented an increase in the postoperative EF. However, not only did 85.7% of the patients with an ESV ≥148 mL exhibit no increase, in 66.6% of them, a decrease was observed.

There were no significant differences between the preoperative EF in the patients with and without a significant increase in the postoperative EF (P=.234; 95% CI, -2 to 8).

When compared with the patients with a preopereative ESV of less than 101 mL, those having an ESV between 101 and 148 mL exhibited a postoperative decrease in EF of 4.5%, which was not statistically significant (*P*=.0001; 95% CI, -14% to 5.1%). In contrast, when compared with the patients with a preoperative ESV of less than 148 mL, those with an ESV  $\geq$ 148 presented a highly significant postoperative decrease in EF of 20.3% (*P*=.0001; 95% CI, -29.6% to 10.9%).



**Figure 2.** Relationship between the probability of improvement in the ejection fraction (EF) >5% following surgery and (A) the preoperative end-systolic volume (ESV), (B) the preoperative end-diastolic volume (EDV), and (C) the preoperative summed difference score (SDS) for stress and resting perfusion. Light-colored lines: 95% confidence intervals.

# DISCUSSION

The improvement in left ventricular systolic function after myocardial revascularization depends not only on the surgical procedure (surgical skills, complete revascularization, cardiopulmonary bypass, ischemia time, type of myocardial protection) and the possible postoperative complications, but on the state of the coronary tree and the myocardial viability as well.



In studies involving cardiac catheterization,<sup>13</sup> echocardiography,<sup>14-16,23,23</sup> equilibrium radionuclide ventriculography,<sup>5,25</sup> SPECT,<sup>23,26,27</sup> positron emission computed tomography (PET),<sup>28,29</sup> and magnetic resonance,<sup>30,31</sup> a number of variables that predict an improvement in left ventricular function have been described. These include the presence of myocardial viability or myocardial ischemia, and early coronary revascularization.<sup>28,29,32</sup>

However, in patients with ICM and evidence of viability, in whom, in general, myocardial revascularization has been found to improve the prognosis, little is known about the factors that predict the improvement of ventricular function.

The purpose of this study was to analyze the clinical, ergometric, angiographic, and surgical variables, as well as those associated with gated SPECT (ischemia and left ventricular remodeling), that may be predictive of improved left ventricular systolic function following surgical revascularization in patients with ICM who meet criteria for myocardial viability.

# **Myocardial Ischemia**

In our study, patients with an increase in EF $\geq$ 5% following surgery were characterized by a higher prevalence of left main coronary artery disease and greater ischemic burden according to the scintigraphic study prior to surgery. The number of aortocoronary bypass grafts per patient was also significantly higher in this group of patients, and myocardial perfusion SPECT demonstrated that a SDS $\geq$ 4 was predictive of an improvement in left ventricular EF. Employing <sup>201</sup>TI–SPECT and gated magnetic resonance in 21 patients

|                                   | Patients Without $\uparrow$ EF≥5% (n=8) | Patients With $\uparrow$ EF≥5% (n=11) | Р    |
|-----------------------------------|---|---------------------------------------|------|
| Stress test                       |   |                                       |      |
| MET, mean (SD)                    | 5.4 (1.9)                               | 5.6 (0.7)                             | .565 |
| HR max, mean (SD), beats/min      | 123.8 (22)                              | 125.6 (15)                            | .628 |
| SAP max, mean (SD), mm Hg         | 146 (16)                                | 147.3 (13)                            | .242 |
| HR max × SAP max, mean (SD)       | 17 981 (5400)                           | 18 562 (5600)                         | .225 |
| Increase in HR, mean (SD), %      | 76.1 (17)                               | 79.2 (8.7)                            | .374 |
| Duration (minimum)                | 5.9 (2.5)                               | 5.8 (2.4)                             | .242 |
| Watts, mean (SD)                  | 69 (26)                                 | 73.4 (15.7)                           | .773 |
| ST ↓ >1 mm, n (%)                 | 6 (50%)                                 | 7 (41.2%)                             | .98  |
| Angina, n (%)                     | 5 (38.5%)                               | 2 (11.7%)                             | .303 |
| Perfusion                         |   |                                       |      |
| SSS, mean (SD)                    | 26.1 (9.3)                              | 23.6 (7.5)                            | .545 |
| SDS, mean (SD)                    | 3.7 (3)                                 | 7.4 (2.6)                             | .012 |
| Ischemic myocardium, mean (SD), % | 30.8 (13.2)                             | 35.2 (16.9)                           | .571 |

| TABLE 3. | <b>Characteristics of Stress</b> | <b>SPECT in the Patients</b> | Who Experienced | an Improvement in | n the Ejection |
|----------|----------------------------------|------------------------------|-----------------|-------------------|----------------|
| Fraction | ≥5% Following Surgery an         | d Those Who Did Not          |                 |                   |                |

EF indicates ejection fraction; HR, heart rate; MET, metabolic equivalents; SAP, systolic arterial pressure; SDS, summed difference score; SSS, summed stress score.

with an EF <46%, Kitsiou et al<sup>26</sup> observed that the presence of reversible stress-induced defects in asynergic regions was predictive of an improvement in left ventricular systolic function.

# **Ventricular Volumes**

The variable with the highest predictive value for an improved EF in multivariate analysis was the presence of an ESV <148 mL. This finding had not been reported in studies involving gated SPECT with MIBI or tetrafosmin. This predictive cutoff value for ESV is comparable to that found by Schinkel et al.<sup>16</sup> Using radionuclide ventriculography and dobutamine





Figure 3. A: analysis of the linear and quadratic relationship between the different grades of preoperative end-systolic volume (ESV) (1: <101 mL; 2: 101-147 mL; 3: >147 mL) and the postoperative ejection fraction (EF). Although a slight, nonuniform increase is observed, the linear trend was significant. B: relationship between the preoperative ESV and postoperative EF. The y-axis corresponds to the difference between the preoperative and postoperative EF.

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echocardiography, these authors studied 118 patients with ischemic cardiomyopathy, observing that the number of viable segments and an ESV <140 mL were predictive of an improvement in ventricular function. For Yamaguchi et al,<sup>13</sup> the variable that was related to a significant increase in the EF was an ESV index <100 mL/m<sup>2</sup>. Based on SPECT with <sup>18</sup>F-fluorodeoxyglucose and echocardiography performed before and after coronary revascularization. Bax et al<sup>23</sup> also identified the ESV as the only parameter that differed significantly between patients who experienced an increase in the EF ≥5% and those who did not. The greater the preoperative ESV, the lower the probability of improvement.

Following myocardial infarction, especially when it is extensive and transmural, changes are produced in both the infarcted and noninfarcted tissue, with a modification of the ventricular architecture that constitutes the so-called myocardial remodeling. The myocardium of the infarcted region expands and, secondarily, timedependent changes take place in the noninfarcted areas, with an increase in the volumes and stretching of the myocardial fibers. Despite this compensatory mechanism involving left ventricular dilation, heart failure can worsen and survival can be compromised.<sup>33</sup> Pasquet et al<sup>14</sup> studied 66 patients using <sup>82</sup>Rb-dipyridamole, <sup>18</sup>F-fluorodeoxyglucose PET, and echocardiogram with low-dose dobutamine plus atropine, observing that less than 5% of the patients with an EDV>220 mL presented an increase in EF. Although there may be ischemia and/or myocardial viability in different segments of the left ventricle, in many cases, coronary revascularization alone is probably not sufficient to significantly improve left ventricular function in those patients with extensive remodeling of left ventricle.

# Limitations of the Study

The number of patients in our series is small (and the number of patients who underwent a stress test is even smaller) and the study is retrospective, potentially leading to a certain bias in patient selection. Moreover, due to the small number of patients, the differences found to be statistically nonsignificant may actually be significant. Nevertheless, there is a high degree of clinical homogeneity, both before and after surgery, between the patients in whom the EF improved and those in whom it did not once revascularization had been carried out. It could also be pointed out that gated SPECT with technetium-labeled compounds is not the optimal technique for the determination of myocardial viability in these patients. However, its correlation with other techniques, such as PET, echocardiography with lowdose dobutamine and magnetic resonance, is good and it is the approach routinely employed in our hospital for this purpose during the period of patient enrollment. The time interval between revascularization and the subsequent determination of the EF is a factor that should be taken into account, given that if the evaluation takes place very

early, there may be a certain degree of myocardial stunning, which leads to the underestimation of the EF.<sup>11</sup> Although the minimum interval in our study was 2 months, the number of patients with improved EF may have been greater if the gated SPECT had been performed at a later date.<sup>11,34</sup>

# **CONCLUSIONS**

In patients with ICM who fulfill the criteria for myocardial viability, a less extensive left ventricular remodeling and myocardial ischemia are the major determinants of improvement in the EF following surgical revascularization.

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