Clinical and echocardiographic predictors of low cardiac output syndrome after heart valve surgery

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ABSTRACT

Objective: To determine the possible clinical and echocardiographic predictors associated with the onset of low cardiac output syndrome.
Materials and methods: An analytical case-control study was conducted in patients with postoperative low cardiac output syndrome treated at Centro de Cardiología y Cirugía Cardiovascular of Hospital Provincial Docente Saturnino Lora in Santiago de Cuba from January 2019 to December 2021. Both study groups were part of the same population of patients who underwent a cardiovascular surgery but differed in the fact that, at admission, some suffered from postoperative low cardiac output syndrome and others did not. The dependent variable was the presence of low cardiac output and the independent variables were clinical, hemodynamic and echocardiographic factors.
Results: In the series, patients under 65 years of age prevailed in both case and control groups (51.2 % and 73.5 %, respectively). Atrial fibrillation, right ventricular systolic function and perioperative bleeding ($p = 0.008$) were statistically significant ($p < 0.05$). Most patients (102 [91.10 %; $p = 0.047$]) showed a left ventricular ejection fraction (LVEF) > 50 % and a large number of patients (76 [45.24 %; $p \leq 0.05$; *OR*: 2.14]) had undergone emergency surgeries. A logistic regression analysis determined that the clinical and echocardiographic variables, such as age over 65 years, depressed right ventricular function, extracorporeal circulation ≥ 90 minutes and elevated pulmonary artery systolic pressure, had a statistically significant association. The area under the curve (AUC) showed that variables including age, extracorporeal circulation time and perioperative bleeding had predictive capability.
Conclusions: It was observed that some clinical and echocardiographic elements, such as age, atrial fibrillation, depressed right ventricular systolic function and emergency surgery, were associated as predictors of low cardiac output syndrome.

Keywords: Cardiac Output, Low; Thoracic Surgery; Echocardiography (Source: MeSH NLM).

Predictores clínicos y ecocardiográficos del síndrome de bajo gasto cardiaco en la cirugía valvular cardiaca

RESUMEN

Objetivo: Determinar los posibles elementos predictores clínicos y ecocardiográficos asociados a la aparición del síndrome de bajo gasto cardiaco.
Materiales y métodos: Se realizó un estudio analítico de casos y controles en pacientes con síndrome de bajo gasto cardiaco posoperatorio atendidos en el Centro de Cardiología y Cirugía Cardiovascular del Hospital Provincial Docente Saturnino Lora de Santiago de Cuba, desde enero 2019 a diciembre 2021. Ambos grupos de estudio formaron parte de la misma población de pacientes operados de cirugía cardiovascular, diferenciados por presentar o no síndrome de bajo gasto cardiaco postoperatorio al ingreso. La variable dependiente fue la presencia de bajo gasto cardiaco; las variables independientes, factores clínicos, hemodinámicos y ecocardiográficos.
Resultados: En la serie predominaron los pacientes menores de 65 años tanto en el grupo de casos como de controles (51,2 % y 73,5 %, respectivamente). La fibrilación auricular, la función sistólica del ventrículo derecho y la hemorragia periprocedimiento ($p = 0,008$) presentaron alta significación estadística $p < 0,05$. Se observó mayoría de pacientes con FEVI > 50 % (102 [91,10 %; $p = 0,047$]), así como amplio dominio de pacientes (76 [45,24 %; $p \leq 0,05$; OR: 2,14]) con cirugías de emergencia. Se realizó una regresión logística, y se determinó que las variables clínicas y ecocardiográficas tales como la edad superior a 65 años, la función de ventrículo derecho deprimida, la circulación extracorpórea ≥90 minutos

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y la presión sistólica de arteria pulmonar elevada tuvieron una asociación estadísticamente significativa. El AUC mostró que variables como la edad, el tiempo de circulación extracorpórea y la hemorragia perioperatoria tuvieron capacidad predictiva.
Conclusiones: Se observó que algunos elementos clínicos y ecocardiográficos, como la edad, la presencia de fibrilación auricular, la función sistólica del ventrículo derecho deprimida y la cirugía de emergencia, se asociaron como predictores de síndrome de bajo gasto cardíaco.

Palabras clave: Gasto Cardíaco Bajo; Cirugía Torácica; Ecocardiografía (Fuente: DeCS BIREME).

INTRODUCTION

Low cardiac output syndrome (LCOS), a clinical manifestation of decreased cardiac output and peripheral tissue perfusion, was first proposed by Rao et al. [1] Previous studies have shown that all-cause mortality in LCOS ranges from 14.8 to 62.5 % in the short term (one month after its onset) and from 21.4 to 36.6 % in the long term (two months to one year after its onset) [2]. LCOS after heart surgery leads not only to poor tissue perfusion but also to multiple organ dysfunction of the brain, lungs, liver, kidneys and gastrointestinal tract, which increases the use of health care resources and associated costs [3]. More importantly, LCOS may cause reversible decrease in cardiac output (CO) after heart surgery. The early detection and appropriate treatment of LCOS can prevent its progression to refractory cardiogenic shock and improve clinical outcomes, so its early detection is extremely important [4].

According to studies conducted in North America (USA and Canada), 45 % of worldwide surgical activity decreased between March and April 2020 compared to that performed in 2019. There was an increase of up to 7 % in coronary artery surgeries, probably at the expense of urgent surgeries, with significant decreases in heart valve surgeries of up to 7.5 % [5].

In 2020 [6], in Spain, heart valve replacement and coronary artery surgeries showed a mortality rate of 13.61 %. Polyvalvular and coronary artery surgeries also showed similar figures (12.07 %), which is associated with intra- and postoperative complications such as low cardiac output (LCO).

According to Vera-Rivero et al. [7], Cuba is one of the few developing countries capable of cooperating in the cardiovascular surgery field, and the specialty got started with the creation of heart centers in different regions of the country.

Statistical data [8] shows that between 2019 and 2020 a total of 3,004 patients underwent surgical treatment due to a cardiovascular pathology.

Bertini et al. [9] state that perioperative morbidity and mortality remain two of the main limitations of heart surgery with extracorporeal circulation, despite they have progressively been reduced over the last decades.

Based on the foregoing, this research was conceived to determine the possible clinical and electrocardiographic predictors associated with the onset of LCOS and how they can influence on its progression.

MATERIALS AND METHODS

Study design and population

An analytical case-control study was conducted in patients with preoperative LCOS after undergoing cardiovascular surgery and extracorporeal circulation at Centro de Cardiología y Cirugía Cardiovascular (Cardiology and Cardiovascular Surgery Center) of Hospital Provincial Docente Saturnino Lora in Santiago de Cuba from January 2019 to December 2021.

For that purpose, two study groups were formed and the members thereof were selected as follows:

Shoonen et al. [10] defined a case as a patient who had oliguria (diuresis under 0.5 ml/kg/h), central venous oxygen saturation < 60 % (with normal arterial oxygen saturation) and/or lactate > 3 mmol/l (without relative hypovolemia). The administration of inotropes continued in patients who underwent surgery in order to achieve an adequate hemodynamic state.

Both study groups (cases and controls) were part of the same population of patients who underwent cardiovascular surgery (360 patients) but differed in the fact that, at admission, some suffered from postoperative LCOS and others did not. The case group consisted of all the patients with LCOS (56 patients) and the control group of those without LCOS selected by 1:1 simple random sampling (56 patients).

The study excluded those controls that showed, during the medical record review, lack of information to meet the objectives of the research.

Variables and measurements

Dependent variable: postoperative LCOS.

Independent variables: clinical, hemodynamic and echocardiographic factors.

The following variables were defined and operationalized in order to meet the objectives of the research:

1. Age: over 65 years, under 65 years.
2. Sex: male, female.
3. Comorbidities of interest in the research: chronic obstructive pulmonary disease (COPD), diabetes mellitus (DM), ischemic heart disease, atrial fibrillation (if the medical record shows evidence that the patient had a history of such condition).
4. Echocardiographic variables.

Echocardiograms were performed using Philips iE33 xMATRIX ultrasound system 48 hours before the surgery in patients scheduled for elective surgery, and the day of the surgery in those who required urgency surgery.

I. Left ventricular ejection fraction (LVEF):

- LVEF ≥ 50 %
- LVEF < 50 %

II. Tricuspid annular plane systolic excursion (TAPSE): it allows the evaluation of the right ventricular systolic function. Values over 17 mm are considered normal.

- RVEF ≥ 17 mm (conserved right ventricular systolic function)
- RVEF < 17 mm (depressed right ventricular systolic function)

III. Pulmonary artery systolic pressure (PASP): it is estimated by calculating the systolic pressure gradient between the right atrium and ventricle from the peak tricuspid regurgitation velocity. Values under 30 mmHg are considered normal.

- PASP Yes (for values over 30 mmHg)
- PASP No (for values under 30 mmHg)

Statistical analysis

Data on the epidemiological, clinical and echocardiographic variables of interest was obtained from the medical records. It was entered in a collection sheet designed for that purpose, which ensured its preservation in the event of irreversible damage to the digital media, since the data was collected in a Microsoft Excel spreadsheet.

The Microsoft Excel spreadsheet containing the primary information, both on cases and controls, was imported using IBM SPSS Statistics V22, with which all the statistical processing was carried out. Numbers and percentages were calculated as summary measures for the qualitative variables; the Kolmogorov–Smirnov test was used to examine the normality of the variables for the quantitative variables.

A chi-square test was carried out. All the statistical analyses were two-tailed (two-sided) and p values < 0.05 were considered statistically significant. To determine the association strength, the odds ratio (OR) with a 95 % confidence interval (CI), as well as the population attributable risk percent (PARP) and the attributable risk percent for the exposed (ARPE), were calculated.

The tables were analyzed and discussed by means of inductive and deductive scientific methods. The results were compared to similar studies, thus allowing us to come to conclusions and give recommendations.

Ethical considerations

The authors state their commitment to confidentiality and protection of the information collected during the research. Authorization of the Center's management and approval of the Research Ethics Committee and the Scientific Board were also requested to conduct the research.

RESULTS

Table 1 shows the prevalence of patients under 65 years of age (51.81 %), a larger number of patients in the case group (60.71 %) and a p value = 0.008, which corresponds to a highly significant association. Furthermore, it shows that 96 (85.68 %) patients had atrial fibrillation, with a smaller number in both study groups, though an extremely high statistical association (p = 0.007) was found. Concerning the echocardiographic parameters, a high prevalence of patients with LVEF > 50 % (91.10 % [p = 0.047]) was observed, with a larger number in both groups of patients. Moreover, a larger number of patients with RVEF > 17 mm (88.40 % [p = 0.008]) was evidenced. Both variables were statistically significant; other variables such as sex, DM, COPD, ischemic heart disease and PASP were not statistically significant (Table 1).

Table 1. Multivariate analysis by study group

Clinical and echocardiographic variables		Study group: Cases *n*	Cases %	Controls *n*	Controls %	Total *N*	Total %	*p*
Age	< 65 years	22	39.29	36	64.24	58	51.81	0.008
	> 65 years	34	60.71	20	35.76	54	48.19	
Sex	Female	31	55.45	25	44.53	56	50.15	0.257
	Male	25	44.55	31	55.47	56	49.85	
DM	No	44	78.61	39	69.62	83	74.10	0.281
	Yes	12	21.39	17	30.38	29	25.90	
COPD	No	40	71.28	45	80.23	85	75.88	0.269
	Yes	16	28.72	11	19.77	27	24.12	
Atrial fibrillation	No	43	76.83	53	94.62	96	85.68	0.007
	Yes	13	23.17	3	5.38	16	14.31	
Ischemic heart disease	No	40	71.42	41	73.15	81	72.27	0.833
	Yes	16	28.58	15	26.75	31	27.72	
LVEF	< 50 %	8	14.32	2	3.65	10	8.90	0.047
	> 50 %	48	85.68	54	96.35	102	91.10	
RVEF	< 17 mm	11	19.60	2	3.55	13	11.60	0.008
	> 17 mm	45	80.40	54	96.45	99	88.40	
PASP	No	39	69.61	42	75.25	81	72.30	0.526
	Yes	17	30.39	14	25.75	31	27.70	

Chi-square: $p \leq 0.05$; COPD: chronic obstructive pulmonary disease; LVEF: left ventricular systolic function; RVEF: right ventricular systolic function; PASP: pulmonary artery systolic pressure.
Source: medical records.

Emergency surgery was one of the parameters evaluated in this research. As shown in Table 2, a large number of patients (45.24 % [$p \leq 0.05$; *OR*: 2.14]) underwent emergency surgery, thus showing statistical significance, and LCO posed a risk factor for those patients.

Measures of public health impact such as ARPE and PARP showed that 33 % of the cases, i.e., patients with LCO, were the result of non-elective surgeries. In the event that adequate elective surgeries were performed, these sequelae would be reduced by 51.7 % (Table 2).

Table 2. Patients by emergency surgery and study group

Emergency surgery	Cases *n*	Cases %	Controls *n*	Controls %	Total *N*	Total %	*p*	*OR*
Yes	34	60.71 %	42	37.50 %	76	45.24 %	0.004	2.14
No	22	39.29 %	70	62.50 %	92	54.76 %		

ARPE = 33 %; PARP = 51.7 %

Chi-square: $p \leq 0.05$; *OR*: odds ratio; ARPE: attributable risk percent for the exposed; PARP: population attributable risk percent.
Source: medical records.

As for parameters such as extracorporeal circulation time, data from 50 patients (29.76 % [*p* = 0.000; *OR*: 1.54; *LL*: 0.73; *UL*: 3.24]) demonstrated that it is a predisposing factor in patients whose time exceeds 90 minutes. Concerning the perioperative bleeding, a small number of patients (12.50 % [*p* = 0.013; *OR*: 3.12; *LL*: 1.22; *UL*: 7.93]) showed an extremely high statistical significance; moreover, bleeding more than 500 ml posed a risk factor for the onset of LCOS (Table 3).

Table 3. Multivariate analysis according to the study group

Periprocedural variables		Study group						*p*	*OR*	*LL*	*UL*
		Cases		Controls		Total					
		n	%	*n*	%	*N*	%				
ECC time	≥ 90 minutes	31	55.36	19	16.96	50	29.76	0.000	1.54	0.73	3.24
	< 90 minutes	25	44.64	93	83.04	118	70.24				
Perioperative bleeding	≥ 500 ml	12	21.43	9	8.04	21	12.50	0.013	3.12	1.22	7.93
	< 500 ml	44	78.57	103	91.96	147	87.50				

ECC time: extracorporeal circulation time; chi-square: $p \leq 0.05$; OR: odds ratio; LL: lower limit; UL: upper limit.
Source: medical records.

A logistic regression analysis was used to determine how the clinical and echocardiographic variables affect the probability of presenting LCOS. A total of 112 cases were used in the analysis. The model explained 78.9 % of LCOS cases in surgical patients. Variables such as age, RVEF, EEC and PASP showed *p* values ≤ 0.05, which allows us to conclude that they have a statistically significant association with complications. Variables such as LVEF and perioperative bleeding did not have statistical significance ($p > 0.05$) (Table 4).

Table 4. Logistic regression analysis according to the study variables

Variables	B	Wald	Sig.	Exp(B)	95 % CI for Exp(B)	
					Lower	Upper
Age	-2.039	23.317	0.000	0.130	0.057	0.298
Perioperative bleeding	-1.028	3.246	0.072	0.358	0.117	1.095
ECC time	1.639	12.574	0.000	5.150	2.082	12.744
LVEF	-0.826	2.021	0.155	0.438	0.140	1.368
RVEF	1.894	10.566	0.001	6.644	2.121	20.812
PASP	-1.089	4.137	0.042	0.337	0.118	0.961
Constant	0.952	0.246	0.620	2.592		

Chi-square: $p \leq 0.05$; LVEF: left ventricular systolic function; RVEF: right ventricular systolic function; PASP: pulmonary artery systolic pressure.
Source: medical records.

When analyzing the area under the curve (AUC) (Table 5) and the receiver operating characteristics (ROC) curve (Figure 1), based on sensitivity and specificity, it was found that the AUC had a range of 0.452–0.762. Thus, variables such as LVEF, extracorporeal circulation time and perioperative bleeding can predict LCOS risk.

Table 5. AUC analysis

Variable(s)	AUC Area	Asymptotic significance	95 % CI	
			LL	*UL*
Age	0.699	0.000	0.614	0.784
LVEF	0.574	0.106	0.493	0.654
RVEF	0.452	0.293	0.358	0.546
ECC time	0.762	0.000	0.683	0.840
Perioperative bleeding	0.660	0.000	0.574	0.746

Chi-square: $p \leq 0.05$; LVEF: left ventricular systolic function; RVEF: right ventricular systolic function; ECC time: extracorporeal circulation time; ; LL: lower limit; UL: upper limit.
Source: medical records.

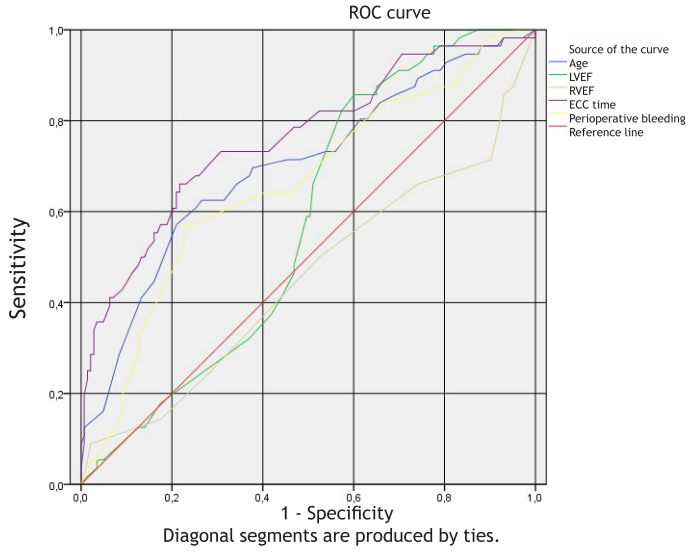

Figure 1. AUC of predictor variables

DISCUSSION

LOCS is a frequent and serious complication in heart surgery patients. However, both the incidence and response to treatment and later progression have been highly variable in different publications to date.

Age is an independent cardiovascular risk factor; therefore, the probability of death increases with age, which has been validated in different risk scales. Although the risk of death increases exponentially, some studies show that the probability of dying triples in people over 75 years of age [11].

Lorenzo [12], in a review article, claimed that being older than 65 years is one predisposing factor for complications and LCO in heart surgery patients.

Pérez Vela et al., in a multicenter study published in 2018, stated that 68.3 ± 9.3 years of age was one of the factors mostly associated with the onset of postoperative low output and that 65.2 % were males [13]. A study conducted by Fernández Mesa et al. [14], which included 156 patients who underwent surgery due to left valvular heart diseases in 2018, reported that 46 of them had LCO and patients over 65 prevailed in this group.

The abovementioned authors' statements agree with what is shown in this study.

Zhao et al. [15], in a study conducted at Guangdong Provincial People's Hospital, showed the prevalence of males (69.8 %) compared to females (30.2 %). Males did not have the highest scores in the research results, which disagrees with the literature and this research results.

The presence of comorbidities such as DM, high blood pressure and COPD, among others, is also associated with complications, including LCO. According to Cubides Núñez, the most frequent comorbidity in his study was high blood pressure, followed by COPD [16].

In the previously mentioned study conducted by Fernández Mesa et al. [14], COPD and chronic atrial fibrillation were the most frequent comorbidities in the group of patients with LCO.

Pérez Vela et al. [13] reported in their study that high blood pressure and dyslipidemia were found in patients that developed LCOS in their series, with 70.8 % and 63.5 %, respectively.

The research on atrial fibrillation conducted by Gómez Núñez et al. [17] showed that one of the most frequent complications was LCO, which was observed in 23 % of the patients.

When comparing such evidence to this research, there are similar aspects in the description of atrial fibrillation by the aforementioned authors. In this research, fibrillation had high statistical significance, which agrees with what has been stated.

Perioperative left ventricular systolic dysfunction has been considered a predisposing factor for postoperative LCOS, as shown in the literature. Sepúlveda et al. [18] reported segmental contraction abnormalities in 273 patients (58.6 %), out of which 208 (59.4 %) required intraoperative inotropic support. Moreover, they stated that 35 (83.3 %) out of 42 patients with reduced ejection fraction or ejection fraction under 40 % had LCO. This agrees with a study conducted by Li et al. [19], where an ejection fraction under 40 % was considered a predictor. Burstein et al. [20] found ejection fraction values of approximately 47.3 % with a standard deviation of ± 16.2 %. Our study showed the onset of LCO in patients with an ejection fraction > 50 %, which demonstrates the varying nature of this condition.

The evaluation of the right ventricular (RV) function is a key aspect in heart surgery patients, not only before surgery but also in the early postoperative period. This is evidenced in studies such as those conducted by Fernández et al. [14], who claimed that patients with LCO had lower RVEF, higher mean pulmonary arterial and right atrial pressure, and higher pulmonary arterial systolic pressure, all of them showing significant differences ($p < 0.0001$). This is consistent with the findings of this research.

Fernández Mesa et al. [14], in their multivariate analysis, found that the main predictors of the onset of LCO were prolonged extracorporeal circulation time (*OR*: 4.89; $p = 0.001$), age over 65 years, sex and LVEF ≤ 40 %, which agrees with this research.

Additionally, González Kadashinskaia et al. [21] mentioned that extracorporeal circulation was one of the most common procedures in surgical operations, with almost 55 %, which indicates that this is a widely used technique. Likewise, Fernández Mesa et al. [14] pointed out in their study that prolonged extracorporeal circulation time is associated with a higher probability of suffering such complication, which is consistent to the results of this study.

In another article by Fernández Mesa et al. [22], they concluded that patients with LCO were 3.5 times more likely to die in the five-year period after surgery than those who did not had this condition.

Lorenzo [12], in his review article, mentioned that a single-center study published by Ding et al. included 1,524 heart surgery patients, out of which 205 developed LCOS. Then, a multivariate analysis led to conclude that age over 65 years, LVEF < 50 % and surgery with extracorporeal circulation were independent factors for LCO. In this regard, Jiménez Hernández et al. [23] drew similar conclusions.

Aslan et al. [24] reported that markedly prolonged aortic clamp time and total cardiopulmonary bypass time are predictors of the onset of LCO.

Maganti et al. [25] claimed in a study that 7 % of the cases presented postoperative LCO, which was associated with urgency surgery and low ejection fraction.

Kochar et al. [26] stated in a multivariate and multicenter research that the factors mostly associated with a higher risk of LCO were preoperative ejection fraction and age, thus resulting in patients with the worst results. In this regard, Lui et al. [27] showed evidence of a predictive model based on variables such as age, and preoperative factors such as low LVEF and aortic clamp time.

Elhenawy et al. [28] associated mitral valve surgery with a higher prevalence of postoperative LCOS when factors such as age, urgency surgery and preoperative left ventricular function were involved. In turn, Seguel et al. [29] reported low incidence of LCO.

Additionally, De Lima et al. [30] described in their research that the conditions that exacerbate complications during the immediate postoperative period after heart surgery are perioperative bleeding and atrial fibrillation, the former with an incidence of up to 50 %.

The main limitation of this research was basically not having an adequate sample size to determine the behavior of postsurgical complications. It should be noted that this data was collected from a center of cardiovascular medicine, which allows—in any case—reflecting its strengths and obvious limitations.

In conclusion, clinical and echocardiographic elements such as age, atrial fibrillation, LVEF and PASP were independently associated with the onset of LCO.

Author contributions: YRG conceived the idea of drafting an original article, as well as its conceptualization, data curation, project administration; performed the primary data collection from patients' medical records, tabulation, bibliographic search, statistical analysis and table creation; and participated in the group discussion of the final version. YGG participated in the statistical analysis, bibliographic search, formal analysis, methodology and supervision; wrote the discussion and conclusions sections; and participated in the group discussion of the final version. LCC assisted with the bibliographic search, display, writing and group discussion of the final version.

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