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ORIGINAL PAPER

Improving risk assessment for post-surgical low cardiac output syndrome in patients without severely reduced ejection fraction undergoing open aortic valve replacement. The role of global longitudinal strain and right ventricular free wall strain

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Abstract Low cardiac output syndrome (LCOS) after surgical aortic valve replacement (SAVR) is related to increased mortality and treatment related costs. We aimed to evaluate whether echocardiography-derived left ventricular global longitudinal strain (LV-GLS) relates to the occurrence of postoperative LCOS in patients undergoing SAVR. We prospectively enrolled 75 patients with symptomatic severe aortic stenosis, left ventricular ejection fraction (LVEF) >40%, NYHA Class <IV, without other significant valve disease. Echocardiographic examination, including LV-GLS assessment was performed before SAVR. In a subgroup of patients right ventricular free wall strain (RVFWS) was also measured. The main outcome was the occurrence of LCOS. Secondary outcome was 30-day mortality. Patients were divided according to LCOS occurrence, which was found in 41% of the population. Baseline clinical characteristics were similar between groups except for LVEF, and LV-GLS. We found LV-GLS to be related to 30-day mortality (OR 1.3, $p<0.041$, 95% CI 1.02–1.69). After multivariate analysis for variables related to LCOS, only age ($p=0.034$), LVEF ($p=0.037$) and LV-GLS ($p=0.040$) independently predicted LCOS. Mean RVFWS was lower in patients in whom the primary outcome occurred (-12.8 ± 4.3 vs. -17.1 ± 3.9, $p=0.0081$). In ROC curves analysis a RVFWS of −15% yielded a sensitivity of 81.2% and specificity of 71.4% for the occurrence of LCOS. LV-GLS is a useful parameter for risk stratification in patients with severe aortic stenosis without severely depressed LVEF, and is independently associated with LCOS occurrence. RVFWS wall strain may be useful for risk stratification in patients undergoing AVR.

Keywords Aortic stenosis · Cardiac surgery · Low cardiac output syndrome · Strain

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Introduction

Aortic stenosis (AS) currently constitutes the most common form of valvular heart disease in developed countries. Although an increasing number of patient subgroups are being considered for transcathether aortic valve implantation (TAVI), surgical aortic valve replacement (SAVR) remains the main therapeutic modality [1].

Low cardiac output syndrome (LCOS) is a feared complication of cardiac surgery, which significantly increases mortality and treatment-related costs [2, 3]. In patients

in whom SAVR is performed, LCOS is associated with a 30-day mortality of 38%, in contrast to 1.5% in patients without LCOS [2]. Despite recent studies suggest a wide LCOS incidence of 3–45%, [3, 4] mortality related to this entity remains a matter of concern [5].

Although several parameters have been found to predict LCOS after SAVR, risk stratification remains less than optimal. Among such parameters preoperative renal failure, depressed left ventricular ejection fraction (LVEF), shock before surgery, female sex and age have been previously described [6–8].

Novel echocardiographic techniques based on speckle tracking, have proved to closely correlate with myocardial contractility [9, 10]. In particular, global longitudinal strain (LV-GLS) has been shown to be a powerful tool for risk assessment, offering prognostic value beyond LVEF in patients with valvular heart disease and cardiomyopathies [11–13].

Although LV-GLS has been found to correlate with other early postoperative outcomes [14], its role in LCOS development has not been explored. Therefore, the aim of the present study was to evaluate whether echocardiography-derived LV-GLS is related to the occurrence of postoperative LCOS in patients undergoing SAVR.

Methods

Study population

We prospectively included patients with symptomatic severe AS who were scheduled to undergo SAVR in our institution. Eligible patients (n = 110) were offered participation in the study. Inclusion criteria were symptomatic severe AS defined by peak aortic velocity > 4 m/s and/or mean gradient > 40 mmHg. Patients with severe mitral regurgitation, severe aortic regurgitation, acute decompensated heart failure (ADHF) and more than moderately depressed LVEF (<40%) were excluded. Our study complies with the Declaration of Helsinki and was previously approved by our institution local ethics committee. All subjects provided informed consent. Baseline clinical characteristics were obtained from the patients' electronic records. After SAVR, a single observer blinded to echocardiographic data followed patients' status and events.

Outcome

The primary outcome was the occurrence of LCOS defined as: requirement of inotropic medications (dobutamine, norepinephrine, levosimendan) or an intra-aortic balloon pump (IABP) for at least 12 h after ICU admission to maintain a cardiac index (CI) of at least 2.2, and the presence of at least one of the following, pulmonary capillary wedge pressure (PCWP) > 18 mmHg, central venous oxygen saturation < 60%, or urinary output less than 0.5 ml/kg/h [4]. Secondary outcomes included in hospital and 30 day mortality.

Echocardiography

Comprehensive echocardiography was performed preoperatively using a Phillips IE33 system (Phillips Medical Systems, Andover, MA, USA). Conventional views were obtained and measures were performed as recommended by current guidelines [16]. A four chamber, two chamber and apical long axis view were recorded with a frame rate ranging from 50 to 70 frames/s. Offline analysis was performed using QLAB 10.3 software (cardiac motion quantification (CMQ); Phillips Medical Systems). LVEF was calculated using Simpson's biplane method with automated 2D cardiac quantification (A2DQ). Longitudinal strain was computed using 2D Splecke Tracking Analysis (aCMQ). LV-GLS was not assessed if more than two segments in the same view were not adequately tracked. Right ventricular free wall strain (RVFWS) was measured in patients in whom a focused right chamber view with high frame rate was available. RVFWS was assessed using a six segment ROI model and is expressed as a mathematical mean, derived from manually averaging the value of the three free wall segments. Inter and intra-observer variability for LV-GLS was assessed offline in ten patients.

Statistical analysis

Normality was assessed using Kolmogorov–Smirnov test. Continuous variables are expressed as mean and standard deviation (SD) or median and interquartile range (IQR), as appropriate. Differences in continuous variables were tested using an independent-samples t or Wilcoxon signed rank test. Categorical variables are expressed as absolute numbers with percentages. Comparisons were made using Pearson's Chi-squared test. After univariate analysis, a multiple stepwise logistic regression analysis was performed including previously reported clinically relevant variables and LV-GLS in order to evaluate for significant predictors of the occurrence of LCOS. Colinearity was not found between LV-GLS and other variables included in the model. Additionally, significant variables associated with all-cause mortality at 30 days were evaluated using logistic regression. To explore the value of RVFWS in the occurrence of LCOS, receiver operating characteristic (ROC) curves were constructed to determine sensitivity, specificity, +LR and −LR.

A two sided p-value <0.05 was considered statistically significant. All statistical analyses were performed using STATA v.12.1 (Version 22.0. Armonk, NY: IBM Corp.).

Results

We recruited 110 patients, 35 patients were excluded: 17 had severe valvular disease apart from AS, 12 ADHF, 4 LVEF <40%, and 2 patients two or more segments without adequate tracking in the same view when LV-GLS was measured. The final population consisted on 75 patients. Right ventricular free wall strain was assessed in 32 patients with optimal echocardiographic views were available.

Patients were divided according to the occurrence of LCOS, which occurred in 41% of patients. There were no significant differences between groups. Baseline clinical characteristics are shown in Table 1. Mean ICU stay time was longer and arrhythmias occurred more frequently among patients who developed LCOS although these were not statistically significant. All recorded deaths occurred in patients with LCOS. Figure 1. Regarding echocardiographic parameters only LVEF, and LV-GLS were different between groups, being lower in patients who developed LCOS. Table 2.

LCOS predictors

The final multiple logistic regression analysis was constructed based on the univariate analysis results, and previously documented variables associated with LCOS in the literature (age, gender, ischemic heart disease, diabetes mellitus (DM), LVEF, LV-GLS, and aortic clamp and extracorporeal circulation times). In this analysis, only age ($p < 0.034$), LVEF ($p < 0.037$) and LV-GLS ($p < 0.040$) resulted to be significant independent predictors for the occurrence of LCOS, as shown in Table 3.

Table 1 Baseline clinical characteristics in patients with and without LCOS

Variable	Non LCOS patients n = 44	LCOS patients n = 31	*p*-value
Age, years (SD)	60.4 ± 8.4	63.8 ± 9.2	0.103
Male, n (%)	27 (61)	19 (61)	0.950
Diabetes mellitus, n (%)	15 (34)	5 (16)	0.08
Hypertension, n (%)	19 (43)	15 (48)	0.685
Chronic renal disease, n (%)	2 (5)	2 (6)	0.725
Ischemic heart disease, n (%)	6 (14)	6 (19)	0.518
Previous atrial fibrillation, n (%)	0 (0)	2 (6)	0.089
NYHA class			0.786
I, n (%)	14 (32)	8 (25)	
II, n (%)	29 (66)	22 (70)	
III, n (%)	1(2)	1 (3)	
Creatinine, mg/dl (IQR)	0.88 (0.76–1.05)	0.925 (0.79–1.1)	0.652
BUN, mg/dl (IQR)	16.7 (14–19.6)	17.5 (15–25)	0.652
Biological prosthetic valve, n (%)	31 (68.8)	25 (78.1)	0.370
Mechanical prosthetic valve, n (%)	14 (31.1)	7 (21.8)	
CABG, n (%)	6 (13.3)	6 (18.7)	0.518
Mitral valve replacement, n (%)	1 (2.2)	2 (6.27)	0.368
Transfusion, n (%)	42 (95.4)	30 (96.7)	0.774
Extracorporeal circulation time, minutes (IQR)	99 (85–116)	101 (93–120)	0.219
Aortic clamp time, minutes (IQR)	72 (59–89)	79 (63–93)	0.383
Postsurgical AF, n (%)	7 (15.9)	10 (32.2)	0.096
Death, n (%)	0 (0)	5 (16.13)	0.006
ICU stay length, days (IQR)	5 (3.5-7)	6 (4–8)	0.054
Hospital stay, days (IQR)	26.5 (23–35)	31 (22–37)	0.209
Perioperative acute renal failure, n (%)	2 (4.5)	3 (9)	0.380
Renal replacement therapy, n (%)	0 (0)	3 (9)	0.300
Bleeding, n (%)	1 (2.27)	4 (12)	0.69
Infection, n (%)	6 (13.6)	6 (19)	0.506

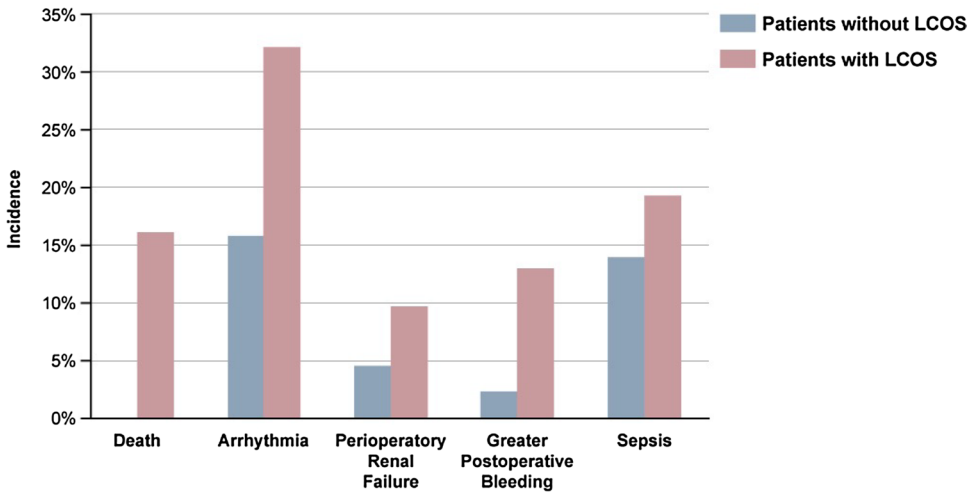

Fig. 1 Peri-opertaive events according to LCOS occurrence. Incidence of postoperative outcomes in patients with and without LCOS data is presented as percentage

Table 2 Echocardiographic parameters in patients with and without LCOS

Variable	Non LCOS N = 44	LCOS N = 31	p
LVIDD, mm (SD)	42.5 ± 6.7	44.5 ± 8.2	0.263
LVIDS, mm (IQR)	27.5 (23–30)	29 (23–38)	0.174
Septal wall thickness, mm (SD)	13.0 ± 2.2	13.6 ± 2.1	0.220
LVEF, % (IQR)	61 (55–65)	57 (44–62)	0.031
TAPSE, mm (IQR)	20 (19–23)	20 (18–24)	0.728
RVFAC, % (IQR)	45 ± 8.2	43 ± 6.4	0.472
S',cm/s (IQR)	11 (10–14)	11 (10–11)	0.246
RVSP, mmHg (IQR)	37.5 (29.5–45)	31 (25–47)	0.388
Aortic valve area, cm^2 (SD)	0.65 ± 0.15	0.62 ± 0.13	0.466
Aortic mean gradient, mmHg (SD)	61.8 ± 17.3	61.9 ± 16.6	0.987
Aortic peak gradient, mmHg (SD)	98.6 ± 26.2	98.9 ± 25.8	0.962
Aortic peak velocity, m/s (SD)	4.9 ± 0.63	4.8 ± 0.63	0.738
Posterior wall thickness, mm (SD)	12.9 ± 2.2	13.8 ± 2.0	0.07
LV-GLS, % (SD)	−17.0 ± 3.8	−14.1 ± 3.8	0.0017
Basal longitudinal strain, % (SD)	−14.7 ± 3.6	−13.4 ± 4.6	0.254

Although LV-GLS showed a modest risk increase with an OR of 1.19, 95% CI (1.0–1.4), this was independent from LVEF.

Secondary analyses

LV-GLS was significantly associated with 30-day mortality (OR 1.3, p < 0.041, 95% CI 1.02–1.69) in the univariate analysis. However, the association was lost in the multivariate analysis.

RVFWS was significantly lower in patients with LCOS (−12.8 ± 4.3 vs. −17.1 ± 3.9) [p = 0.008]), and this difference was greater than for LV-GLS (−14.1 ± 3.8 vs. −17.0 ± 3.8) Fig. 2. In order to evaluate the utility of RVFWS to predict LCOS occurrence, ROC curves were built. A cut off of 15% yielded a sensitivity of 81.2% and specificity of 71.4%, AUC 0.76, +LR of 2.86 of and –LR of 0.25 as shown in Fig. 3.

Interobserver and intraobsever variability

LV-GLS showed excellent reproducibility with a low interobserver variability ICC of 0.993 (95% CI 0.9473–0.998, p < 0.0001), and intra-observer variability ICC of 0.995 (95% CI 0.977–0.999, p < 0.0001).

Discussion

The present study demonstrates the association between LV-GLS and the occurrence of post-SAVR low cardiac output syndrome, independent from age, sex, LVEF and other relevant variables previously described. It should be noted that the incidence of LCOS is not consistent among studies, and a uniform definition is highly needed. In a previous study looking at prolonged inotropic support > 48 h a prevalence of 32% was found [14]. The higher prevalence of LCOS in our population can be explained by the definition selected and the lower absolute strain values found in our study, reflecting a higher degree of LV subclinical dysfunction.

In patients with AS, LVEF is regarded as one of the most useful parameters for risk assessment to predict mortality and other hard outcomes. Furthermore, LVEF is included in risk models such as EUROSCORE [15]. The optimal parameter for risk assessment should identify patients

Table 3 Multivariate analysis for predictors of postoperative LCOS

Variable	Odds ratio	p	95% CI
Age	1.076139	0.034	1.00–1.15
Gender	0.6501681	0.468	0.20–2.0
Chronic renal disease	0.7351581	0.822	0.05–10.6
Ischemic heart disease	1.109703	0.894	0.23–5.14
DM	0.2959	0.075	0.07–1.13
LV-GLS	1.19565	0.040	1.0–1.4
LVEF	0.9174841	0.037	0.84–0.99
Aortic clamp time	0.9174841	0.55	−0.042 to 0.022

in which a therapeutic intervention results in improved prognosis and myocardial function recovery. However, in patients with AS who undergo AVR, LVEF may not improve in up to 50%, suggesting that LVEF lacks sensitivity as it identifies patients with advanced myocardial damage in which myocardial function may not improve after surgery [8].

Recently, strain imaging has become available for routine echocardiographic examinations allowing accurate assessment of myocardial mechanics. LV-GLS is the preferred parameter as it can assess the subendocardial

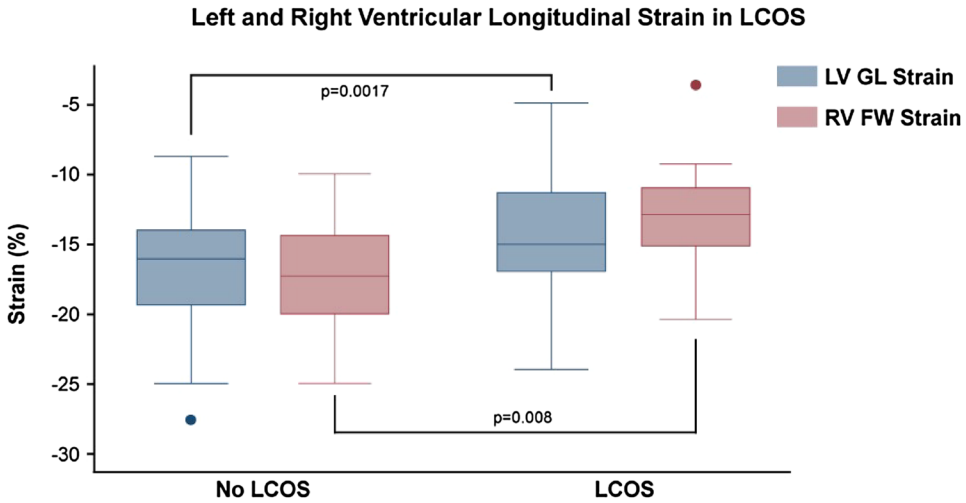

Fig. 2 LV-GLS and RVFWS among patients with and without LCOS. Mean difference in strain values among patients with or without LCOS. LV-GLS is shown in *blue, right* ventricular free wall strain shown in *red*

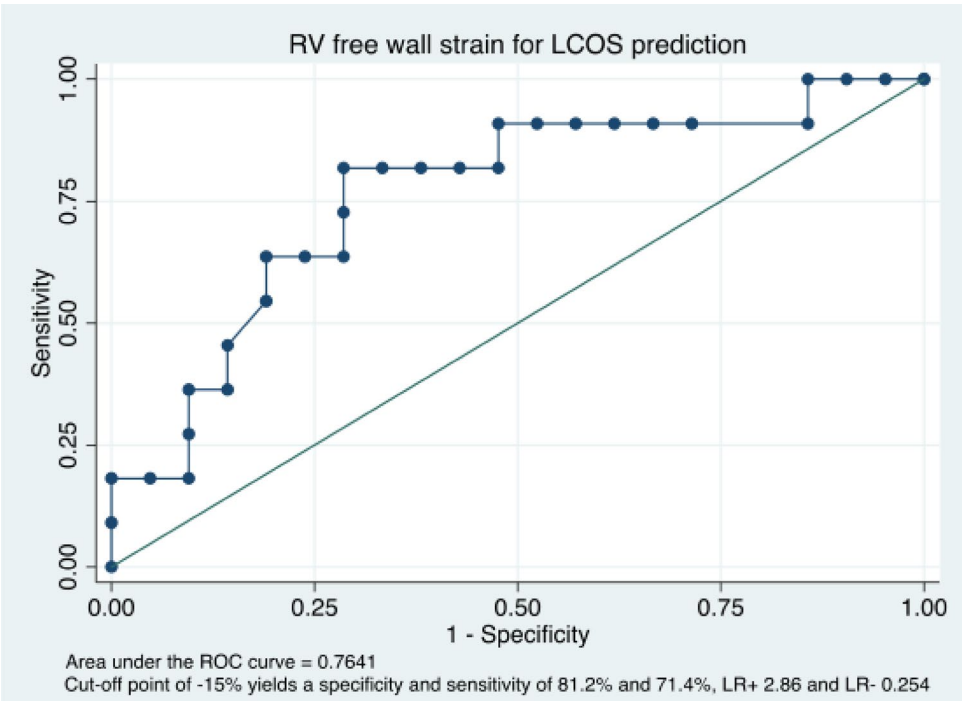

Fig. 3 *Right* ventricular free wall strain for LCOS occurrence prediction. Recieveng operating characteristic (ROC) curve for prediction of LCOS occurrence. Area under the curve 0.7641 for a cut-off of −15%, sensitivity 81.2%, specificity 71.4%

layers with predominant longitudinal fibers [10]. Although LVEF is widely used to study myocardial function it has been shown from a clinical point of view that only variations over time higher than 11% can be detected using 2D echocardiography, making it a less than ideal technique for this purpose. In contrast LV-GLS does not rely on geometric assumptions, has a higher reproducibility and is not affected by tethering of adjacent segments [16]. As such, LV-GLS has been found to be useful to predict early postoperative mortality and need of prolonged inotropic performed in patients with AS and LVEF>50% undergoing AVR [14].

In the present study LV-GLS was independently associated with the development of LCOS and related to 30-day mortality. The fact that LV-GLS was not associated to 30 day mortality in the multivariate analysis is most likely due to the small event number. However these data supports the role of LV-GLS for risk stratification before SAVR in patients without severe LV dysfunction. And is in accordance with previous studies in patients with AS and LV dysfunction in which LV-GLS continues to be of prognostic value, and related to 3-year mortality among patients with reduced LVEF [17].

RV dysfunction in patients with AS is not uncommon, and may affect up to 25% of patients [18]. Gali et al. found in a non-selected population with severe AS that the combination of LV and RV dysfunction resulted the strongest predictor of CV death (HR 4.08, 95% CI 1.36–12.22, p 1⁄4 0.012 and HR 3.1, 95% CI 0.96–10.07, p 1⁄4 0.05, respectively). As RV and LV share common fibers [19] molecular changes that affect the LV may also account for RV remodeling and dysfunction [20]. Since RV function is not part of current surgical risk scores its assessment might add important prognostic information. In the present study notably RV function evaluated by conventional RV parameters was not different between patients with and without LCOS. However, RVFWS did show differences between groups, as patients with LCOS had lower values. Using a cut off of −15% LCOS was predicted with a sensitivity of 81.2% and specificity of 71.4%, +LR of 2.86, −LR 0.254. Although a small patient number was included, to our knowledge this is the first study in which RVFWS has been related to LCOS, providing important pathophysiologic insight of the role of the RV in its occurrence. It is possible that as RV fibers are predominantly longitudinal this parameter is accurate for identifying RV dysfunction even when conventional RV function parameters remain normal. Supporting this evidence, RVFWS in patients with low flow, low gradient AS has been related to increased mortality irrespective of surgical or conservative treatment [21]. Due to the patient number with available RVFWS, multivariate analysis was not performed, future studies are needed to confirm the relationship between RVFWS and the occurrence of LCOS.

The increasing availability of strain imaging, the good reproducibility, and clinical added value for myocardial function assessment may foster its incorporation into routine clinical practice. In patients with severe AS undergoing AVR, without severely abnormal ejection fraction, decreased LV-GLS and RVFWS increase the risk of LCOS. Better risk stratification is needed, as highlited by the results of a recent trial which failed to show advantage of prophylactic levosimendan based on LVEF values [22]. The use of strain parameters may aid in patient selection for prophylactic therapy to prevent this dreaded complication.

Larger studies are needed to confirm the role and value of left and right ventricular strain for predicting LCOS after heart surgery and further support its incorporation to pre-surgical risk assessment models.

Conclusions

LV-GLS is a useful parameter for risk stratification in patients with severe AS without depressed LVEF, and is rvfwsindependently associated with LCOS occurrence, and related to 30-day mortality. RVFWS may be useful for risk stratification in patients undergoing AVR although its role for this matter needs further study.

Author contributions FJ and JOLE performed statistical analysis, AJ and MR were responsible for funding and supervision, CAO, AVN, RPS acquired the data. BMK, BRE, and GMM were responsible for patient follow up and clinical data registry. Offline strain analysis was performed by RZH, DMB. CAO, FJ and RZH wrote the manuscript. All other authors made critical revision of the manuscript for key intellectual content.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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