Hemodynamic Changes during Myocardial Revascularization without Extracorporeal Circulation

Silvia Minhye Kim [1], Luiz Marcelo Sá Malbouisson [2], José Otávio Costa Auler Jr. [3], Maria José Carvalho Carmona [4]

Summary: Kim SM, Malbouisson LMS, Auler Jr. JOC, Carmona MJC – Hemodynamic Changes during Myocardial Revascularization without Extracorporeal Circulation.

Background and objectives: Cardiac positioning and stabilization during myocardial revascularization without extracorporeal circulation (ECC) may cause hemodynamic changes dependent to the surgical site. The objective of this study was to evaluate these changes during distal coronary anastomosis.

Methods: Twenty adult patients undergoing myocardial revascularization without ECC were monitored by pulmonary artery catheter and transesophageal Echo Doppler. Hemodynamic data were collected at the following times before removing the stabilizer wall: (1) after volume adjustments, (2) at the beginning of distal anastomosis, and (3) after 5 minutes. Treated coronary arteries were grouped according to their location in the lateral, anterior, or posterior wall. Two-way ANOVA with repetition and Newman-Keuls post-test were used in the analysis. A p value < 0.05 was considered statically significant.

Results: During myocardial revascularization without ECC, pulmonary artery wedge pressure showed elevation from 17.7 ± 6.1 to 19.2 ± 6.5 ($p < 0.001$) and 19.4 ± 5.9 mmHg ($p < 0.001$), while the central venous pressure went from 13.9 ± 5.4 to 14.9 ± 5.9 mmHg ($p = 0.007$) and 15.1 ± 6.0 mmHg ($p = 0.006$). Intermittent cardiac output was reduced from 4.70 ± 1.43 to 4.23 ± 1.22 ($p < 0.001$) and 4.26 ± 1.25 $L.min^{-1}$ ($p < 0.001$). According to transesophageal Doppler, a significant group-time interaction was observed in cardiac output, which was reduced in the lateral group from 4.08 ± 1.99 to 2.84 ± 1.82 ($p = 0.02$) and 2.86 ± 1.73 $L.min^{-1}$ ($p = 0.02$), and aortic blood flow, which went from 2.85 ± 1.39 to 1.99 ± 1.26 ($p = 0.02$) and 2.00 ± 1.21 $L.min^{-1}$ ($p = 0.02$). Other hemodynamic changes were not observed during anastomoses.

Conclusions: A significant hemodynamic deterioration was observed during myocardial revascularization without ECC. Transesophageal Doppler detected a decrease in cardiac output only in the lateral group.

Keywords: Hemodynamics; Echocardiography, Transesophageal; Coronary Artery Bypass; Extracorporeal Circulation.

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INTRODUCTION

Important hemodynamic changes may occur during myocardial revascularization without extracorporeal circulation (ECC), a period in which the heart must maintain its pumping function while it is being operated and manipulated. Prompt recognition of hemodynamic instability is possible when any such changes are predict and there is continuous monitoring and rapid response, which enables the optimization of cardiac function to reduce heart suffering and overload during external manipulation [1-3].

Hemodynamic monitors have been developed to provide information on cardiac function. Pulmonary artery catheters with thermal filament are capable to measure the right ventricular ejection fraction and right ventricular end-diastolic volume. Intraoperative transesophageal echocardiography allows direct visualization of cardiac chambers to obtain volumes and pressures during cardiac cycle. Based on analysis of aortic blood flow, transesophageal Doppler of the aorta can provide information on cardiac output and ventricular ejection time [4]. In cases of changes in hemodynamic conditions, mixed venous oxygen saturation (SvO_2) can be rapidly altered [5] as a function of the increased peripheral oxygen extraction. Analyzing the SvO_2, along with aortic blood flow, it is possible to get additional information regarding cardiac function and peripheral oxygen delivery during aggressions to the heart.

The objective of the present study was to evaluate the hemodynamic changes during distal coronary anastomoses in myocardial revascularization without ECC considering the different walls approached.

Received from the Instituto do Coração (InCor) do Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo (FMUSP), Brazil.

1. PhD in Sciences; Assistant Physician of Instituto do Câncer do Estado de São Paulo Octavio Frias de Oliveira
2. PhD in Sciences; Supervising Physician of the Unidade de Terapia Intensiva e Recuperação Pós-anestésica da Disciplina de Anestesiologia do Hospital das Clínicas da FMUSP; Counselor of the Programa de Pós-graduação em Anestesiologia da FMUSP
3. Professor of Anesthesiology, Departamento de Cirurgia; Disciplina de Anestesiologia, FMUSP
4. Associated Professor of the Disciplina de Anestesiologia da FMUSP; Director of the Divisão de Anestesia do Instituto Central do Hospital das Clínicas da FMUSP

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Correspondence to:
Dra. Silvia Minhye KimSecretaria de Anestesia
Av. Dr. Enéas de Carvalho Aguiar, 44, 2º andar
Cerqueira César
05403-000 – São Paulo, SP, Brazil
E-mail: silviakim@hotmail.com

METHODS

The research protocol was approved by the Scientific Commission of the Instituto do Coração and by the Ethics Commission for Analysis of Research Projects (CAPPesq) of the Board of Clinical Directors of Hospital das Clínicas and Medical School of USP.

Adult candidates of both genders scheduled for elective myocardial revascularization without ECC were evaluated. Surgical risk was stratified according to Higgins criteria [6], and only patients with minimal to moderate risk were included in the study. Inclusion criteria were age < 80 years; renal function within normal limits or creatinine < 1.4 $mg.dL^{-1}$; ventricular function within normal limits (ejection fraction > or equal to 50%), according to echocardiography or ventriculography. Patients scheduled for cardiac reoperations, with valvulopathies associated with coronary insufficiency or with the diagnosis of chronic obstructive pulmonary disease were excluded.

To detect differences in measurements among groups with a level of significance of 0.05, and considering that a mean of three coronary anastomoses would be performed in each patient, it was established that 20 patients would be investigated. The study consisted of analysis of hemodynamic parameters obtained during distal anastomosis of each coronary artery. Data obtained were grouped according to the location of the procedure: anterior wall (distal anastomoses of the anterior descending [AD] and diagonal [DI] arteries), lateral wall (distal anastomosis of the left marginal artery), or posterior wall (distal anastomosis of the right coronary artery or their posterior branches).

The decision to perform the surgical procedure without ECC, the arteries, and the order of revascularization were determined by the heart surgeon. The procedures were performed by two teams of heart surgeons. Whenever a change in surgical conduct was determined during the surgery indicating the need of ECC, the patient was excluded from the study.

All patients obeyed a minimal fasting period of 8 hours, and premedication consisted of oral midazolam 7.5 mg 30 minutes before the surgery. In the operating room patients were monitored by electrocardiogram, pulse oximeter and invasive blood pressure. Anesthetic induction was achieved with titrated administration of sufentanil up to a dose of 0.5 $\mu g.kg^{-1}$, and propofol (until loss of reflexes), or etomidate (0.2 $mg.kg^{-1}$). For muscle relaxation, pancuronium bromide 0.1 $mg.kg^{-1}$, or atracurium 0.5 $mg.kg^{-1}$, was administered. Anesthesia was maintained with variable concentrations of isoflurane (FE of 0.7 to 0.9%) and intermittent boluses of sufentanil up to a total dose of 1.0 $\mu g.kg^{-1}$.

After tracheal intubation and the onset of controlled mechanical ventilation, the right internal jugular vein was punctured and a 7.5F pulmonary artery catheter with thermal filament was introduced (CCO catheter, Baxter Edwards Critical Care, Irvine, CA, USA) through an 8.5F introducer. The catheter was connected to the Vigilance monitor (Baxter Edwards Critical Care, CA, USA) for continuous recording of cardiac output, which was calculated based on a pattern of signs emitted by the thermal filament and detected by the transmitter on the tip of the catheter. The cardiac output obtained after the emission of each signal pulse, approximately every 30 to 60 seconds, was recorded on the STAT screen of the monitor.

An esophageal probe with Doppler and M-mode echocardiography transducers (Hemosonic 100, Arrow International Inc., Reading, PA, USA) protected by its disposable sheath was introduced. Depth and rotation of transducers in relation to descending thoracic aorta were adequate, according to the characteristic Doppler tracing of aortic blood flow, and images of the aorta walls on echocardiography. This method allows M-mode echocardiography of the anterior and posterior walls of descending thoracic aorta to determine the aorta diameter and Doppler of aortic blood flow velocity, from which the distance covered by the blood ejected during systole is obtained, and then systolic aortic volume and cardiac output are calculated.

During the period immediately anterior to coronary anastomoses, volemia was adjusted by the administration of 10 $mL.kg^{-1}$ of 6% hydroxyethylamide 130/0.4 (Voluven, Fresenius Kabi, Bad Homburg, Germany), and Ringer's lactate until hemodynamic stabilization was achieved in order to obtain a cardiac index measured by intermittent thermodilution > 3.0 $L.min^{-1}.m^{-2}$.

Dobutamine was the inotropic agent of choice for cases in which despite volume optimization cardiac output remained reduced. In case vasodilation was necessary, continuous infusion of nitroprusside or nitroglycerine was used. To provide rapid adjustments in blood pressure, a bolus of 4 μg of noradrenaline was administered in case of hypotension, or 200 μg of nitroglycerine in case of hypertension.

Hemodynamic evaluation was performed at the following moments:

Baseline: after sternotomy, cardiovascular stabilization, and volume optimization, being considered the baseline measure for the first anastomosis, and repeated before each anastomosis, before positioning the heart;
Beginning of anastomosis: at the beginning of coronary anastomosis, with the Octopus (Medtronic, Inc., Minneapolis, MN, USA) tissue stabilizer for beating heart surgery positioned;
End of anastomosis: 5 minutes after beginning the anastomosis, near completion and before removing the Octopus.

Hemodynamic parameters analyzed included: heart rate (HR), mean arterial pressure (MAP), mean pulmonary artery pressure (MPAP), pulmonary artery occlusion pressure (PoAP), central venous pressure (CVP), mixed venous oxygen saturation (SVO_2), intermittent cardiac output (ICO), semi-continuous cardiac output – STAT mode (CCO), right ventricular end-diastolic volume index (RVEDVI), cardiac output by transesophageal Doppler (COED), aortic blood flow (ABF), rate-corrected left ventricular ejection time (cLVET), peak velocity (PV), and maximal acceleration (MA).

At the time of each evaluation, we recorded cardiac output values indicated by the Vigilance monitor set in the STAT mode. Cardiac output was measured by thermodilution using a 10 mL injection of 5% glucose solution at room temperature.

Thermodilution curves were evaluated and the mean of three consecutive measurements was recorded.

Continuous variables are presented as mean ± standard deviation, and two-way ANOVA with repetition was used to compare them. This method included the following factors: GROUP (lateral, anterior, or posterior wall), TIME (baseline, initial, or final), and the GROUP-TIME interaction. Whenever significant differences were observed, we used Newman-Keuls post-test for multiple comparisons between times and Tukey's test for multiple comparisons between groups. A value of p below 0.05 was considered statistically significant.

RESULTS

Twenty patients, 15 males and five females, ages ranging from 39 to 79 years, were included in the study. Anthropometric and surgical data are presented in Table I. Each patient was evaluated to determine the surgical risk according to Higgins criteria [6]. In this score, some of the factors that could represent a high postoperative mortality were already part of the exclusion criteria.

Two to four distal coronary anastomoses were performed in each patient; therefore, a total of 57 coronary anastomoses were evaluated. Among the arteries treated a greater number of procedures were observed in the arteries of the anterior group, 19 in the anterior descending (DA) and 13 in the diagonal (DI) arteries. The lateral group included 14 anastomoses in the marginal arteries (Mg and Mg2), and the posterior group included 11 anastomoses in the posterior branches of the right coronary (RC) or posterior ventricular (PV) artery.

Table I – Demographic and Surgical Data

	n
Gender (M/F)	15 / 5
Age (39 to 79 years) *	61.7 ± 10.4
Body surface (m^{-2}) *	1.76 ± 0.19
Surgical risk	
Minimal	9
Low	11
Coronary anastomoses	
2 arteries	
DD + Mg	3
AD + DI	3
AD + RC	1
3 arteries	
AD + DI + Mg	4
AD + DI + RC/PV	3
AD + Mg + RC	1
Mg + Mg2 + RC	1
4 arteries	
AD + DI + Mg + RC/PV	3

Coronary arteries: AD: anterior descending, DI: diagonal, Mg: marginal, RC: right coronary, RC/PV: right coronary posterior ventricular.

Coronary anastomoses lasted on average 5.7 minutes (SD = 1.6 minutes), and the intervals between them ranged from 6 to 79 minutes, the time required for positioning the heart for the following procedure or realization of proximal anastomoses. The order of anastomoses was not uniform and it followed the indication established by the surgical team for each case. Hemodynamic data is shown in Table II.

A significant change was observed in PoAP (Figure 1), which went from a baseline value of 17.7 ± 6.1 to 19.2 ± 6.5 mmHg ($p < 0.001$) at the beginning of anastomosis, and 19.4 ± 5.9 mmHg ($p < 0.001$) at the end of anastomosis; and CVP (Figure 2), which went from 13.9 ± 5.4 to 14.9 ± 5.9 mmHg (p = 0.007) and 15.1 ± 6.0 mmHg (p = 0.006). However, a difference was not observed among groups.

Intermittent cardiac output (Figure 3) was reduced from 4.70 ± 1.43 to 4.23 ± 1.22 $L.min^{-1}$ ($p < 0.001$) and 4.26 ± 1.27 $L.min^{-1}$ ($p < 0.001$), without difference among groups. A statistically significant group-time interaction was observed on COED (Figure 4), which was reduced in the lateral group from 4.08 ± 1.99 to 2.84 ± 1.81 $L.min^{-1}$ (p = 0.02) and 2.86 ± 1.73 $L.min^{-1}$ (p = 002). ABF is used to calculate COED and due to this mathematical coupling it also showed a significant interaction (p = 0.01, Figure 5), and the reduction was observed in the lateral wall, from 2.85 ± 1.39 to 1.99 ± 1.26 $L.min^{-1}$ (p = 0.02) and 2.00 ± 1.21 $L.min^{-1}$ (p = 0.02).

Peak velocity also showed a significant group-time interaction on ANOVA (p = 0.02, Figure 6), but Newman-Keuls post-test for multiple comparisons did not show a statistically significant difference in groups and times.

DISCUSSION

Significant hemodynamic alterations were observed during myocardial revascularization without ECC, with an increase on PoAP and CVP and reduction in cardiac output obtained by intermittent thermodilution (ICO). Using the transesophageal Doppler monitor we observed a reduction in cardiac output and ABF on lateral wall procedures.

Other studies have demonstrated more significant hemodynamic changes when approaching posterior and lateral wall arteries [7-13], expressed mainly by variations in atrial and right ventricular end-diastolic pressures. Our results have confirmed these observations and, using the transesophageal Doppler monitor, it was possible to obtain additional information, such as pre-load and cardiac contractility.

The increase in atrial pressures during surgical manipulation can be explained by the anatomical distortion of the dislocated heart, especially close to atrioventricular valves, causing partial flow obstruction or valvular insufficiency. It can also be explained by migration of the catheter to an inadequate position, therefore detecting wrong pressures. Note that atrial pressure measurements are highly influenced by cham-

Table II – Hemodynamic Data. Results of Two-Way ANOVA with Repetition

	Times			p		
	Baseline	Beginning anastomosis	End of anastomosis	Between groups	Between times	Interaction
Mean Arterial Pressure(mmHg)				0.47	0.46	0.37
Ant	69.59 ± 9.86	71.28 ± 9.02	69.06 ± 8.61			
Lat	69.21 ± 9.15	66.50 ± 5.36	66.93 ± 8.40			
Post	68.55 ± 11.61	73.36 ± 8.95	70.36 ± 7.72			
Pulmonary Artery Occlusion Pressure (mmHg)				0.22	< 0.001 *	0.09
Ant	17.72 ± 5.95	18.88 ± 6.09	18.78 ± 5.57			
Lat	16.71 ± 6.58	17.21 ± 5.98	18.07 ± 5.76			
Post	18.64 ± 6.04	22.55 ± 7.39	22.64 ± 6.00			
Central Venous Pressure (mmHg)				0.10	< 0.01 *	0.69
Ant	13.09 ± 4.99	13.72 ± 5.02	14.00 ± 5.02			
Lat	13.93 ± 6.06	14.86 ± 7.08	14.93 ± 6.90			
Post	16.18 ± 5.62	18.36 ± 6.07	18.55 ± 6.98			
Mixed Venous Oxygen Saturation (%)				0.89	0.08	0.16
Ant	75.13 ± 8.82	74.83 ± 8.77	74.67 ± 9.25			
Lat	78.86 ± 6.77	75.50 ± 9.85	73.71 ± 10.92			
Post	75.82 ± 9.89	76.73 ± 8.63	75.27 ± 10.47			
Intermittent Cardiac Output ($L.min^{-1}$)				0.90	< 0.001 *	0.07
Ant	4.46 ± 1.267	4.36 ± 1.12	4.26 ± 1.08			
Lat	5.13 ± 1.72	4.01 ± 1.61	4.42 ± 1.80			
Post	4.82 ± 1.49	4.13 ± 0.96	4.06 ± 1.08			
Semi-continuous Cardiac Output (STAT mode) ($L.min^{-1}$)				0.66	0.07	0.19
Ant	5.41 ± 1.41	5.59 ± 1.41	5.41 ± 1.37			
Lat	6.07 ± 1.73	5.81 ± 1.57	5.54 ± 1.77			
Post	5.29 ± 1.38	5.43 ± 1.33	5.20 ± 1.59			
Cardiac Output by Transesophageal Doppler ($L.min^{-1}$)				0.15	0.19	0.02 *
Ant	4.03 ± 1.48	4.08 ± 1.44	4.29 ± 1.86			
Lat	4.08 ± 1.99	2.84 ± 1.81	2.86 ± 1.73			
Post	3.59 ± 1.62	3.61 ± 1.66	3.71 ± 1.56			
Right Ventricular End-diastolic Volume Index ($mL.m^{-2}$)				0.50	0.61	0.08
Ant	124.47 ± 29.19	123.57 ± 29.07	125.17 ± 33.52			
Lat	147.08 ± 48.74	137.46 ± 53.29	131.92 ± 32.55			
Post	124.73 ± 38.57	134.91 ± 59.08	130.64 ± 49.42			
Aortic Blood Flow ($L.min^{-1}$)				0.16	0.19	0.01 *
Ant	2.82 ± 1.03	2.88 ± 1.01	3.00 ± 1.30			
Lat	2.85 ± 1.39	1.99 ± 1.26	2.00 ± 1.21			
Post	2.51 ± 1.13	2.53 ± 1.16	2.59 ± 1.09			
Rate-corrected Left Ventricular Ejection Time (ms)				0.60	0.07	0.86
Ant	339.34 ± 63.74	341.50 ± 48.78	363.50 ± 62.73			
Lat	349.14 ± 55.72	330.07 ± 69.18	356.14 ± 77.38			
Post	326.82 ± 65.93	324.73 ± 69.86	341.36 ± 42.08			
Peak Velocity ($cm.s^{-1}$)				0.81	0.5	0.02 *
Ant	42.75 ± 13.39	42.53 ± 13.45	41.56 ± 13.91			
Lat	49.43 ± 17.10	41.57 ± 16.17	41.43 ± 16.68			
Post	41.82 ± 13.43	47.55 ± 15.04	45.45 ± 11.15			

*statistically significant; Ant: anterior wall (distal anastomoses of the anterior descending coronary artery [AD] and diagonal artery [DI]); Lat: lateral wall (distal anastomosis of the left marginal artery); Post: posterior wall (distal anastomosis of the right coronary artery or its posterior branches).

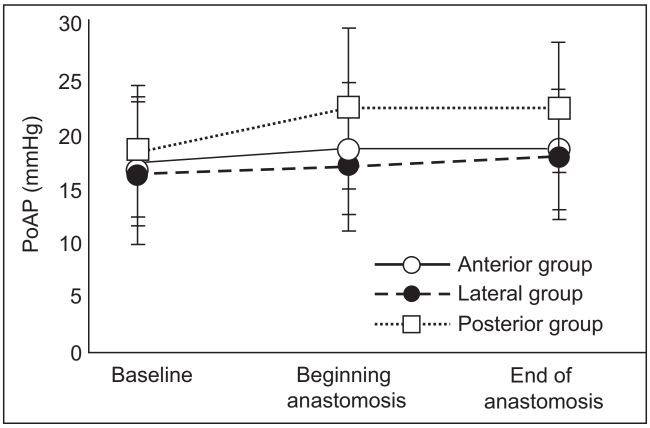

Figure 1 – Pulmonary Artery Occlusion Pressure (mean and SD, in mmHg).
$p < 0.001$ for initial and final times when compared to baseline levels. A significant difference between groups was not observed.

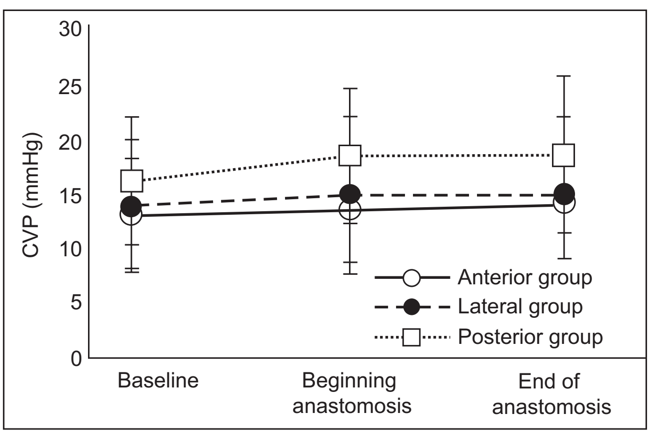

Figure 2 – Central Venous Pressure (mean and SD, in mmHg).
$p = 0.007$**,** for the initial time, and 0.006, for the final time, when compared to baseline levels. A significant difference between groups was not observed.

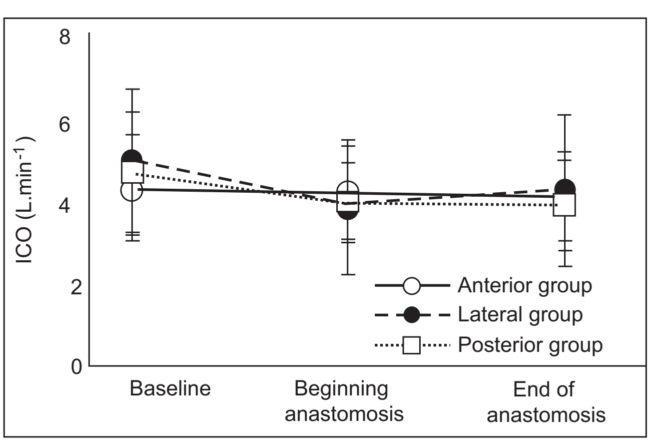

Figure 3 – Intermittent Cardiac Output (mean and SD, in $L.min^{-1}$).
$p < 0.001$ for initial and final times when compared to baseline levels. A significant difference between groups was not observed.

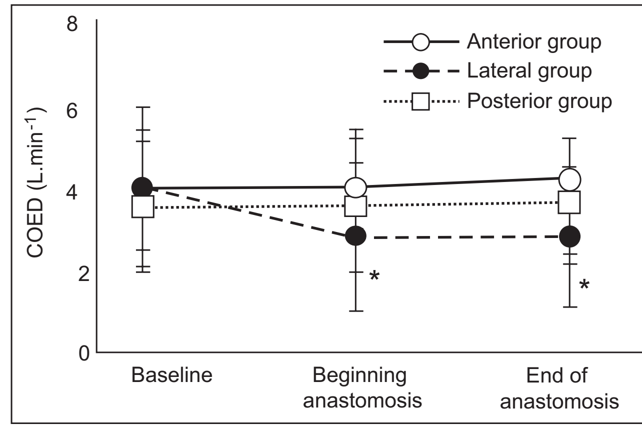

Figure 4 – Cardiac Output by Transesophageal Doppler (mean and SD, in $L.min^{-1}$).
* $p = 0.02$ in the lateral group for initial and final times when compared to baseline levels.

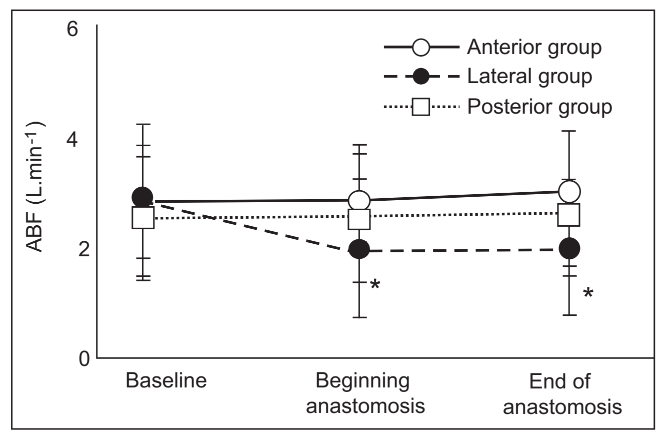

Figure 5 – Aortic Blood Flow (mean and SD, in $L.min^{-1}$).
* $p = 0.02$ in the lateral group for initial and final times when compared to baseline levels.

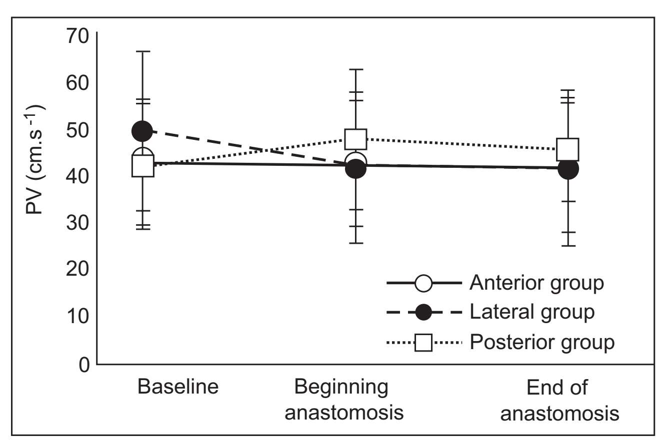

Figure 6 – Peak Velocity Levels (mean and SD, in $cm.s^{-1}$).
A significant difference between groups or times was not observed.

ber complacency, which might have changed by the greater alteration in cardiac axis in these situations.

A statistically significant group-time interaction was observed for some parameters obtained by transesophageal Doppler: aortic blood flow and cardiac output derived from this flow, in addition to peak velocity. The former, along with the level of maximal acceleration of aortic blood flow, is an indicator of myocardial contractility, which correlates to the dP/dt index obtained by left ventricular catheterization [4].

Analysis of the left cardiac output by analyzing the aortic blood flow with Doppler can provide the flow value effectively directed to the target-organ perfusion. For this monitor, manipulation of the heart could have less influence on cardiac output, but we observed that manipulation with surgical instruments occasionally compressed or dislocated the thoracic aorta, especially during procedures on postero-lateral walls of the heart.

Other parameters that indicate cardiac pre-load were analyzed, such as RVEDVI, obtained with the pulmonary artery catheter, and cLVET obtained with the transesophageal Doppler monitor. As these indices did not show any changes between the study groups during the procedure, it could be an indication of volemic adjustment efficacy.

Hemodynamic data of interest were collected at two distinct times: immediately after surgical positioning and after approximately 5 minutes. These times were chosen because the first one would indicate initial hemodynamic instability, and the second would represent a relative stabilization of the parameters in the position set. Coronary anastomoses were performed in different sites in the three study groups. However, procedures within each group also could vary if performed in more proximal or distal sites in the same coronary artery. Besides, the order of anastomosis was not uniform, but established by the surgical team. It was not possible to indicate whether the time for hemodynamic recovery of baseline data would have been enough.

Myocardial revascularization without ECC has been improving, both in surgical technique and anesthetic management and monitoring. Current studies provide new information describing the behavior of hemodynamic parameters in this specific condition of instability.

In summary, significant hemodynamic changes were observed during myocardial revascularization without ECC, with increase in PoAP and CVP, and reduction in ICO. Reduction in COED and ABF was only observed in distal coronary anastomosis performed on the lateral wall.

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Resumen: Kim SM, Malbouisson LMS, Auler Jr. JOC, Carmona MJC – Alteraciones Hemodinámicas Durante la Revascularización del Miocardio sin Utilización de Circulación Extracorpórea.

Justificativa y objetivos: El posicionamiento y la estabilización cardíaca durante la revascularización miocárdica sin circulación extracorpórea (CEC), puede causar alteraciones hemodinámicas de acuerdo con el local abordado. El objetivo de este estudio fue evaluar esas alteraciones durante la realización de las anastomosis coronarias distales.

Métodos: Veinte pacientes adultos fueron sometidos a la revascularización del Miocardio sin CEC, y recibieron monitorización con catéter de arteria pulmonar y ecodoppler transesofágico. Los datos hemodinámicos fueron recolectados así: (1) posteriormente a los ajustes volémicos, (2) al inicio de las anastomosis distales y (3) después de cinco minutos antes de la retirada del estabilizador de pared. Las coronarias tratadas fueron agrupadas según su ubicación: en la pared lateral, anterior o posterior. Fue realizada ANOVA de doble factor con repetición y un nuevo test de Newman-Keuls. Se tuvo en cuenta el p mayor que 0,05.

Resultados: Durante la revascularización del Miocardio sin CEC, la presión de oclusión de la arteria pulmonar se elevó de 17,7 ± 6,1 para 19,2 ± 6,5 ($p < 0{,}001$) y 19,4 ± 5,9 mmHg ($p < 0{,}001$), y la presión venosa central de 13,9 ± 5,4 para 14,9 ± 5,9 ($p = 0{,}007$) y 15,1 ± 6,0 mmHg ($p = 0{,}006$). El débito cardíaco intermitente sufrió una reducción de 4,70 ± 1,43 para 4,23 ± 1,22 ($p < 0{,}001$) y 4,26 ± 1,27 $L.min^{-1}$ ($p < 0{,}001$). Hubo una interacción grupo-tiempo significativa en el débito cardíaco obtenido por Doppler transesofágico, que sufrió una reducción en el grupo lateral de 4,08 ± 1,99 para 2,84 ± 1,81 ($p = 0{,}02$) y 2,86 ± 1,73 $L.min^{-1}$ ($p = 0{,}02$), y en el flujo sanguíneo aórtico, de 2,85 ± 1,39 para 1,99 ± 1,26 ($p = 0{,}02$) y 2,00 ± 1,21 $L.min^{-1}$ ($p = 0{,}02$). No se observaron otras alteraciones hemodinámicas durante las anastomosis.

Conclusiones: Se produjo una deterioración hemodinámica significativa durante la revascularización del miocardio sin CEC. Con el Doppler transesofágico se detectó una reducción del débito cardíaco solamente en el grupo lateral.

Descriptores: CIRUGÍA: Cardíaca, Vascular; EQUIPOS: Oxigenador, Circulación Extracorpórea; EXAMENES DIAGNÓSTICOS: Ecocardiografía, transesofágica; MONITORIZACIÓN; TÉCNICAS DE MEDICIÓN: Hemodinámica.

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