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How Much Myocardial Revascularization Can We Do Without Extracorporeal Circulation?

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Ricardo de Carvalho Lima, MD, MSc, PhD,[1] Mozart Augusto Soares de Escobar MD, MSc,[2] Roberto Diniz MD,[2] Nadja Arraes de Alencar França, MD,[2] Eugênia Cabral, MD,[2] José da Luz, MD[2]

[1]Division of Cardiothoracic Surgery, Department of Surgery, Oswaldo Cruz University Hospital, Faculty of Medical Sciences, Pernambuco State University, Recife, Pernambuco, Brazil.
[2]Unitórax-Real Hospital Português, Recife, Pernambuco, Brazil

ABSTRACT

Objective: The main goal of this study is to present a technical alternative that allows myocardial revascularization to be performed on the marginal branches of the circumflex coronary artery without the use of extracorporeal circulation (ECC).

Methods: The technique for exposing the coronary vessels is performed by placing a stitch in the posterior pericardium. The surgeon lifts the heart using his or her left hand with the aim of exposing the posterior pericardium. A single polypropylene "O" stitch on a #4 needle is threaded into a cardiac ribbon folded back on itself and run twice through the region between the inferior pulmonary vein and the inferior vena cava. The suture thread is run along a tourniquet-type rubber tube and the latter is then directed down to the pericardium, bringing the cardiac ribbon with it. Handling the thread by means of such a tourniquet and the two parts of the ribbon makes it possible to maneuver the heart into different positions in order to expose the coronary arteries: anterior interventricular, diagonal, circumflex, and right coronary. In the present study, the position exposing the coronary arteries was adopted. The circumflex artery was exposed by separating the two legs of the ribbon and pulling one of them ± 90 degrees to the right and the other ± 90 degrees to the left of the patient's main axis, with the polypropylene thread being pulled in the direction of the patient's main axis and fixed in the inferior angle of the surgical wound.

Results: From August 1981 to June 1999, 609 patients had their arteries revascularized without the use of ECC. Among this group, 147 patients (24.14%) had the circumflex artery revascularized. Of the 609 patients, 48 (7.88%) presented serious complications and 21 (3.44%) died.

Conclusions: It was possible to modify the anatomical position of the heart by exposing the circumflex artery with its marginal obtuse branches and performing anastomosis in a simple manner with no loss of quality or hemodynamic involvement, permitting a complete revascularization without the aid of extracorporeal circulation.

INTRODUCTION

In the 1960s, there was a trend toward approaching the coronary arteries directly through procedures such as endoarterectomy and reconstruction of the arterial wall through the use of vein segments. During this period, the work that was considered most significant was that of Kolessov, who described six patients who underwent operations without the aid of extracorporeal circulation (ECC) and also without coronary angiography [Kolessov 1967].

After the series performed by Ankeney [Ankeney 1972] and by Trapp and Bysarya [Trapp 1975], an interval of almost a decade passed before Buffolo [Buffolo 1982] in Brazil and Benetti [Benetti 1985] in Argentina began their experiments with myocardial revascularization on the beating heart in consecutive series. The first reports by these surgeons presented a large number of patients who underwent operations through longitudinal medial sternotomy, demonstrating low mortality and morbidity rates, thus making this method comparable to the traditional procedure with ECC.

In 1993, Lima et al. presented their pioneering experience in the northeastern region of Brazil, which had begun in 1991 with the use of this method in 130 surgical patients [Lima 1993]. In these patients, the revascularized arteries were the left anterior descending (LAD), the right coronary artery (RCA), and the diagonal branch (DIA). This work was a joint effort in which results indicated a mortality rate of 2.5%, with a 3.8% rate for acute myocardial infarction. The authors concluded that this method would be reproducible for other groups and a good option for high-risk patients such as those with kidney failure, reoperations, and elderly patients, and those with associated morbid conditions.

During the period of the resurgence and demonstration of the reproducibility of revascularization without ECC, the

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Address correspondence and reprint requests to: Ricardo Lima, Rua dos Navegantes, 1515/101, Boa Viagem-Recife – PE, Brazil 51021-010, Phone: +55 81 421 2802 (office), +55 81 997 49345 (mobile), Fax: +55 81 221 275, Email: rclima@elogica.com.br

method was severely criticized. Various arguments were advanced, with the harshest criticism being reserved for the limitation of the operation to the anterior arteries of the heart (that is, the LAD, RCA, DIA). The impossibility of revascularizing the circumflex artery and its marginal branches was consistently viewed as a limitation of the procedure, which was also considered inappropriate for complete myocardial revascularization. Another criticism referred to the quality of the anastomoses, which were considered to be inferior to the quality of the anastomoses performed with the aid of ECC.

Of these criticisms, the difficulty of revascularizing the posterior arteries appeared to be the hardest to refute. The reason for this limitation is the difficulties associated with maintaining hemodynamic stability when the heart is repositioned during the approach to the posterior vessels. Generally speaking, the heart did not tolerate this type of handling, and significant hemodynamic instability consequently occurred. Starting in 1991, Lima et al. [Lima 1995a, Lima 1995b, Granja 1996], who placed the heart in the so-called *ectopia cordis* position, overcame this difficulty with no inhibitory compromise of hemodynamic function for the creation of anastomoses of the posterior wall. This advance made it possible to expand the applicability of the method and also allowed complete myocardial revascularization to be performed.

The main goal of this study is to present a technical alternative that allows myocardial revascularization to be performed on the marginal branches of the circumflex coronary artery without the use of ECC. Another goal is to confirm the applicability of the method, based on clinical experience.

MATERIALS AND METHODS

During the period from August 1991 to June 1999, myocardial revascularization without the use of ECC was performed on 609 patients with coronary insufficiency. All patients had been informed about the alternatives and the nature of the procedure and consented to it. The general information about patients in whom at least one marginal artery was revascularized without ECC was checked against hospital files through June 30, 1999. The distribution of the number of revascularization procedures performed without ECC over time is shown in Figure 1 (). The age range of patients was from 25 to 93 years, with a mean of 61.38 ± 10.51 years. Distribution of the sexes was homogeneous. Female patients were a slight majority, accounting for 311 patients (51.07%), and there were 298 male patients (48.93%).

The number of bypasses per patient ranged from 1 to 7. The most frequently revascularized artery was the LAD, with 495 procedures (47.32%), followed by the RCA with 268 procedures (25.62%), the circumflex artery with 159 procedures (15.20%), and the DIA with 124 procedures (11.86%).

A total of 1046 anastomoses were performed. Of these procedures, 811 (77.53%) used venous grafts, 234 (22.37%) used arterial grafts, and one patient (0.10%) received a polytetrafluoroethylene (PTFE) graft due to the non-availability of other grafts. The average number of bypasses per patient was 1.72. Of the 609 patients, 147 (24.14%) had the circumflex artery or the marginal branch revascularized.

Anesthesia

Arterial and venous catheters were introduced under local anesthesia. General anesthesia was administered in the same way as for patients undergoing operations with ECC. Intravenous induction was performed with ethomidate, fentanyl chloride, midazolam, and pancuronium. Maintenance was performed with sevofluoran, fentanyl chloride, and midazolam. After the sternotomy, arterial pressure was controlled at 60-80 mmHg and the heart rate was kept at 60-90 beats per minute. Isosorbide-5-mononitrate or diltiazem was routinely used in an infusion pump.

General Operating Method

The operation was performed by means of a longitudinal median sternotomy. The left internal mammary artery (LIMA) was dissected and prepared (in those cases in which it was used), and the great saphenous vein was simultaneously dissected. In the more recent cases, a platform and a stabilizer were installed. The stabilizer was a CTS Access Ultima System, manufactured by CardioThoracic Systems (CTS). The pericardium was opened in the form of an inverted "T," and its left edge was anchored to the platform. The patients were heparinized with heparin at a dose of 200 units/kg of body weight and were monitored through the measurement of the activated coagulation time (ACT). The minimum acceptable ACT value was 300 seconds.

A stitch was then placed in the posterior pericardium and the anastomoses were performed in the following order: The distal anastomosis of the graft to the LAD, the distal anastomosis of the graft to the RCA, and lastly, the distal anastomosis of the graft to the circumflex artery and/or its branches. In order for the anastomoses to be performed, the coronary artery is temporarily constricted with 5-0 polypropylene anchored in bovine pericardium; an incision is made and a CTS FloCoil intracoronary shunt (ranging in length from 1.5 to 2.5 mm) is installed. The constriction is then removed. The distal anastomoses were performed with continuous 7-0 polypropylene sutures. The heart was returned to its anatomical position in the pericardial sac and the proximal anastomoses were performed on the aorta, with tangential pinching and the use of continuous 6-0 polypropylene suture material. The heparin was then neutralized with protamine sulfate at a 1:1 ratio, and the chest was closed in accordance with standard procedure.

Exposure of the Circumflex Artery and Its Branches

The technique for exposing the coronary vessels was implemented through the placement of a stitch in the posterior pericardium. This single stitch (consisting of "0"-gauge polypropylene on a 4.0 cm needle) was passed through a polyester strip folded back on itself. The heart was luxated temporarily in order to expose the posterior pericardium, and the stitch was passed twice through the posterior pericardium between the inferior pulmonary vein and the inferior vena cava (Figure 2,).

Attention should be given to determining the location of the esophagus in order to avoid injuring it. The first pass of the stitch through the pericardium should be superficial, and the second pass should be deeper (Figure 3,). The suture thread is then passed through a rubber tube and brought

closer to the pericardium, so as to raise the cardiac strip. The purpose of the rubber tube is to keep the thread from abrading the ventricular wall. The tube also serves as a tourniquet.

After this step has been performed, the rubber tube also serves as a tourniquet, joining the two parts of the polyester strip to the same stitch in the posterior pericardium. Thus, three elements (i.e., two strips and a suture thread enclosed within the rubber tube) are provided that can be manipulated in various ways to position the heart. The coronary arteries (i.e., the anterior interventricular and diagonal arteries, the marginal branches, and the right coronary artery) are exposed through manipulation of the suture thread and the two surgical strips. Our research focused on the position of the posterior arteries of the heart, as exposed through the application of traction to the polypropylene thread in the direction of the patient's longitudinal axis and the anchoring of the thread in the lower corner of the surgical wound. Then the two segments of the polyester strip were separated and traction was applied to each of them, approximately 90° to the left and 90° to the right of the patient's major axis (Figure 2a and 2b,).

The heart then assumed the *ectopia cordis* position as a result of the traction applied to the suture thread in a caudal direction in relation to the patient's longitudinal axis, and to the polyester strips anchored laterally to the platform, in accordance with the above-mentioned angular orientations. The stabilizer was then installed and the anastomosis was performed (Figure 3,).

RESULTS

It was found that 48 of the 609 patients (7.88%) who underwent the operation displayed severe complications. Acute myocardial infarction and low cardiac output accounted for 47.92% of complications. Of the patients who underwent the operation, 21 out of 609 (3.44%) displayed severe complications and died. The cause of death was acute myocardial infarction in 13 patients (2.13%), cerebrovascular accident in three patients (0.50%), arrhythmia in two patients (0.33%), pulmonary embolism in one patient (0.16%), reduced cardiac flow in one patient (0.16%) and mesenteric thrombosis in one patient (0.16%). The number of off-pump coronary artery revascularizations increased throughout the time period of the study and we are now doing it on 100% of our patients (Figure 4,).

DISCUSSION

Varied terminology has been used to describe the branches originating from the circumflex artery. Ochner and Mills [Ochner 1978] presented an extensive discussion that adopted Favaloro's description of the most proximal branches as lateral branches and the most distal branches as diaphragmatic branches. Meanwhile, Baltaxe described the diaphragmatic branches as postero-lateral branches, and Gensini referred to the most proximal branches as obtuse marginal branches and the most distal branches as postero-lateral branches. In an attempt to simplify and define which branch was being treated, Ochner and Mills [Ochner 1978] identified the marginal branches of the circumflex artery as the first marginal branch, the second marginal branch, the third marginal branch, and so on. We have also adopted this terminology in surgical practice, so that the retrospective analysis of this material will refer only to revascularization of the marginal branches of the circumflex artery. We believe this classification will be satisfactory, inasmuch as the coronary anatomy displays a very high degree of variation, and because the goal of the present study was solely to demonstrate the viability of revascularization of the posterior arteries of the heart without the use of extracorporeal circulation.

Myocardial revascularization without the use of ECC has developed rapidly in recent years, and different groups have shown great interest in the present method, applying it routinely [Ochner 1978, Cham 1993-94, Lima 1995b, Bergsland 1997].

One of the sharpest criticisms leveled at the method involves the impossibility of revascularizing the circumflex artery and its marginal branches, thereby contradicting the concept of complete revascularization, which is considered to be one of the most important requirements in myocardial revascularization. The good functional results and long-term survival rates achieved with myocardial revascularization depend on initial complete revascularization. Kirklin and Barratt-Boyes [Kirklin 1986] reported a 96% survival rate over five years for patients with three-vessel coronary artery disease, with normal or only slightly compromised ventricles, in comparison with a survival rate of 88% ($p = 0.005$) for patients whose revascularization was incomplete.

Messmer [Messmer 1990] published an editorial questioning whether coronary surgery without ECC constituted a benefit or an additional risk for the patient. He also contended that the precocious occlusion of circumflex artery grafts in the treatment of coronary insufficiency, and the impossibility of creating anastomoses without the appropriate decompression of the heart, made the use of ECC a mandatory procedure. In the same editorial, the author offered severe criticisms of the work described by Buffolo [Buffolo 1985], acknowledging an excellent anastomosis of the left internal thoracic artery to the anterior interventricular artery but asking why the anastomosis was not made to the marginal branch of the circumflex artery.

Perhaps the explanation for the low average number of grafts per patient among the various series of patients who underwent procedures without ECC lies not only in the difficulty of revascularizing the posterior arteries but also in the method that was used to select the patients. Buffolo et al. [Buffolo 1996] described their results from 13 years of experience with 1274 patients who underwent operations with an average of 1.7 grafts per patient. In this series the patients were carefully selected. Patients who required treatment of the circumflex artery and those with lesions of the trunk of the left coronary artery were not admitted to the study. This technique was also used in particular with high-risk patients, such as those with kidney failure, respiratory problems, advanced age, cerebrovascular accident, and other systemic disorders.

In a series of 2052 patients, Tasdemir et al. [Tasdemir 1998] performed an average of 1.9 grafts per patient. In this

series, 61.5% of patients received a single graft to the anterior interventricular artery. These patients were also subjected to a strict selection process. A regression analysis indicated that when a patient was not placed on ECC, it became necessary to accept, as a risk factor, the non-revascularization of the circumflex artery, with the corresponding expectation of a sub-optimal outcome.

Laborde [Laborde 1989] suggested that myocardial revascularization could be performed safely and effectively without the use of ECC, but these results could be achieved only through rigorous selection and an appropriate surgical procedure. These authors confirmed that excellent anastomoses can be obtained with this method, and that the results are as good as those achieved when the heart is stopped under anoxia. However, these authors believe that when a patient has lesions that involve the anterior interventricular, diagonal, and right coronary arteries, complete revascularization can be achieved only through an approach to these arteries via sternotomy. According to them, the same concept can be applied to the circumflex artery if approached through a left thoracotomy, which can also be performed for the anterior interventricular and diagonal arteries.

Revascularization of the marginal branches of the circumflex artery without ECC has always presented as an inherent difficulty the hemodynamic stabilization of the heart because, in order properly to expose these arteries, the heart must be luxated and removed from the pericardial sac. Whenever the heart is handled in an attempt to expose the posterior branches, unidentified changes occur in the internal dynamics of the organ that are expressed as a change in hemodynamic parameters, primarily with arterial hypotension, which is sometimes serious.

In hemodynamic terms, the handling that is required in order to create anastomoses on the anterior interventricular artery, the diagonal branch, and the right coronary artery and its branches is generally very well tolerated. Moises et al. [Moises 1998] presented their observations regarding the use of a transesophageal echocardiograph (TEE) during revascularization without ECC, and its immediate postoperative effects. Although this study stopped with an analysis of the segmental movement of the ventricular wall, researchers called attention to the fact that the surgeon needs to rotate the heart in order to allow anastomosis to be performed on the anterior interventricular and right coronary arteries. This action could cause distortions in the actual contraction of the left ventricle. Based on this observation, much more significant changes must occur when an approach is made to the circumflex artery and/or its branches.

Although the hemodynamic changes displayed by the heart when an approach is made to the circumflex artery and its branches appear to be serious, their precise nature is entirely unknown. Through simple observation during the procedure, we can speculate on the presence of mechanical changes, such as torsion of the major vessels (the aorta, the pulmonary artery, the inferior vena cava, and the superior vena cava) and functional alterations in the atrial ventricular valves, which would cause a certain degree of temporary insufficiency.

Our experience with coronary artery operations without ECC began in August 1991 [Lima 1993], with operations on patients with lesions in arteries on the anterior wall. However, as early as November 1991, we performed the first revascularization of a marginal branch of the circumflex artery. The great difficulty still lay in placing the heart in a position in which the circumflex artery and its branches could be clearly seen and approached by the surgeon. This difficulty was gradually overcome as we became able to place the stitches in the left lateral surface of the pericardium. These stitches were always placed in the most posterior region, depending on the difficulty of exposing the artery. Lastly, we succeeded in identifying a region between the left inferior pulmonary vein and the inferior vena cava as the site for the installation of one, two, or three stitches which, when traction was applied to them, would induce a true state of *ectopia cordis*. The stitches that are placed in the posterior pericardium are quite deep. Heavy-gauge suture threads, such as "0" gauge polypropylene, should be used, in conjunction with a 4 cm needle. The passage through the pericardium covers a distance of approximately 2 cm from the needle's entry point to its exit point. This large area of passage for the needle is needed in order to permit the application of heavy traction to the suture threads and to the strips. The thread and the strips are pulled in the patient's postero-anterior direction and are anchored in the lower corner of the surgical wound. Thus, the thread and the strips make it possible to change the normal position of the pericardium and also of the heart, so that the posterior arteries are exposed and can be treated [Lima 1995b].

Because the pericardium cradles the posterior portion of the heart, the shape of the pericardium is normally concave. However, when the suture threads are deeply installed in the posterior portion of the pericardium and traction is applied to them, this shape tends to change to semi-convex. When this shape is assumed by the pericardium, the area on which the heart rests is reduced. Thus, the heart assumes a position similar to the *ectopia cordis* position, as if it were about to be expelled from the mediastinum. Oddly, in patients with true *ectopia cordis*, what is generally observed is an absence of the normal pericardial space, which thereby prevents the heart from being located within the thorax [Escobar 1993]. Generally speaking, when hearts are located outside the thorax at birth and subsequently assume the normal anatomical position, they apparently do not display changes in their hemodynamics. When any type of alteration occurs, it is generally transitory. The same thing happens with temporarily induced *ectopia cordis*, as in the case of the stitch installed in the posterior pericardium. Proper handling, in terms of the adjustment of the suture thread and of the strips, allows these difficulties to be overcome quite easily. The published literature contains no reports explaining why the hemodynamic alterations are minimal or transitory when the heart assumes the thoracic herniation position. Because the present procedure is a new one, there are no published studies of intracardiac pressures during the procedure. Escobar et al. [Escobar 1993] described two cases in which *ectopia cordis* was corrected. These conditions were diagnosed *in utero*, and no hypotension was observed when the heart was placed inside the thorax. Perhaps the heart tolerates these movements well unless the major vessels are distorted.

Once the circumflex artery and its branches have been exposed, the anastomoses are performed in accordance with the standard method used for the arteries of the anterior wall. In our experience, we were able to increase the number of

patients operated on off pump coronary surgery from 24% to 55% simply through the introduction of the method for exposing the circumflex artery.

Lobo et al. [Lobo 1997] achieved a high number of patients operated on off pump (90%) for revascularization without ECC and did not use mechanical cardiac stabilizers of any kind. These authors performed an average of 1.9 grafts per patient, using only the technique described in the present study. Their work is important because it demonstrated that the technique for exposing the arteries of the posterior surface of the heart is a reproducible surgical procedure. When we used the proposed technique, our applicability index did not exceed 55%. Nevertheless, when this procedure was combined with the systematic use of cardiac stabilizers, we were able to achieve an increase to 100% over the one-year period from March 1998 to February 1999.

CONCLUSION

We believe that the difficulties of performing anastomoses on the posterior wall of the heart can be overcome through the systematic use of the technique described in this report. The applicability index can be increased not only through the exposure of the posterior arteries of the heart but also through the associated use of cardiac stabilizers. The procedure is safe and reproducible, and the use of stabilizers further refines the effectiveness of the method.

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Figure Legend

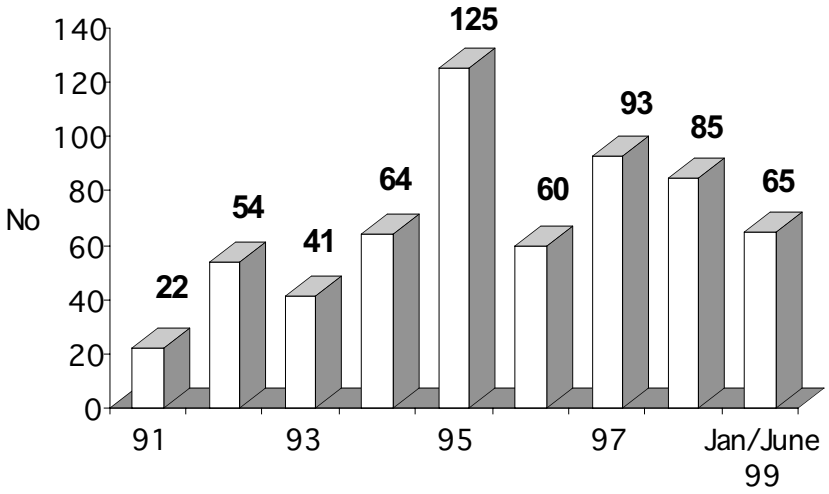
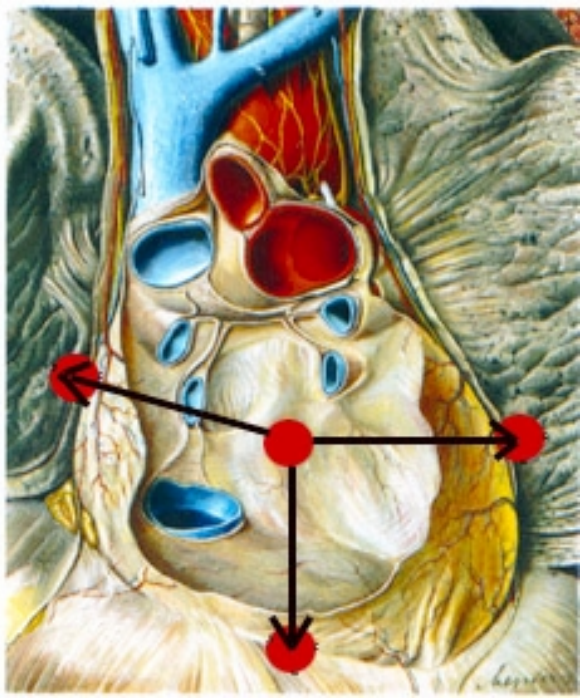


Figure 1
Myocardial revascularization surgery without extracorporeal circulation and its distribution over time (August 1991 through June 1999).



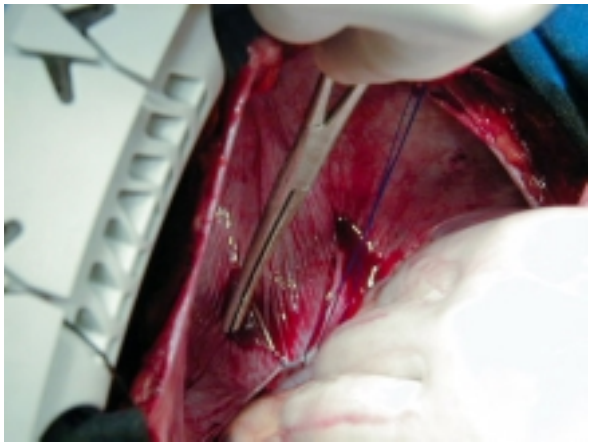


Figure 2
Anatomical drawing of the posterior mediastinum. The heart has been omitted in order to show the exact location of the stitch. The arrows indicate the directions in which traction is applied to the suture thread and to the surgical strips.
Surgical photograph showing how the stitch is passed twice through the posterior pericardium in the region between the left inferior pulmonary vein and the inferior vena cava.

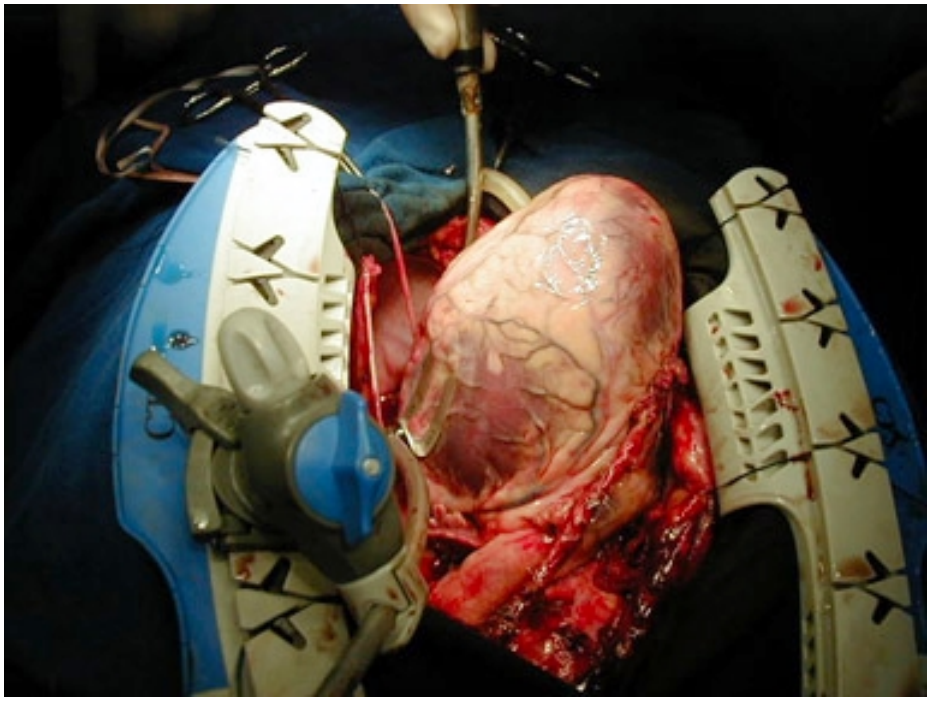


Figure 3
Surgical photograph of the heart in the *ectopia cordis* position. A coronary stabilizer has been installed on the marginal branch of the circumflex artery. [There is] a graft between the left internal thoracic artery and the anterior interventricular artery. The polyester strip is visible, with traction applied in the direction of the patient's transverse axis. Also visible is the suture thread, with traction applied in the direction of the patient's longitudinal axis.

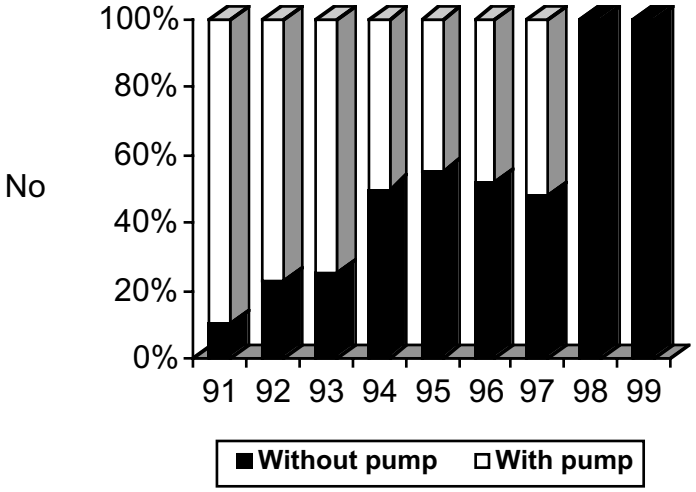


Figure 4
Myocardial revascularization surgery with and without extracorporeal circulation and its percentage distribution over time (August 1991 through August 1999).