Coronary Artery Bypass Surgery Using the Mini-Extracorporeal Circulation System: A Spanish Unit's Experience

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Introduction and objectives. The increasing use of percutaneous interventions has resulted in a significant reduction in coronary artery bypass grafting. Today, patients referred for surgery are older, have more comorbidities, and have undergone previous percutaneous intervention, and their ventricular function is poorer. As a result, surgery has attempted to improve its results by adopting a number of different strategies. The aim of this study was to investigate and describe one cardiac surgery unit's initial experience with coronary artery bypass grafting using mini-extracorporeal circulation (MECC), which had become its technique of choice.

Methods. A retrospective analysis of 408 patients who underwent isolated coronary artery bypass grafting using MECC between January 2004 and April 2007 was carried out. Of the 408, 329 (80.6%) were men, their mean age was 63.5 years (28-83 years), 63% had hypertension, 49.3% had diabetes, 69% had hyperlipidemia, and 52% were smokers.

Results. The surgical mortality rate predicted by the logistic EuroSCORE was 3.7% (range, 1-38). Overall, 34% of patients had left main coronary artery disease and 87% had 3-vessel disease. In 74%, complete revascularization was carried out using a mean of 2.97 (range, 1-7) grafts per patient. A mammary artery graft was used in all cases. The in-hospital mortality rate was 0.74%. There were few postoperative complications: 0.98% of patients required further surgery because of bleeding, 3.4% had a significantly elevated troponin-I level, 6.4% developed kidney failure, and 0.5% suffered a stroke.

Conclusions. Coronary artery bypass grafting using MECC enabled complete revascularization to be performed in most patients, and morbidity and mortality rates were low.

Key words: *Mini-extracorporeal circulation. Cardiac surgery. Mortality. Morbidity.*

Cirugía coronaria con mini-circulación extracorpórea: experiencia de un grupo en España

Introducción y objetivos. El incremento del intervencionismo percutáneo ha conllevado una disminución significativa de la cirugía coronaria. El perfil del paciente coronario que se remite a cirugía es más añoso, con mayor comorbilidad, peor función ventricular y con procedimientos percutáneos previos. En este sentido la cirugía ha intentado mejorar sus resultados desde varios frentes de actuación. El objetivo es analizar y describir la experiencia inicial de la cirugía coronaria con mini-circulación extracorpórea (MCEC) en un grupo de cirugía cardiaca en el que se ha convertido en técnica de elección.

Métodos. Entre enero de 2004 y abril de 2007, se analizó de forma retrospectiva a 408 pacientes sometidos a cirugía coronaria aislada con MCEC, 329 (80,6%) varones, con media (intervalo) de edad de 63,5 (28-83) años. Un 63% tenía hipertensión; el 49,3%, diabetes; el 69%, dislipemia, y el 52% eran fumadores.

Resultados. El EuroSCORE logístico (mortalidad esperada) era del 3,7% (1-38%). El 34% de los pacientes tenía afección del tronco común y el 87%, enfermedad de 3 vasos. En el 74% de los casos se realizó revascularización completa, con un número medio de injertos de 2,97 (1-7). Se utilizó injerto de mamaria en el 100% de los casos. La mortalidad hospitalaria fue del 0,74%. Las complicaciones postoperatorias fueron pocas: el 0,98% precisó reintervención por sangrado, en el 3,4% se elevó la troponina I de forma significativa, en el 6,4% se desarrolló insuficiencia renal y el 0,5% tuvo accidente vascular cerebral.

Conclusiones. La cirugía coronaria con MCEC permite realizar una revascularización completa en la mayoría de los pacientes, con buenos resultados de morbimortalidad.

Palabras clave: *Mini-circulación extracorpórea. Cirugía cardiaca. Mortalidad. Morbilidad.*

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ABBREVIATIONS

CPB: cardiopulmonary bypass
MECC: mini-extracorporeal circulation

INTRODUCTION

The ongoing development of percutaneous coronary interventional techniques, their use in centers in which cardiac surgery is not available, and the good immediate results, with a low morbidity and short hospital stay, have led to a progressive and significant decrease in the performance of coronary artery bypass grafting.[1,2] The American registry of the Society of Thoracic Surgeons (STS database) reveals an uninterrupted decrease in coronary artery bypass grafting from 1997 (185 000 procedures/year) to the present (less than 100 000 procedures/year). This circumstance is also observed in Europe, where the ratio between coronary artery bypass surgery and percutaneous interventions clearly tends to decrease.[3] This trend has been detected mainly in the subgroup of patients who classically would have been considered surgical. According to the data obtained from the centers participating in the SYNTAX study,[4] up to 30% of the patients in Europe with 3-vessel disease were treated with percutaneous techniques, as were up to 26% of those with left main coronary artery disease. In Spain, many cardiac surgery units perform between 250 and 400 surgical procedures a year. Some of the data from the registry of the Spanish Society for Thoracic and Cardiovascular Surgery (Sociedad Española de Cirugía Torácica y Cardiovascular [SECTCV]) concerning the activity involved in coronary artery surgery in Spain are shown in Table 1.

On the other hand, the profile of the patient who is to undergo surgery has changed considerably in recent years. The patients are increasingly older and there is a growing proportion of women. The coronary artery disease is more diffuse and severe, ventricular function is poorer, there is a high incidence of comorbidity, and the patients have often undergone previous percutaneous intervention. Moreover, the incidence of associated procedures, such as the repair of ischemic mitral insufficiency or ventricular reconstruction in ischemic dilated cardiomyopathy, has also increased.

Given this new situation, attempts have been made to improve the results in terms of morbidity and mortality, to reduce the invasiveness of the surgical procedure and to provide more complete, and long-lasting revascularization.[5,6] In this respect, there have been a number of major objectives: *a)* to reduce surgical trauma; *b)* to minimize the inflammatory response, for example, by performing coronary artery bypass surgery without cardiopulmonary bypass (CPB) or employing mini-extracorporeal circulation (MECC) techniques[3]; and *c)* to prolong the duration of revascularization using arterial grafts and with systematic addition of lipid-lowering and antiplatelet agents, angiotensin-converting enzyme (ACE) inhibitors, and beta-blockers.

Cardiopulmonary bypass has made it possible to perform extensive and complex coronary artery bypass surgery in an arrested, exsanguinated heart, and with hemodynamic stability, although at the cost of producing varying degrees of systemic damage such as hemodilution, coagulation activation and changes in platelets, activation of complement and the overall inflammatory response, endothelial dysfunction, and the risks associated with the manipulation of the aorta. MECC is among the methods that have been developed for the purpose of reducing some of the complications associated with conventional CPB techniques. Although it has yet to become widely employed in Spain, in our center, it has become the technique of choice.

Our aim was to analyze our initial experience with MECC in patients undergoing isolated coronary artery bypass grafting.

METHODS

Of the 667 consecutive patients referred for isolated coronary artery bypass surgery between January 2004 and April 2007, we excluded from the study all those who had undergone revascularization with conventional CPB or without CPB. The final study group consisted of 408 patients whose surgery was performed with MECC. With respect to the baseline characteristics of the patients, we considered systemic arterial disease to be present when there was clinical evidence of peripheral arterial disease of the supra-aortic trunk arteries, the intracranial

TABLE 1. **SECTCV Data on Coronary Artery Surgery in Spain Between 2001 and 2005**

	2001	2002	2003	2004	2005
Coronary surgery with CPB, n	5175	5356	4735	4586	4092
Mortality, %	4.96	4.51	4.62	3.68	4
Arterial grafts, %	96	93.5	89.8	90.6	88.7
Coronary surgery without CPB, n	1905	1905	2063	1901	1606
Mortality, %	4.56	4.46	3.58	3.2	3.4

CPB indicates cardiopulmonary bypass; SECTCV, Sociedad Española de Cirugía Torácica y Cardiovascular (Spanish Society for Thoracic and Cardiovascular Surgery).

trunk arteries, or both. Chronic obstructive pulmonary disease was considered when the patients had had decompensations of this disease or had received regular bronchodilator therapy. Obesity was defined as a body mass index over 30. Operative mortality was defined as that ocurring within 30 days after surgery or during the hospital stay. The morbidity taken into account was that occurring during the hospital stay. Renal failure was diagnosed when the serum creatinine levels were over 2.2 mg/dL. Perioperative acute myocardial infarction was defined as the presence of a troponin I level over 12 ng/mL.

The premise to seek the maximum quality in health care, the improvement of the results, and the possibility of attenuating the harmful effects of conventional CPB without losing some of its advantages was highly important when it came to choosing this type of surgery, with a very young group of surgeons who had little experience in coronary artery bypass surgery, in patients who required complex revascularizations and with the greatest possible number of arterial grafts. The key to making this decision was the team of perfusionists at our center, with their extensive experience with centrifugal pumps for CPB, which are indispensable for this technique.

The MECC system is a biocompatible closed CPB circuit, with no blood-air interface, with a reduced priming volume that is associated with less hemodilution, and a smaller contact surface, and makes it possible to separate the blood from the aspirators of the operative field. In addition, it requires an extracorporeal centrifugal pump, a membrane oxygenator, and a shorter arteriovenous loop, as compared with CPB.

The MECC systems employed, always with a centrifugal pump, were the Jostra® MECC system and the Synergy Sorin Group® system. A cell-saver was utilized in only 15% of the cases. The learning curve was short, and all the members of the team were able to perform the procedure correctly within 2 months.

RESULTS

Of the 667 patients subjected to isolated coronary artery bypass surgery between January 2004 and April 2007 in our center, 148 underwent conventional CPB, in 111 CPB was not performed, and in 408, MECC was employed. The characteristics of the patients are shown in Table 2.

Emergency surgery was required in 28% of the cases. Complete revascularization was performed in 74.5% of the cases, with a mean number of grafts per patient of 2.97 (range, 1-7). One coronary graft was performed in 16 patients (3.9%), 2 grafts in 111 (27.2%), 3 grafts in 174 (42.6%), 4 grafts in 85 (20.8%), 5 grafts in 20 (4.9%), and 6 and 7 grafts in 1 patient each (0.25% and 0.25%, respectively). Complete arterial revascularization was carried out in 84 patients (21%). Mammary artery was employed in 100% of the cases, left mammary artery in 98.3%, and right mammary artery in 19%. The radial artery was utilized in 29% of the patients. The median postoperative stay was 8.2 days (range, 0 to 101 days). Eighty-seven percent of the patients were extubated within the first 12 hours after surgery. Only 13 patients (3.1%) required prolonged intubation (more than 24 hours). The mean duration of assisted ventilation was 14.48 (58.61) hours and the length of the intensive care unit stay was 3.08 (4) days. The rate of operative mortality (occurring within the first month or during the hospital stay) was 0.74% (3 patients).

TABLE 2. **Baseline Characteristics of the Patients**

Characteristics	
Age, mean (SD), y	63.5 (9.57)
Men, n (%)	329 (80.6)
Smokers, n (%)	212 (52)
Hypertension, n (%)	257 (63)
Diabetes, n (%)	200 (49)
Dyslipidemia, n (%)	281 (69)
Family history of IHD, n (%)	44.9 (11)
Arterial disease, n (%)	77.5 (19)
COPD, n (%)	44 (10.8)
Previous stroke, n (%)	28 (7)
Obesity, n (%)	38.7 (9.5)
Renal failure, n (%)	20 (5)
Vessels affected, n (%)	
Left main	139 (34)
1 vessel	5 (1.3)
2 vessels	41 (10)
3 vessels	353 (86.5)
LVEF, %	
≥50%	69.8
49%-30%	26.9
<30%	3.2
Logistic EuroSCORE, mean (SD), %	3.7 (3.96)
Numerical EuroSCORE, mean (SD)	3.7 (2.67)

BMI indicates body mass index; COPD, chronic obstructive pulmonary disease; IHD, ischemic heart disease; LVEF, left ventricular ejection fraction; SD, standard deviation.

The complications included severe bleeding in 16 patients (3.9%), only 4 of whom (0.98%) required reintervention. Despite that fact, the mean blood loss over the first 24 hours was 497 mL. The transfusion rate was 38.7%. Fourteen patients (3.4%) had a perioperative acute myocardial infarction. Of these patients, only 1 presented extensive acute myocardial infarction, with significant deterioration of systolic function, and ultimately died. Among the remaining patients, there was no loss of contractile function. Early occlusion of at least 1 graft requiring reintervention occurred in 3 patients (0.74%). Only 2 patients (0.49%) required an intraaortic counterpulsation balloon, which had been implanted preoperatively in both cases. During the hospital stay, 63 patients (15.4%) developed atrial fibrillation, which required electrical cardioversion to restore sinus rhythm in only 1 case. Renal failure, defined as a plasma creatinine

level greater than 2.2 mg/dL, was detected in 26 patients (6.4%), and 8 (1.9%) required hemofiltration. Intestinal ischemia was reported in 1 patient (0.2%), who ultimately died. There were only 3 cases (0.75%) of deep sternal infection; 2 patients (0.5%) developed a permanent neurological deficit, 1 of whom died, and 3 patients (0.74%) experienced a transient neurological deficit.

DISCUSSION

Improvements in Coronary Artery Bypass Surgery

There are currently a number of surgical options for coronary artery revascularization. It can be performed with or without CPB or with MECC, and using different surgical approaches: left or right minithoracotomy,[7] median sternotomy, partial sternotomy,[8] placement of thoracoscopic ports,[9] and robotic surgery. At the present time, consensus exists as to the consideration of median sternotomy as the approach that permits the safest and most effective access to all the arteries of the heart. Although the cosmetic outcome of median sternotomy is debatable, the wound heals well, it usually produces less pain and it rarely affects the ventilatory mechanics of the patient.[10,11]

Coronary artery bypass surgery without CPB, or off-pump, has been adopted enthusiastically by some surgeons over the past 10 years. It involves a highly different concept of performing coronary artery bypass grafting and requires a specific anesthetic management, a different approach to the control of coagulation and special attention to the presentation, stabilization, and control of the anastomoses. Off-pump coronary artery bypass surgery can be performed systematically and with excellent results in terms of morbidity and mortality,[12] although its use has not become widespread among surgical teams. After many studies[13,14] and an extensive controversy, it could be concluded that: *a)* the results of coronary artery bypass surgery performed either with or without CPB are excellent; *b)* blood loss and the need for transfusion, increased enzyme levels, early neurocognitive function, and renal function appear to be favored by off-pump surgery; and *c)* the hospital stay, mortality, morbidity, and long-term neurocognitive function are the same with and without CPB; in the latter, there are fewer grafts per patient; and the analysis of the small number of randomized studies with respect to the permeability of the grafts in this type of surgery shows that it tends to be less than that achieved when CPB is performed. Both forms of carrying out coronary artery bypass surgery are probably suitable therapeutic alternatives when adapted to the different subgroups of patients, with their advantages and disadvantages.[15] In reality, at the present time, only 25% of all the coronary artery bypass procedures are performed without CPB.[16] In Spain, the prevalence is also 25% to 30%,[17] although some groups have adopted it for nearly all their coronary artery bypass patients,[18] with good results. It can be said that off-pump coronary artery bypass surgery continues to be employed in a minority of the patients, that there are few groups and few surgeons who use this technique systematically, that it requires a different philosophy and discipline, as well as a multidisciplinary approach with considerable involvement of the anesthetist, and a learning curve, and number of patients that are rarely achieved. Moreover, many surgeons continue to question its clinical benefits and are concerned that it may compromise the quality and duration of the revascularization. Thus, off-pump coronary artery bypass surgery may not be reproducible by all surgeons or all the surgical teams, a circumstance that affects the results.[16,19,20]

Coronary Artery Bypass Grafting With Mini-Extracorporeal Circulation

Coronary artery bypass surgery with MECC has proved to be highly reproducible and has a short and simple learning curve. It makes it possible to revascularize any coronary artery territory, even those with small vessels or very diffuse disease, and can be performed by any surgeon with different degrees of experience. This is because it maintains the fundamental advantages of conventional CPB (a motionless, bloodless field with total hemodynamic stability), with markedly reduced systemic damage. Thus, this technique should be considered when the objective is to improve the results, given the increasing complexity of the patient with coronary artery disease and the decrease in the performance of this type of surgery. It has numerous potential advantages. The utilization of a closed circuit with no blood-air interface, the use of minimum priming volumes in a shorter circuit, the absence of a venous reservoir, the use of highly biocompatible material, together with the systematic use of the cell saver system, reduce blood loss and hemodilution, as well as the need for transfusion, and minimize the contact of the blood with polymers and air. These factors reduce the complications derived from the systemic inflammatory response and provide greater organic protection during the surgical procedure. A number of authors affirm that there is a marked benefit in patients who do not require transfusion during or after surgery in that their long-term survival, quality of life, and ability to recover from the surgery are greater.[21,22]

Several reports have demonstrated reductions in bleeding,[23] in the need for blood product transfusion,[24-26] and in the concentration of markers of organic damage[24,27] with this technique. In our series, the mean blood loss was 497 mL and 38.7% of the patients received transfusions. Remadi et al,[28] who had employed this technique previously with excellent results,[29] performed a prospective, randomized comparison of 400 patients who underwent coronary revascularization, 50% of them

with a conventional CPB technique and the remainder with MECC. They observed differences in terms of morbidity in favor of MECC with respect to conventional CPB, although there were no differences in terms of 30-day mortality (1.5% and 2.5%, respectively). In their study, the authors concluded that MECC was reproducible and safe, and probably resulted in a better biological profile than CPB. Other data[30] also indicate that, although the incidence of postoperative complications and the use of blood products are reduced with MECC, no differences were observed with respect to the length of the hospital stay or 30-day mortality when compared with conventional CPB. A prospective French study,[31] with 279 patients, also reported good results in terms of morbidity and mortality, although the EuroSCORE of these patients was low.

Myocardial damage during coronary artery bypass surgery has been found to be reduced with MECC,[32] and a significant decrease in the incidence of postoperative atrial fibrillation has also been observed.[32,33] In our series, only 3.4% of the patients had a significant increase in the troponin I level and the incidence of atrial fibrillation was 15.4%.

The neurological complications secondary to the cerebral hypoperfusion and microembolization associated with CPB are well known. In this respect, it has been observed that the MECC systems, which utilize closed circuits that prevent the contact between the blood and air, can preserve brain tissue oxygenation and reduce cerebral microembolization with respect to conventional CPB.[34] In our series, there were only 2 cases (0.5%) of permanent neurological deficit and 3 cases (0.74%) of transient ischemic attack. While this is certain, we should point out that the major cause of brain damage in coronary artery bypass surgery is the manipulation of the aorta, which can present atheromatosis. The way to avoid its manipulation is by performing the surgery without CPB and without grafts that require anastomoses proximal to the aorta. The MECC technique requires total aortic clamping and, on occasion, partial as well. Thus, this complication could also develop in these cases. Despite this circumstance, the new MECC circuits make it possible to perform proximal anastomoses with no need for additional partial clamping. The possible role of MECC in cerebral protection would refer to the reduced overall inflammatory response.

Another aspect that is equally important is the benefit of MECC in terms of the sex of the patient. Ischemic heart disease is increasingly common among women, meaning that the proportion of women who undergo coronary artery bypass surgery is growing. It used to be considered that the rate of mortality associated with coronary surgery was higher in women[35,36] and, thus, female sex was included in surgical risk evaluation systems like the EuroSCORE.[37] Although there are a number of theories that attempt to explain this fact,[38] there is evidence that off-pump or minimally invasive techniques could benefit women, bringing their mortality rates closer to those of men.[39]

The development of certain treatments has led to an apparent and progressive disregard for the benefits of revascularization surgery.[40] It is absolutely true that in multivessel and left main coronary artery disease, surgery has been associated with a decrease in the mortality, in the recurrence of angina, and in reinterventions.[41] As our series shows, in patients undergoing isolated coronary surgery, MECC offers good surgical results with a low rate of morbidity and, thus, could be an acceptable alternative to conventional CPB in those cases in which it can be performed.

Limitations

The limitations are those characteristic of retrospective studies. In our series, there are classification biases in that our patients were not consecutive and, moreover, they underwent coronary artery bypass grafting with MECC, with CPB or without CPB depending on the preferences of the surgeon.

CONCLUSIONS

Coronary revascularization surgery using MECC techniques makes it possible to perform complete revascularization in most patients with good results in terms of morbidity and mortality. It could be the technique of choice in those patients with coronary artery disease who do not require the performance of other procedures during the surgical intervention, in the attempt to reduce the complications derived from conventional CPB techniques.

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