SURGERY

Trends in Coronary Artery Bypass Surgery: Changing Type of Surgical Patient

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Introduction and objectives. In the last few years, the percentage of high-risk patients proceeding to coronary artery bypass surgery has increased. The most common risk factors are older age and the presence of comorbid complaints. We carried out a retrospective study to confirm this new risk profile and to evaluate its impact on surgical results.

Patients and method. We analyzed the changing risk profile of 1360 patients who underwent coronary artery bypass surgery in our hospital between 1993 and 2001, divided into three historical cohorts: 1993-1996, 1997-1999, and 2000-2001. The main factors associated with morbidity and mortality were analyzed by logistic regression analysis. The introduction of new operative techniques, such as off-pump surgery and arterial grafting, was also evaluated.

Results. The patients' risk profile worsened over time: patients were older, comorbid complaints were more common, and ventricular function was poorer. EuroSCORE figures reflected this trend: estimated mortality in the three historical cohorts was 2.0%, 4.0%, and 4.2%, respectively (P<.001). However, risk-adjusted mortality, at 3.7%, 2.7%, and 1.5%, respectively, decreased (P<.05), and combined overall morbidity and mortality remained stable, at 16.7%, 16.4%, and 13.8%, respectively (P<.39). There was a nonsignificant tendency for arterial grafting and off-pump surgery to reduce in-hospital morbidity and mortality.

Conclusions. The risk profile of patients undergoing surgery has worsened as their mean age has increased and as comorbid complaints have become more prevalent. However, there has been no simultaneous increase in risk-adjusted mortality. The potential benefits of new surgical advances such as off-pump surgery and multiple arterial grafting must be corroborated by future studies.

Key words: *Surgery. Morbidity. Mortality. Revascularization.*

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Tendencias en cirugía coronaria: cambios en el perfil del paciente quirúrgico

Introducción y objetivos. En los últimos años se ha producido un aumento del riesgo en los pacientes en los que se realiza una derivación coronaria. La mayor edad y comorbilidad son las causas involucradas con más frecuencia. Se ha realizado un estudio retrospectivo para constatar este nuevo perfil y valorar su impacto.

Pacientes y método. Se ha analizado la tendencia de riesgo de 1.360 pacientes en los que se realizó una derivación coronaria consecutivamente entre 1993 y 2001 en nuestro centro. Se han considerado 3 cohortes históricas: en los años 1993-1996, 1997-1999 y 2000-2001. Se ha estudiado la morbimortalidad y sus principales factores asociados mediante un análisis de regresión logística. Se ha valorado la influencia de nuevas técnicas, como la revascularización con injertos arteriales o la cirugía sin circulación extracorpórea.

Resultados. Se ha constatado un riesgo quirúrgico creciente: mayor edad, mayor frecuencia de morbilidad asociada y peor función ventricular. El EuroSCORE ha ratificado esta tendencia (el 2,0, el 4,0 y el 4,2% de mortalidad estimada en las cohortes respectivas; p < 0,001). Pese a ello, la mortalidad ajustada al riesgo ha descendido (el 3,7, el 2,7 y el 1,5%; p < 0,05) y la morbimortalidad global se ha mantenido (el 16,7, el 16,4 y el 13,8%; p = 0,39). El empleo de injertos arteriales y la cirugía sin circulación extracorpórea han mostrado una tendencia hacia una menor morbimortalidad hospitalaria.

Conclusiones. Ha empeorado el riesgo quirúrgico de los pacientes coronarios debido a una mayor edad y comorbilidad. Pese a ello, no se ha producido un aumento de la mortalidad ajustada al riesgo. El probable efecto beneficioso de la cirugía sin circulación extracorpórea y el empleo de injertos arteriales debe ser corroborado por futuros estudios.

Palabras clave: *Cirugía. Morbilidad. Mortalidad. Revascularización.*

ABBREVIATIONS

CABG: coronary artery bypass graft.
COPD: chronic obstructive pulmonary disease.
CVA: cerebrovascular accident.
ECC: extracorporeal circulation
IABP: intra-aortic ballon pump.

INTRODUCTION

Over the last decade, improvements in medical and interventional treatments have changed the basic profile of the subgroup of patients needing surgery for ischemic heart disease. Given the presence of severe disease and multiple prior procedures, treating these patients is usually complicated. Moreover, patients today are older and have more comorbid complaints. As a result, operative risk has risen over the years. As early as the 1980s some studies reported the surprising finding that operative mortality did not rise despite the increase in surgical risk.[1,2] More recent studies have also shown a decrease in mortality rates, despite the trend towards a worsening risk profile.[3,4] Furthermore, surgical outcomes in older patients are usually encouraging, notwithstanding the high-risk inherent to this population.[5-8]

Cardiac surgery has also improved over the years. Some examples of this progress include improved perioperative management and myocardial protection, minimally invasive surgery, off-pump coronary artery bypass surgery (that is, with the heart beating and without recurring to extracorporeal circulation [ECC]), and multiple arterial grafting. As a result, the combined morbidity and mortality rate has remained unchanged—despite the higher risk. Moreover, optimization of patient management through the use of surgical risk assessment scales has become widespread.[9]

Given this context, the objective of our study was to describe the general trend of coronary artery bypass surgery over the last 9 years and to assess the impact and extent of the worsening risk-profile of our patients. We also analyzed the impact of new technical advances.

PATIENTS AND METHODS

Patients Included in the Study

We retrospectively evaluated 1360 consecutive patients who underwent myocardial revascularization at our hospital between May 1993 and July 2001. Patients who underwent related procedures, such as valvular surgery or ventricular aneurysm resection were excluded. Off-pump bypass surgery and the use of multiple arterial grafting, however, were included because these techniques were introduced during the study period and were deemed likely to affect the results.

Surgical Technique

Patients who underwent coronary artery bypass graft surgery (CABG) with ECC received standard treatment: median sternotomy, cannulation of the ascending aorta, and right atrium, and cold blood antegrade-retrograde cardioplegia to achieve moderate hypothermia (28° to 32°C). After each distal anastomosis, cardioplegia was performed through the saphenous vein grafts. Controlled reperfusion with warm blood cardioplegia (*hot shot*) was performed before removing the aortic cross-clamp.

The left internal mammary artery was used for single grafts to the anterior descending coronary artery. In cases requiring multiple arterial grafts, the right mammary artery and radial artery were used for grafts to the circumflex artery. Revascularization with multiple arterial grafts has become more common, especially since 1998, when we began to use the radial artery on a systematic basis. Prior to this time, the predominant arterial revascularization technique was double mammary arterial grafting.

We have been using off-pump CABG since 1997, steadily increasing its use to current levels (around 30%). It was used selectively in high risk patients and the Octopus II stabilizer system (Medtronic Inc., Minneapolis, MN, USA) was used in most cases.

Statistical Analysis

The preoperative, surgical, and postoperative clinical data for all patients were collected prospectively and exported to the SPSS 10.0 Statistical Software Package (SPSS; Chicago, IL, USA) for later analysis. This was a retrospective study, with the patients divided into 3 successive historical cohorts: 1993-1996, 1997-1999, and 2000-2001, with 281, 523, and 556 patients, respectively. Risk factors were assessed, and the EuroSCORE[9] system was used to determine operative risk (Table 1). Findings analyzed included hospital mortality and postoperative complications. Continuous variables were expressed as means± standard deviation calculated for each variable. Categorical variables were expressed as frequencies or proportions. The continuous variables were compared using one-way analysis of variance (ANOVA) for the 3 cohorts. The χ^2 test or Fisher exact test, as appropriate, was used to analyze the categorical variables. The functional degree of dyspnea (New York Heart Association [NYHA] classification) and angina (Canadian Heart Association [CHA] classification) were collected as dichotomous continuous and categorical variables

TABLE 1. **EuroSCORE Variables***

		Score
Patient-related variables		
Age	Per 5 years or part thereof over 60 years	1
Sex	Female	1
COPD	Long-term use of bronchodilators or steroids for lung disease	1
Extracardiac arteriopathy	Any one or more of the following: claudication, carotid occlusion or >50% stenosis, previous or planned intervention on the abdominal aorta, limb arteries or carotids	2
Neurological dysfunction	Disease severely affecting ambulation or day-to-day functioning	2
Previous cardiac surgery	Requiring opening of the pericardium	3
Serum creatinine	>200 µL/L preoperatively	2
Active endocarditis	Patient still under antibiotic treatment for endocarditis at the time of surgery	3
Critical preoperative state any	One or more of the following: ventricular tachycardia or fibrillation or aborted sudden death, preoperative cardiac massage, preoperative assisted ventilation before arrival in the an esthetic room, preoperative inotropic support, intraaortic balloon counterpulsation, or preoperative acute renal failure (anuria or oliguria <10 mL/h)	3
Cardiac-related variables		
Unstable angina	Rest angina requiring intravenous nitrates until arrival in the surgery room	2
Left Ventricular dysfunction	Moderate: EF, 30%-50%	1
	Severe: EF<30%	3
Recent myocardial infarction	(<90 days)	2
Pulmonary hypertension	Systolic PA pressure >60 mm Hg	2
Operation-related variables		
Emergency	Carried out on referral before the beginning of the next working day	2
Other than isolated CABG	Major cardiac procedure other than or in addition to CABG	2
Surgery on thoracic aorta	For disorder of ascending, arch or descending aorta	3
Post-AMI septal rupture		4

*COPD indicates chronic obstructive pulmonary disease; EF, ejection fraction; CABG, coronary artery bypass graft surgery; AMI, acute myocardial infarction.

(NYHA I-II compared to III-IV and CHA I-II compared to III-IV). The ejection fraction (EF) was considered both a continuous and categorical variable and EF values less than 35% were considered indicative of severe systolic dysfunction.

A forward selection stepwise logistic regression analysis was applied to determine the independent predictors of hospital mortality and combined morbidity-mortality. A univariate model, with $P \leq .10$, was first used to assess the variables. Criteria for entering or removing variables in the stepwise model was set at $P<.05$ and $P \geq .10$, respectively. To assess the independent effect of each study period on mortality, the study periods were broken down into their component dummy variables, which were coded as indicator variables, with the latest study period as the reference category (the categories corresponding to the first and second periods are shown in the model). Likewise, the EuroSCORE was used to adjust for severity of disease in a separate mortality model (the final model was adjusted for the study period and EuroSCORE). The discriminatory power of this final model was evaluated by using the area under the receiver operating characteristic curve (ROC or C statistic), which estimates the model's ability to correctly classify deceased or living patients. This was then compared to the C statistic obtained for the EuroSCORE (Figure). The Hosmer-Lemeshow goodness of fit test was used to measure calibration between all of the models and the degree of agreement between predicted and observed mortality.

To determine if changes in surgical technique influenced mortality and combined mortality-morbidity, the variables "multiple arterial grafts" and "off-pump surgery" were entered into the respective models.

The expected mortality rate (E) for each period was calculated from the first mortality model by applying the following formula:

$$\text{Expected mortality rate (\%)}=100/1+e^{-X}$$

where X is the result of the equation formed by the regression coefficients (β) and the values of each independent variable (x_i) in the model, such that:

$$X=\beta_0+\beta_1 x_1+\ldots+\beta_n x_n$$

The method used to calculate risk-adjusted mortality was similar to that used by Abromov et al[3]: observed mortality (O) was divided by expected mortality (E) to obtain the O/E ratio for each period. Risk-adjusted mortality for each cohort was obtained by multiplying overall observed mortality by the O/E ratio specific to each period.

Definitions

– Hospital mortality: death occurring during hospitalization or within the first 30 postoperative days.

– Hospital morbidity and mortality: occurrence of any of the following events in the time interval described above (death, myocardial infarction, low cardiac output, acute renal failure, acute cerebrovascular accident [CVA], pneumonia, mediastinitis, or sepsis).

– Emergency myocardial revascularization surgery: surgery performed while patient is hospitalized for acute coronary syndrome.

– Prophylactic insertion of an intra-aortic balloon pump (IABP) in patients with an EF<40% before initiating cardiopulmonary bypass as a preventative measure against acute ventricular failure after cardiopulmonary bypass and low postoperative cardiac output.

– Post-cardiopulmonary bypass IABP: IABP insertion after ECC or during interruption maneuvers, used to treat acute ventricular failure after cardiopulmonary bypass or low postoperative cardiac output.

– Low postoperative cardiac output: the need for inotropic medical or mechanical support for more than 48 hours after surgery, or persistence of a cardiac index of <2 mL/min/m^2 during the first 48 hours.

– Postoperative acute renal failure: postoperative increase in levels of serum creatinine >2 mg/dL or the need for any method of artificial renal support.

Definitions for the main risk factors evaluated are shown in the Appendix.

RESULTS

Trends in Preoperative Characteristics

The study included 1360 patients who underwent CABG. Table 2 shows the trends for the demographic and clinical characteristics over the 9-year period. The mean patient age increased significantly, as did the number of patients over age 70. The percentage of women in each cohort also rose over time, which is consistent with the changing distribution by sex that occurs as the population ages. The following associated comorbid processes and risk factors were more common in later cohorts: hypertension, type 1 diabetes mellitus, chronic obstructive pulmonary disease (COPD), and peripheral artery disease (Table 2). The functional degree of dyspnea (NYHA classification) and angina (CHA classification) worsened significantly, and the percentage of emergency cases also increased significantly, while the mean EF—which is inversely related to these factors—decreased over time. Given this higher risk, expected mortality, as determined by the EuroSCORE, increased significantly, especially between the first and second cohorts (Table 3).

Surgical Technique

The use of 2 or more arterial grafts increased in the third cohort, accounting for more than 40% of the interventions, compared to just 5.4% in the first cohort (Table 3). This difference may be due to our increased use of the radial artery. We began to use off-pump surgery in the second study period, although its use only became common—in percentage terms (up to 30%)—in the third period. Off-pump CABG was used selectively—not systematically—in higher-risk patients as well as those who would be better off without ECC.

The number of coronary artery bypasses per patient also increased, especially the number of patients with multiple (5 or 6) arterial grafts (Table 3). The mean aortic cross-clamp time, which was longer in the second and third cohorts, reflected this trend and was consistent with the increase in distal anastomoses. The overall duration of cardiopulmonary bypass, however, showed no difference. The number of patients with 3-vessel coronary artery disease with involvement of the left main coronary artery increased; as a result, the number of patients with 2-vessel disease decreased (Table 3). The surgical technique for 1-vessel disease remained unchanged, despite the growing use of percutaneous procedures.

Surgical Morbidity and Mortality

We observed no increase in the overall rate of surgical morbidity. The incidence of perioperative acute myocardial infarction (AMI), acute renal failure, cerebrovascular accident (CVA), mediastinitis, and prolonged ventilation (>48 hours) was similar in the 3 cohorts. The rate of postoperative low cardiac output syndrome decreased, as did the length of hospital stays. However, the rate of postoperative atrial fibrillation and—especially in the second cohort—reoperation due to bleeding both increased (Table 3).

The overall mortality rate for the entire group was 2.7%, which increased slightly over the course of the study, especially in the second cohort. The respective mortality rates were, by cohort, 2.1%, 3.3%, and 2.5% (P=.60) (Table 4). The main predictors of mortality are shown in Table 5. The addition of the EuroSCORE as a variable in the mortality model was significant (Table 5c). The variable "study period," whose compo-

TABLE 2. **Preoperative Variables for Each Period***

Variable	1993-1995 (n=281)	1996-1998 (n=523)	1999-2001 (n=556)	*P*
Mean ±SD age, years	60.8±9.1	62.8±9.2	63.5±9.3	.0001
Age >70 years, n (%)	40±14.2	113±21.6	141±25.4	.001
Female, n (%)	50±17.8	104±19.9	118±21.2	.50
Hypertension, n (%)	97±34.5	239±45.7	271±48.7	.0001
Type 1 DM, n (%)	16±5.7	35±6.7	63±11.3	.004
COPD, n (%)	15±5.3	75±14.3	74±13.3	.001
CRF, n (%)	6±2.1	17±3.3	21±3.8	.44
Prior CVA, n (%)	10±3.6	21±4.0	36±6.5	.08
Peripheral vascular disease, n (%)	11±3.9	47±9.0	66 ±11.9	.001
Prior AMI, n (%)	144±51.2	266±50.9	305±54.9	.37
Recent AMI, <90 days, n (%)	21±7.5	48±9.2	85±15.3	<.0001
Prior AF, n (%)	5±1.8	15±2.9	12±2.2	.57
Reoperation, n (%)	5±1.8	11±2.1	14±2.5	.77
Emergency, n (%)	42±14.9	71±13.6	120±21.6	.001
NYHA III-IV, n (%)	39±13.8	109±20.8	150 ±27.0	.0001
Angina (CHA), mean ±SD	2.6±0.5	2.7±0.4	3.0±0.6	<.0001
CHA III-IV, n (%)	171±60.9	363±69.4	426±76.6	<.0001
EF, mean±SD	57.42±12.7	55.8±14.1	53.53±12.8	.0001
EF=30%-50%, n (%)	75±26.7	162±33.8	176±34.5	.06
EF<35%, n (%)	19±6.8	47±9.0	52±9.4	.43
EF<30%, n (%)	9±3.2	24±4.6	29±5.2	.419

*CVA indicates cerebrovascular accident; COPD, chronic obstructive pulmonary disease, DM, diabetes mellitus; CRF, chronic renal failure; EF, ejection fraction; AF, atrial fibrillation; AMI, acute myocardial infarction; CHA, Canadian Heart Association; SD, standard deviation.

TABLE 3. **Surgical and Postsurgical Variables for Each Study Period***

Variable	1993-1995 (n=281)	1996-1998 (n=523)	1999-2001 (n=556)	*P*
Surgical variables				
EuroSCORE, mean ±SD	2.0±1.8	4.0±2.0	4.2±2.1	.0001
LMCA disease, n (%)	41±14.6	115±22.0	145±26.1	.001
No. of vessels involved, n (%)				.002
3	152±54.0	345±66.0	356±64.0	
2	93±33	133±254	128±23	
1	36±13	45±8.6	72±13	
No. of grafts/patient, mean ±SD	2.5±0.8	2.9±0.9	2.9±1.1	.0001
Fifth bypass, n (%)	1±0.4	21±4.1	41±7.4	.0001
Sixth bypass, n (%)	0	2±0.4	3±0.5	.47
Two or more arterial grafts, n (%)	15±5.3	71±13.6	241±43.3	.0001
Off-pump surgery, n (%)	0	15±2.9	177±31.8	.0001
ECC duration, mean ±SD (min)	125±42	130±43	136±46	.35
Isquemia time, mean ±SD (min)	54±20	75±30	80±31	.0001
Postoperative variables				
Low cardiac output, n (%)	20±7.1	25±4.8	12±2.2	.002
Prophylactic IABP, n (%)	1±0.4	22±4.1	21±3.8	.01
Post-ECC IABP, n (%)	1±0.4	19±3.6	21±3.8	.014
Perioperative AMI, n (%)	1±0.4	4±0.8	4±0.7	.77
Perioperative CVA, n (%)	5±1.8	8+1.5	9±1.6	.96
Acute renal failure, n (%)	10±3.6	24±4.6	37±6.7	.11
Mediastinitis, n (%)	4±1.4	9±1.7	5±0.9	.49
Atrial fibrillation, n (%)	13±4.6	67±12.8	79±14.2	.0001
Reoperation due to bleeding, n (%)	5±1.8	18±3.4	12±2.2	.26
Prolonged ventilation†, n (%)	6±2.1	12±2.3	13±2.3	.98
Length of hospital stay, days, mean ±SD	12.4±8.5	11.6±7.8	10.3±7.4	.0001

*CVA indicates cerebrovascular accident; ECC, extracorporeal circulation; IABP, intraoperative balloon counterpulsation; LMCA, left main coronary artery; SD, standard deviation; AMI, acute myocardial infarction.
†Artificial ventilation >48 hours.

TABLE 4. **Hospital Morbidity and Mortality in Each Period of the Study**

Variable	1993-1995	1996-1998	1999-2001	*P*	P, Linear Trend
Morbidity and Mortality*	16.7%	16.4%	13.8%	.39	
Mortality					
Observed (O)	2.1%	3.3%	2.5%	.60	
Expected (E)†	1.5%	3.3%	4.2%	.003	.001
O/E ratio	1.4	1	.59		
Adjusted‡	3.7	2.7	1.59	.01	.001

*Ocurrence of one or more of these events: death, acute myocardial infarction, low cardiac output, acute renal failure, cerebrovascular accident, pneumonia, mediastinitis, or sepsis.
†Expected mortality in each period estimated with the mortality model calculated in this study (Table 5a).
‡Risk-adjusted mortality=overall observed mortality (2.7%)xO/E ratio.

nents are broken down into dummy variables (the categories corresponding to the first and second periods are shown), nearly reached statistical significance in this last model.

Overall morbidity and mortality decreased slightly (Table 4) and the variables associated with this phenomenon are shown in Table 6. In this model, EuroSCORE was not significant although the variable "study period" was.

The use of multiple arterial grafts showed a protective effect when entered into the mortality model (regression coefficient with a negative β, Table 7), al-

TABLE 5. **Predictors of Hospital Mortality***

Variable	Coefficient β	OR	95% CI	*P*
Unadjusted mortality model†				
CRF	2.15	8.62	1.53-48.33	.014
EF<35%	2.03	7.62	3.05-19.02	.0001
NYHA III-IV	1.94	6.98	2.55-19.12	.0001
Peripheral vascular disease	1.84	6.35	2.60-15.50	.0001
Age >75 years	1.32	3.77	1.18-12.07	.025
Emergency	1.13	3.10	1.30-7.40	.011
Mortality model adjusted for the variable "study period"‡				
CRF	2.24	9.48	1.62-55.31	.012
EF<35%	1.86	6.46	2.52-16.52	.0001
NYHA III-IV	2.24	9.42	3.16-28.05	.0001
Peripheral vascular disease	2.04	7.71	3.01-19.69	.0001
Age >75 years	1.42	4.14	1.29-13.28	.017
Emergency	1.14	3.14	1.29-7.64	.012
Study period$				
1	1.37	3.94	1.07-14.57	.039
2	0.86	2.37	0.89-6.31	.083
*Mortality model adjusted for the variables "study period" and "Euroscore"*II				
CRF	2.82	16.89	2.58-110.33	.003
EF<35%	2.05	7.81	2.71-22.50	.0001
NYHA III-IV	2.35	10.52	3.36-32.92	.0001
Peripheral vascular disease	2.70	14.99	4.70-47.77	.0001
Age >75 years	2.42	11.32	2.56-49.98	.001
Emergency	1.86	6.46	2.15-19.39	.001
Study perioπ				
1	1.31	3.71	0.92-14.90	.064
2	1.00	2.71	0.94-7.83	.064
EuroSCORE	–0.37	0.68	0.50-0.93	.018

*CRF indicates chronic renal failure; EF, ejection fraction; OR, odds ratio; NYHA, New York Heart Association;CI, confidence interval.
†Hosmer-Lemeshow Goodness of Fit Test: χ^2=4.17, df=3, *P*=.244.
‡Hosmer-Lemeshow Goodness of Fit Test: χ^{22}=3.38, df=6, *P*=.760.
$Study period with component dummy variables: period 1, 1993-1995; period 2, 1996-1998; reference category: latest period, 1999-2001.
IIHosmer-Lemeshow Goodness of Fit Test: χ^2=4.58, df=8, *P*=.801.
πStudy period with component dummy variables: period 1, 1993-1995; period 2, 1996-1998; reference category: latest period, 1999-2001.

TABLE 6. **Predictors of Hospital Morbidity and Mortality***

Variable	Coefficient β	OR	95% CI	*P*
Model adjusted for "study period" and "EuroSCORE" variables				
CRF	1.68	5.38	2.02-14.29	.001
EE<35%	1.49	4.44	2.60-7.58	.0001
Peripheral vascular disease	0.61	1.84	1.01-3.35	.046
NYHA III-IV	0.74	2.09	1.32-3.31	.001
Age >70 years	0.44	1.56	0.91-2.68	.102
Emergency	0.20	1.22	0.70-2.12	.468
Study Period‡				
1	0.92	2.52	1.50-4.24	.0001
2	0.56	1.76	1.12-2.75	.013
EuroSCORE	0.06	1.07	0.92-1.23	.359

*OR indicates odds ratio; CI, confidence interval; CRF, chronic renal failure; EF, ejection fraction.
†Hosmer-Lemeshow Goodness of Fit Test: χ^2=5.946, df=8, *P*=.653.
‡Study period with component dummy variables: period 1, 1993-1995; period 2, 1996-1998; reference category: latest period, 1999-2001.

TABLE 7. **Effect of Arterial Grafts and Off-Pump Surgery on Hospital Mortality***

Variable	Coefficient β	OR	95% CI	*P*
CRF	3.00	20.27	2.88-142.62	.002
EF<35%	2.35	10.53	3.40-32.66	.0001
NYHA III-IV	2.29	9.95	3.08-32.06	.0001
Peripheral vascular disease	2.77	16.02	4.89-52.48	.0001
Age >75 years	2.27	9.73	2.21-42.77	.003
Emergency	1.81	6.14	1.97-19.12	.002
Study period‡				
1	1.68	5.36	0.87-32.76	.069
2	1.53	4.64	0.99-21.69	.051
EuroSCORE	–0.47	0.62	0.44.-0.87	.005
Arterial grafts	–1.69	0.18	0.01-2.06	.169
Off–pump surgery	1.49	4.45	0.81-24.36	.085

*OR indicates odds ratio; CI, confidence interval; ECC, extracorporeal circulation; CRF, chronic renal failure; EF, ejection fraction.
†Hosmer-Lemeshow Goodness of Fit Test: χ^2=7.558, df=8, *P*=.478.
‡Study period with component dummy variables: period 1, 1993-1995; period 2,1996-1998; reference category: latest period, 1999-2001.

though this effect was only marginally significant. The use of off-pump surgery resulted in less hospital morbidity and mortality (Table 8). The selective use of off-pump surgery in high-risk patients with a higher EuroSCORE (5.1 [2.3] vs 2.5 [1.9]; *P*<.001), and higher expected mortality rate in the study period model (6.3 [2.8] vs 2.7 [0.7]; *P*<.001) revealed a selection bias that should be taken into account. The mean age (65.9 [10.3] vs 62.1 [9.0] years; *P*<.001), prevalence of unstable angina (CHA class III-IV, 78.1% vs 69.3%; *P*=.01), and heart failure rate (NYHA class III-IV, 35.5% vs 21.2%; *P*<.05) were all higher for patients undergoing off-pump CABG. Comorbidity was also higher for these patients; in particular, the prevalence of peripheral vascular disease (17.2% vs 7.8%; *P*<.001), prior CVA (8.9% compared to 4.3%; *P*<.01), and COPD (18.2% vs 11.0%; *P*<.01) were all higher. As a result, the observed mortality rate for these patients was higher than those who underwent bypass surgery with ECC (4.7% vs to 2.4%; *P*=.06), although it should be noted that the observed mortality rate never exceeded the group's expected mortality rate. The overall rate of morbidity and mortality for these 2 subgroups, however, was similar (15.1% vs to 15.5%; *P*=.88). However, in 1 high-risk subgroup (EuroSCORE ≥6; n=140), the off-pump group had a lower incidence of combined morbidity-mortality (25.4% vs to 32.1%; *P*=.39).

Predicted and Risk-Adjusted Mortality

The worsening risk profile of patients in each successive cohort was clearly evident as the expected mortality rate—as determined by the EuroSCORE (Table 3)—rose; this phenomenon was especially evident in the expected mortality rate calculated by the study period model (Table 4). Interestingly, despite the worsening patient risk profile, risk-adjusted mortality actually decreased over time because expected mortality increased more than observed mortality for each

TABLE 8. **Effect Arterial Grafts and Off-Pump Surgery on Hospital Morbidity and Mortality***,†

Variable	Coefficient β	OR	95% CI	*P*
CRF	1.68	5.38	2.02-14.33	.001
EF<35%	1.46	4.33	2.53-7.43	.0001
Peripheral vascular disease	0.61	1.85	1.01-3.37	.045
NYHA III-IV	0.76	2.15	1.3-3.41	.001
Age >70 years	0.46	1.59	0.92-2.73	.092
Emergency	0.20	1.22	0.70-2.11	.475
Study period‡				
1	0.85	2.35	1.28-4.32	.006
2	0.48	1.63	0.96-2.75	.068
EuroSCORE	0.07	1.07	0.93-1.24	.321
Arterial grafts	0.01	1.01	0.56-1.84	.950
Off-pump surgery	–0.23	0.79	0.41-1.53	.494

*OR indicates odds ratio; CI, confidence interval; ECC, extracorporeal circulation; CRF, chronic renal failure; EF, ejection fraction.
†Hosmer-Lemeshow Goodness of Fit Test: χ^2=10.499, df=8, *P*=.232.
‡Study period with component dummy variables: period 1, 1993-1995; period 2,1996-1998; reference category: latest period, 1999-2001.

successive cohort (Table 4). As a result, the significant linear increase in expected mortality was accompanied by a corresponding significant linear decrease in risk-adjusted mortality. This inverse relationship was apparent in the mortality model after adjusting for the study period and EuroSCORE variables: the mortality rate in the first and second cohorts was higher than in the third (Table 5c). The negative regression coefficient (β) for the EuroSCORE variable shows how expected mortality and observed mortality move in opposite directions after adjustment.

DISCUSSION

The elderly population currently represents the most common type of cardiology patient in daily clinical practice.[10,11] The western population is becoming progressively older, a phenomenon that is especially marked in Spain, where the population pyramid is likely to become inverted within the next 50 years. As the population ages, the presence of comorbid processes increases, changes occur in patient distribution by sex, life-threatening complications become more common, and there are structural and functional changes associated with the aging process.[10]

Many factors—including an aging population and increasing rates of ischemic heart disease combined with higher rates of comorbidity—have had a direct impact on the profile of patients undergoing CABG. These factors, together with advances in interventional cardiology, have led to the current situation: patients with more complex and extensive coronary artery disease, poorer ventricular function, and, in many cases, more prior multiple revascularization procedures.

Given this context, the widespread use of surgical risk assessment scales (EuroSCORE[9]) is more necessary than ever, and new techniques need to be developed to achieve acceptable results. Fortunately, surprisingly favorable results have been reported. The Favaloro Foundation, describing their experience with coronary artery revascularization in patients 75 years of age or older, reported findings that were quite acceptable.[12] Other studies have identified a clear trend towards lower mortality rates after CABG. O'Connor et al[13] found that the death rate after CABG decreased from 4.5% to 3.6% between 1987 and 1993. Ghali et al[14] reported a decrease in observed mortality rates from 4.7% to 3.3% between 1990 and 1994, with a 42% decrease in the risk-adjusted mortality rate over the same period (from 5.7% to 3.0%). Other studies have also shown a clear benefit from CABG in older patients[15,16] although none has focused on analyzing the possible causes of this trend. However, a recent study[3] has shown that advances in surgical techniques have played an important role in the progressive decrease in morbidity and mortality.

We observed an increase in risk from 1993 to 2001. The mean age and number of patients over age 70 increased, as did the incidence of comorbid processes, especially hypertension, type 1 diabetes mellitus, COPD, and peripheral arterial disease. The EuroSCORE reflected this worsening risk profile, with higher mean predicted mortality rates in recent years. Independent predictors of hospital mortality and combined morbidity-mortality included age, EF, a higher level of functional impairment (NYHA classification), chronic renal failure (CRF), the presence of peripheral arterial disease, and emergency surgery. In the study by Abramov et al,[3] the factors associated with mortality were very similar: emergency surgery, EF<35%, CRF, peripheral vascular disease, and age >70 years. If we compare these results with those of the CASS study—one of the key studies underlying the clinical practice guidelines for coronary artery bypass graft surgery published by the ACC/AHA (American College of Cardiology/American Heart Association) (1991)—"cardiac" variables, such as left main coronary artery disease and degree of angina, have lost their predictive ability for mortality.[17] "Extracardiac" factors, such as peripheral vascular disease, CRF, and COPD have emerged as new predictors of morbidity and mortality; in fact, this finding has been confirmed by other important studies (Grover et al[18]).

In our study, the overall mortality rate (2.7%) could be considered low, although it was consistent with rates found by other studies.[3,12] The mortality rate increased slightly over time in the 3 successive cohorts in our study, especially in the second one, although this was not statistically significant (Table 4). Preoperative risk, as measured by external risk models (EuroSCORE), may be over- or underestimated because the variables evaluated may not include all of the real factors in a specific case. The EuroSCORE corresponded quite well to the mortality risk as estimated by our model; the discriminatory power of the EuroSCORE was good, although not quite as good as our model (Figure). As we have mentioned previously, the expected mortality rate showed a progressive increase over time as the patient risk profile worsened. Although we cannot confirm an increase in observed mortality on the basis of our results, we can conclude that, when adjusted for risk, there was a significant and linear decrease in observed mortality. In fact, after adjusting for the EuroSCORE in the mortality model, we can conclude that the probability of mortality was higher during the first and second periods compared to the third, with a statistical significance level close to 5% (Table 5c). In the combined morbidity and mortality model, EuroSCORE was not significant a significant variable, although study period was, especially for the first cohort. Therefore, although the observed morbidity-mortality rate showed no significant decrease in the successive cohorts (Table 4), after adjusting this model for the EuroSCORE, we can also confirm that the probability of morbidity-mortality was higher in the earlier cohorts (Table 6).

The significant increase in predicted mortality —which doubled in the last cohort—was accompanied by a risk-adjusted hospital mortality rate that decreased (by as much as 57%) in each period. This occurred because the increase in expected mortality exceeded that of observed mortality. Abramov et al[3] reported a similar finding. In our patients, the increase in observed mortality was especially evident in the second cohort. One possible explanation for this could be the learning curve required to master the new techniques (off-pump CABG and multiple arterial grafts), whose use increased dramatically in this period.

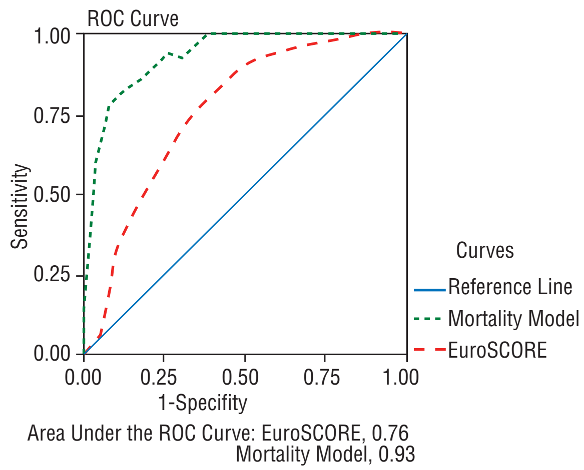

Figure. ROC Curves for EuroSCORE and the Study Mortality Model.

The use of multiple arterial grafts tended, over time, to produce lower hospital mortality rates (negative regression coefficient β; Table 7), although this trend was not significant. Kurlansky et al[19] found that the use of arterial grafts compared to vein grafts alone for revascularization in older patients led to a decrease in hospital mortality while enhancing long-term quality of life; this effect has been confirmed by many studies. In fact, the use of the internal mammary artery in CABG has been the standard technique since the 1980s because it offers better patency and a higher survival rate. Abramov et al[3] showed that the left internal mammary artery had a clear protective effect on both hospital mortality and morbidity. The use of multiple arterial grafts was also a significant variable (P=.0001) in their combined morbidity and mortality model, although its significance decreased (P=.062) in a separate model evaluating operative mortality alone. Given the retrospective character of the study and the probable selection bias, we can only hypothesize about the probable beneficial effect of multiple arterial grafts. It is still not clear if this technique improves early survival, although, in terms of survival, we should mention the preliminary results of CARACASS (Complete Arterial and Conventional Coronary Artery Surgery Study). This randomized prospective study in being carried out in Europe with the participation of Spanish hospitals (European Association for Cardiothoracic Surgery, Congresses, 2002-2003). The study is comparing 2 groups of patients with 3-vessel coronary artery disease. The first group includes patients with at least 1 arterial graft (especially to the anterior descending artery) and whose other grafts are venous. The second group has only arterial grafts. No significant differences in hospital mortality have been found, although the incidence of hemorrhage (P=.08) and postoperative infections (*P*=.056) was higher in the arterial group, while the incidence of CVA was higher in the mixed graft group. The arterial grafts showed better early patency (30 days), especially for the left internal mammary artery.

The systematic use of the radial artery in bypass surgery has allowed us to use arterial grafts more often. The radial artery is easy to harvest and manage; in addition, due to the lack of serious complications, it can be used routinely. Contraindications include a lack of adequate collateral blood flow from the ulnar artery (identified by positive preoperative Allen test or perioperative pulse oximetry), and atheromatous involvement of the radial artery. The use of the radial artery has coincided with an increase in the number bypasses and distal anastomoses and, consequently, with an increase in aortic cross-clamp time. However, we have not noted a proportional increase in cardiopulmonary bypass time. This may be due to the use of bifurcating grafts (Y- or T-grafts of the mammary or radial arteries). These types of grafts allow for fewer anastomoses involving the aorta and they reduce the total duration of cardiopulmonary bypass.

Multivariate statistical analysis showed no significant beneficial effect for the off-pump procedure on morbidity-mortality. Off-pump surgery was used especially for high-risk patients; even so, observed mortality was always less than expected mortality. In a previous review of our experience, improvement in hospital mortality could not be confirmed, although we did identify a trend towards less morbidity and a significant reduction in transfusion and hospitalization time.[20] Many studies have shown that off-pump CABG improves results: there is less morbidity, less expense, and even a decrease in hospital mortality. Mack et al[21] found an approximately 1% decrease in mortality for the period 1996-2000 compared to 1990-1995,[21] and the emergence of off-pump CABG during the second period was an important factor in that result.

In terms of myocardial protection, standard cardioplegia showed no relevant variations during the study. The use of prophylactic IABP, however, was more common in later periods, even though the protective effect of this technique was not significant either. Prophylactic IABP was indicated in patients with poor ventricular function (EF≤40%). The mean EF was moderately lower in more recent years, although the rate of severely diminished contractility (EF<30%) was largely unchanged. Nevertheless, the use of prophylactic IABP increased greatly, perhaps, in part, because the surgical team viewed the technique more favorably given technical advances and the ease of insertion of the new devices. Other factors may have also favored its use: the increase in emergency surgery, more severe angina, and the rise in the number of patients undergoing surgery after a recent heart attack. Emergency procedures have become much more common in recent years as angina has become more severe. Likewise, the growing social pressure caused by longer waiting lists may have resulted in a more aggressive surgical policy towards unstable patients, although these observations are pure speculation.

Finally, we cannot omit the probable effect of other important factors, such as the progressive increase in the number of interventions and the higher rate of complete revascularization (more grafts per patient) on the results. Undoubtedly, the surgical team has acquired more experience as a result of the increased volume of patients undergoing surgery in each successive cohort and this has likely led to higher quality interventions and, consequently, better results.

Limitations of this study include its retrospective design and the fact that it was carried out at a single hospital. Moreover, selection bias may have been present in the different cohorts given the extended time period encompassed by the study. The theoretical criteria for surgical indications were based on the successive clinical practice guidelines for coronary artery disease surgery published by the Spanish Society of Cardiology. While these guidelines were not substantially modified during the study, their practical application may well have varied over time, as did patient risk profiles and the level of experience of the surgical team. Increased demand and the publication of satisfactory surgical results for octogenarians and other high-risk patients may have made surgery more acceptable for these types of patients.

CONCLUSION

Operative risk has increased significantly in patients undergoing CABG in recent years. This phenomenon is the consequence of an aging population and an increase in comorbidity. Nevertheless, risk-adjusted mortality has not increased. The "new profile" patients will likely continue to benefit from current trends in bypass surgery, especially the emergence of promising new techniques such as multiple arterial grafting and off-pump surgery.

APPENDIX. **Definitions of Risk Factors**

COPD (chronic obstructive pulmonary disease): prior diagnosis of chronic lung disease with prolonged used of bronchodilators or steroids, or spirometry indicative of moderate or severe obstruction.

CRF (chronic renal failure): preoperative serum creatinine >2 mg/dL in at least 2 tests.

Peripheral vascular disease: one or more of the following: intermittent claudication, carotid involvement (occlusion or stenosis >50%), previous or planned vascular surgery of the abdominal aorta, lower limb arteries, or carotid arteries.

Prior CVA: transient CVA (or Transient Ischemic Attack) was assessed, as were CVAs whose sequelae included neurological impairment.

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