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Original Article

Comparison of right ventricular measurements by perioperative transesophageal echocardiography as a predictor of hemodynamic instability following cardiac surgery

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Abstract

Background: The relationship between perioperative right ventricular (RV) performance and hemodynamic instability after cardiac surgery seemed less portrayed. Therefore, we sought to elucidate this relationship and compare the accuracy of different RV systolic indices in predicting outcome of cardiac surgery.

Methods: This study enrolled consecutive patients referred for cardiac surgeries. Exclusion criteria were non-sinus rhythm or contraindications to transesophageal echocardiography (TEE). TEE exam and simultaneous pulmonary hemodynamics were recorded in two stages: after induction of anesthesia and before sternotomy (stage 1), and after sternal closure (stage 2). RV measurements performed offline included fractional area change (RVFAC), tricuspid annular plane systolic excursion (TAPSE), peak systolic tricuspid annular velocity (RVS′), myocardial performance index (RVMPI), and global longitudinal strain (RVGLS). The end point was defined as prolonged use (>24 h) of postoperative inotropic agent in the intensive care unit (ICU).

Results: The study population included 68 patients (mean age 61 ± 11 y; 49 men). Twenty-two of these patients (32%) were administered inotropic agents for a prolonged period with a mean duration of 63.9 ± 5.3 h, accompanied with significantly longer ventilator use ($p = 0.006$) and longer ICU stay ($p = 0.001$) than patients without a prolonged inotropic agent use. Multivariable analysis demonstrated that only RVGLS in either stage 1 (odds ratio [OR] 1.11, $p = 0.048$) or stage 2 (OR 1.15, $p = 0.018$) was significantly associated with the outcome, especially a RVGLS > −13.5% in stage 2 demonstrating high risk of prolonged inotropic agent use after cardiac surgery (OR 7.37, $p = 0.016$).

Conclusion: RVGLSs performed using perioperative TEE are reliably associated with hemodynamic instability following cardiac surgery. This finding adds substantial information to postoperative critical care.

Keywords: Cardiac surgery; Global longitudinal strain; Hemodynamic instability; Perioperative transesophageal echocardiography; Right ventricle

1. Introduction

Right ventricular (RV) dysfunction has been identified as a prognostic parameter to patients' outcomes after cardiac surgeries. Previous studies demonstrated that impaired RV systolic function, measured using conventional echocardiographic techniques, had a significant association with postoperative

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morbidities and mortality.[1,2] According to the reviewed pathophysiology,[3,4] RV dysfunction also presents hemodynamic instability, which remains a formidable clinical challenge in the intensive care unit (ICU), although it is usually overshadowed by other causes of low cardiac output syndrome. However, the relationship between RV measurements, especially in perioperative circumstances, and postoperative hemodynamic instability was less investigated. This relationship has the potential to substantially influence postoperative critical care of patients undergoing cardiac surgeries.

Conventional RV measurements, such as RV fractional area change (RVFAC), RV myocardial performance index (RVMPI), peak systolic tricuspid annular velocity (RVS′) using tissue Doppler imaging, or tricuspid annular plane systolic excursion (TAPSE), were assessed through precordial echocardiography.[5] To attenuate the influences of angle and direction encountered during transesophageal echocardiography (TEE), Matyal et al.[6] and Tousignant et al.[7] proposed methods where intraoperative assessments of RV became feasible.

Due to the specific geometry of RV, the newer means of RV global longitudinal strain (RVGLS) using two-dimensional (2-D) speckle tracking imaging was recommended in the term of perioperative TEE measurement as it is independent of angle.[8] Further, by providing more direct tracking, RV strain imaging has the potential to be more responsive to the possible insults. Therefore, in the present study, we sought to explore the relationship between RV measurements (using perioperative TEE) and postoperative hemodynamic instability in patients referred for cardiac surgery. Secondly, we aimed to evaluate whether RVGLS can better predict the outcome than other conventional indices.

2. Methods

2.1. Study population

This cross-sectional study was approved by the Institutional Review Board of Chang Gung Memorial Hospital, Linkou, and written informed consent was obtained from each patient before entering the study (IRB No. 101-1774B; July 17, 2012). We prospectively enrolled patients >20 years old who underwent cardiac surgery between July 2012 and July 2013. Exclusion criteria included contraindications to TEE and nonsinus rhythm. Comprehensive 2D and tissue Doppler TEE exams were obtained in the operating room under general anesthesia with endotracheal intubation. Echocardiographic and hemodynamic measurements were recorded at two stages: after induction of anesthesia and before sternotomy (stage 1) and after sternal closure (stage 2). All echocardiographic studies were performed with commercially available echocardiography systems equipped with a 5.0 MHz transducer (Vivid 7, GE Healthcare, Milwaukee, WI, USA) by an experienced investigator. In our protocol, we acquired TEE data from three to five consecutive cardiac cycles with temporary interruption of ventilator support. Special care was taken during acquisition to ensure an adequate sector for the entire RV free wall was recorded throughout the cardiac cycle, and that the frame rate of >60 Hz was maintained to facilitate optimal tracking of the myocardium. The best visualization of RV was achieved from a slightly lower esophageal four-chamber view, with appropriate adjustment of the probe (through posterior tilting and clockwise rotation). We also changed the multiplane angle from 0 to 20° to maximize and center the RV chamber. These images were transferred, via a network for offline analysis, using dedicated software (EchoPAC ′06, GE Healthcare, Milwaukee, WI, USA). The echocardiographic assessment of RV performance included RVFAC, TAPSE, RVMPI, RVS′, and RVGLS. All measurements were performed offline by one experienced investigator blinded to patients' outcomes. Patient demographics, comorbidities, and postoperative data were retrieved from a review of the medical record.

2.2. Echocardiographic measurements

RVFAC was calculated from the modified four-chamber view as RVFAC = (RV end-diastolic area − RV end-systolic area)/RV end-diastolic area × 100%.[1] TAPSE was acquired from the RV-centered four-chamber view with a floating M-mode cursor placed through the lateral tricuspid annulus and aligned with its motion.[7] TAPSE was measured as the tricuspid annulus excursion in mm from end-diastole to end-systole. RVMPI was obtained using pulse wave tissue Doppler from sample volume at the lateral tricuspid annulus in the RV-centered four-chamber view.[6] Filters were set to exclude high-frequency signals, and gain settings were minimized to allow a clear tissue signal with minimal background noise. RVMPI was calculated as the sum of isovolumic contraction time and isovolumic relaxation time, divided by ejection time. Meanwhile, RVS′ was also recorded.

Using 2D speckle tracking in the modified four-chamber view, a region of interest (ROI) was manually traced along the RV endocardial border starting at the basal septum and ending at the lateral tricuspid annulus.[8] Care was taken to maintain the ROI within the myocardium. In each cycle, the RV was then divided into six segments: three in the septum (apical, mid, and basal) and three in the lateral wall (apical, mid, and basal). Quantitative analysis was performed and a tracking score (pass/fail) was generated for each RV segment by the software (Fig. 1A). If some segments failed, the ROI was readjusted by moving the anchor points appropriately. The process was repeated to generate the largest number of pass scores per cycle. The software also detected the onset of QRS from the simultaneous electrocardiographic recordings to define the point of zero strain, and plotted both segmental and global strain curves. Global peak systolic strain values were recorded (Fig. 1B). The cutoff point of −13.5% for RVGLS was used based on a previous study.[9]

2.3. Endpoints

The primary outcome was evaluated by the need for prolonged use of inotropic agent. Administration of vasoactive

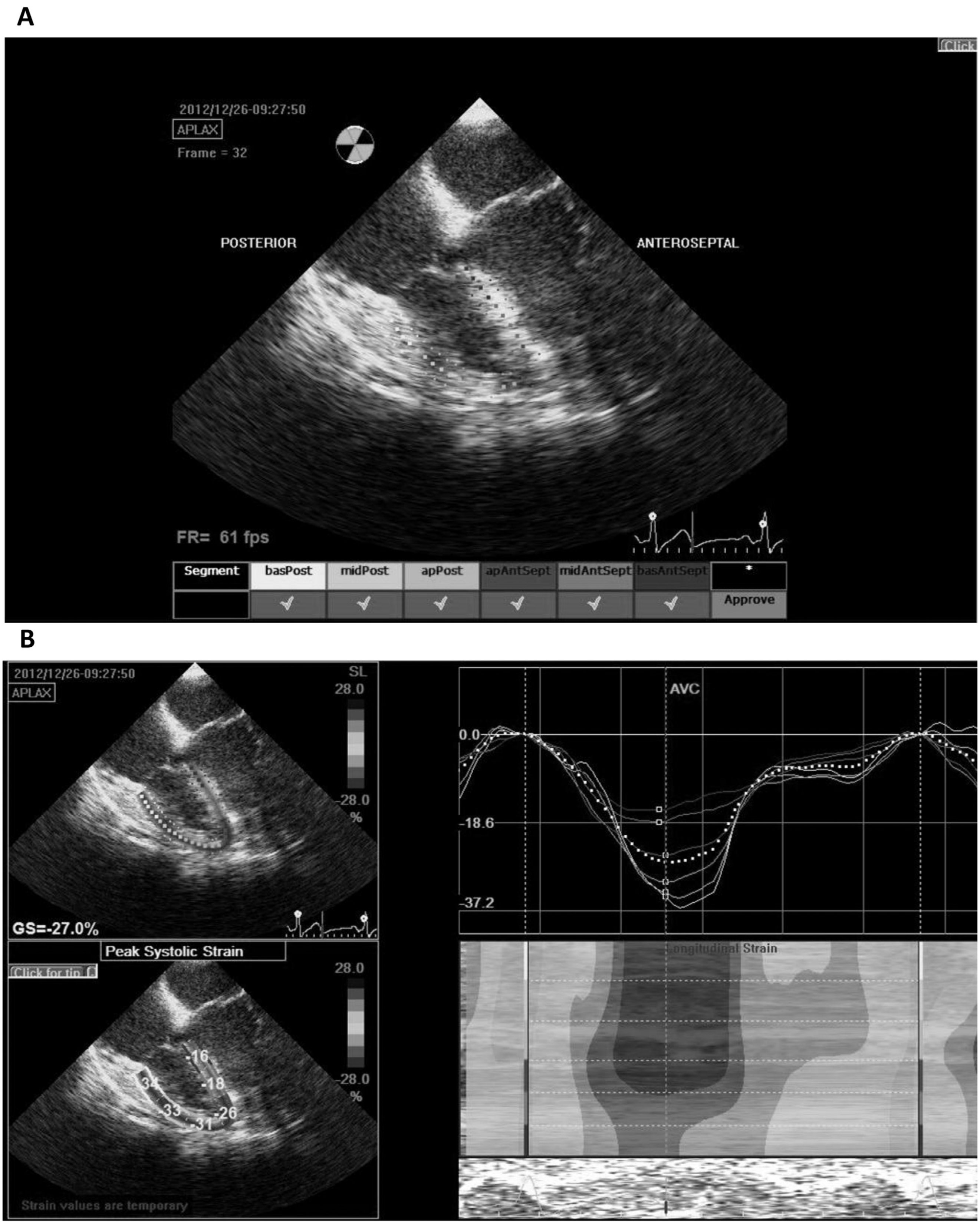

Fig. 1. **RV speckle tracking imaging**. (A) Range of interest was traced along the RV endocardial border. (B) The solid and the dotted lines represented the segmental and the global strain curves respectively. Numbers denoted on the picture were segmental and global peak systolic strain values. RVGLS was measured as −27.0%. GLS = global longitudinal strain, RV = right ventricle.

medication after cardiac surgery was based on the institute's consistent routine: (1) If cardiac index was <2.5 L/min/m^2, dobutamine infusion was started; (2) Mean blood pressure was kept between 65 and 90 mmHg by using vasoactive agents (dopamine or norepinephrine); (3) To rule out hypovolemia, appropriate volume challenge was administered to keep urine output >0.5 ml/kg/h.[2,10,11] The intensivists in the ICU who were treating patients were blind to the perioperative RV measurements. The duration of inotropic support was recorded from the beginning of a patient's admission to the ICU to the cessation of drug use, and prolonged inotropic support was defined as use for >24 h.[2]

2.4. Statistical analysis

The sample size was initially referenced from previous studies.[1,2] The results were expressed as mean ± SD for continuous variables, or as number of cases and percentages for categorical variables. Independent continuous variables were compared using independent Student's *t*-test for normally distributed data. Categorical variables were compared using the Chi-square test or Fisher's exact test. Paired continuous variables were compared by paired *t*-test. Pearson's correlation analysis was performed to correlate data between various echocardiographic and catheterization measurements. To identify independent risk factors associated with the outcome using multivariable logistic regression (enter mode), we constructed two separate models for stage 1 and stage 2, in which individual RV measurements were adjusted to the clinical variables, continuous cardiac output (CCO), and left ventricular ejection fraction (LVEF) in each individual stage, as well as duration of cardiopulmonary bypass (CPB) for stage 2 only. To evaluate the influence of surgical intervention on outcome analysis, the calculated changes of RV systolic indices (the postoperative ones substrate the preoperative ones) were replaced in the regression models for stage 2. Reproducibility for RVGLS was performed by a second independent observer on 18 random patients. For intra-observer variability, analysis was repeated 4 mos after the first measurement in the same 18 patients. Bland–Altman analysis was performed for intra- and inter-observer variability tests. For all tests, a *p*-value < 0.050 was considered statistically significant.

3. Results

The study population included 68 patients who had a complete set of data. Of these 68 patients, 33 (48.5%) underwent pure coronary artery bypass graft (CABG), 10 (14.7%) underwent CABG combined with valvular surgeries, and 25 (36.7%) patients underwent isolated valvular surgeries. After cardiac surgery, prolonged inotropic support was required in 22 (32.4%) patients with a mean duration of 63.9 ± 5.3 h. Patients with prolonged inotropic support also required longer duration of ventilator use (p = 0.006) and longer ICU stay (p = 0.001) compared to patients without prolonged inotropic support. Demographic characteristics, clinical data, and the patients' outcomes are shown in Table 1.

Table 1
Baseline patients' characteristics and outcome data.

	ALL	Inotropic support >24 h		*p*
		No (n = 46)	Yes (n = 22)	
Age (years)	60.6 ± 10.8	60.8 ± 10.9	60.1 ± 10.9	0.813
Gender				0.773
Female	19 (27.9)	12 (26.1)	7 (31.8)	
Male	49 (72.1)	34 (73.9)	15 (68.2)	
BSA (m^2)	1.7 ± 0.2	1.7 ± 0.2	1.7 ± 0.2	0.073
BMI (kg/m^2)	24.6 ± 3.6	25.1 ± 3.5	23.6 ± 3.7	0.135
ASA				0.101
III	66 (97.1)	46 (100)	20 (90.9)	
IV	2 (2.9)	0 (0)	2 (9.1)	
NYHA				0.422
I/II	45 (66.2)	32 (69.6)	13 (59.1)	
III/IV	23 (33.8)	14 (30.4)	9 (40.9)	
Past history				
Hypertension	48 (70.6)	32 (69.6)	16 (72.7)	0.789
Diabetes mellitus	33 (48.5)	23 (50)	10 (45.5)	0.726
Chronic kidney disease	14 (20.6)	9 (19.6)	5 (22.7)	0.758
COPD	9 (13.2)	7 (15.2)	2 (9.1)	0.707
Cirrhosis	2 (2.9)	1 (2.2)	1 (4.5)	0.546
Cerebral infarct	7 (10.3)	4 (8.7)	3 (13.6)	0.673
Coronary artery disease	21 (30.9)	15 (32.6)	6 (27.3)	0.656
Dyslipidemia	21 (30.9)	18 (39.1)	3 (13.6)	0.049
Previous heart surgery	6 (8.8)	3 (6.7)	3 (13.6)	0.386
Operation				
CABG	43 (63.2)	32 (69.6)	11 (50)	0.117
Mitral valve repair	15 (22.1)	8 (17.4)	7 (31.8)	0.218
Mitral valve replacement	12 (17.6)	6 (13)	5 (22.7)	0.316
Aortic valve replacement	10 (14.7)	6 (13)	4 (18.2)	0.717
Tricuspid valve repair	6 (8.8)	2 (4.3)	4 (18.2)	0.081
Bypass time (minute)	139.8 ± 85	125.9 ± 76	169 ± 96.6	0.049*
Intubation time (hour)	22.9 ± 36.4	11 ± 8.3	47.6 ± 56	0.006*
ICU stay (day)	4.2 ± 2.2	3.5 ± 1.7	5.8 ± 2.3	0.001*
Hospital stay (day)	19.6 ± 11.7	19.2 ± 12.1	20.3 ± 11.2	0.721
Early mortality	2 (2.9)	1 (2.2)	1 (4.5)	0.546

Data are presented as mean ± SD or number of patients (%).
Coronary artery disease includes angina, unstable angina and previous myocardial infarct.
ASA = American society of anesthesiologist physical status classification, BMI = body mass index, BSA = body surface area, CABG = coronary artery bypass graft, COPD = chronic obstructive pulmonary disease, ICU = intensive care unit.

The mean differences of RV indices between non-prolonged and prolonged inotropic support groups, and the trend of mean values in the context of surgical stages are illustrated in Fig. 2. All measured echocardiographic variables worsened postoperatively, except RVFAC ($RVFAC_{S1}$ 37.8 ± 8.9%, $RVFAC_{S2}$ 38.5 ± 8.4%; $p = 0.651$). Patients with prolonged inotropic support appeared to have a significantly worse RVGLS in both stage 1 and stage 2 (Table 2) than patients without prolonged inotropic support. However, there was no significant difference among the changes of the RV indices between stage 1 and stage 2.

3.1. Correlation between RV measurements

Of the five RV echocardiographic indices measured, RVGLS correlated well with RVFAC in both stage 1 and stage

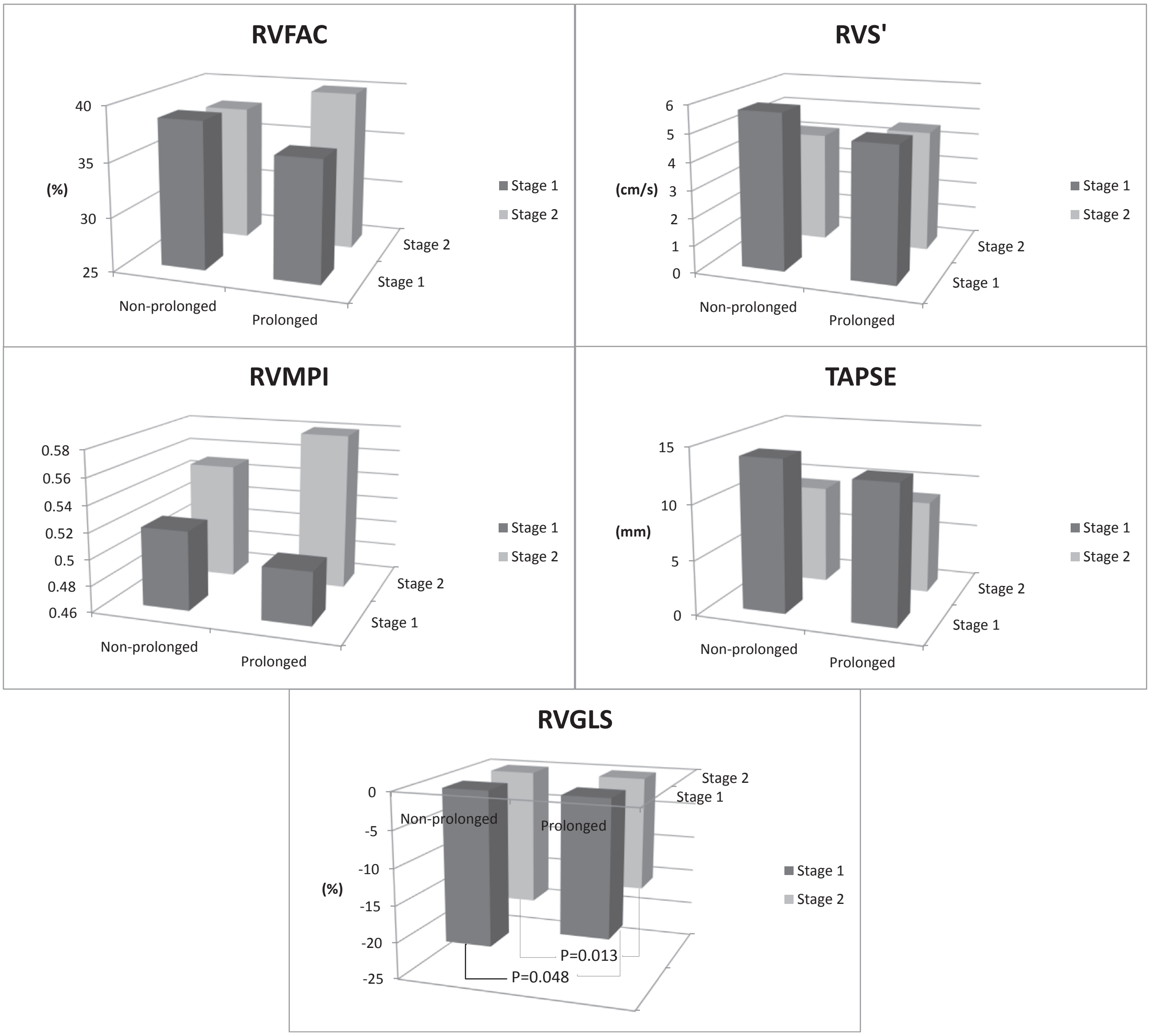

Fig. 2. **The mean differences of RV indices between non-prolonged and prolonged inotropic support groups**. The values of RV indices are shown as mean values.

2 (r = −0.63, $p < 0.001$; r = −0.62, $p < 0.001$, respectively). Regarding the correlations with pulmonary hemodynamics, RVGLS showed modest correlations with mean pulmonary artery pressure (MPAP) and pulmonary vascular resistance (PVR) (r = 0.49, $p < 0.001$; r = 0.32, $p = 0.008$) in stage 1, but these correlations were lost in stage 2. Other RV echocardiographic and hemodynamic measurements showed inconsistent correlations within and between them.

3.2. Regression models

Multivariable analysis demonstrated that RVGLS in either stage 1 (odds ratio [OR] 1.11, 95% confidence interval [CI] 1.01 to 1.22; $p = 0.048$) or stage 2 (OR 1.15, 95% CI 1.02 to 1.28; $p = 0.018$) showed significant association with prolonged inotropic agent support after cardiac surgery, especially RVGLS > −13.5% in stage 2 demonstrating a high risk (OR 7.37, 95% CI 1.46 to 37.36; $p = 0.016$) (Table 3). In another model to evaluate the influence of cardiac surgery, changes in RV indices were not predictive of the outcome.

3.3. Reproducibility

For RVGLS, intra-observer variation coefficient was 8%, and inter-observer variation coefficient was 10%.

4. Discussion

This prospective study determined that RVGLS was a better indicator of RV mechanics than other conventional RV indices in the context of cardiac surgery. Additionally, RVGLS better represented the RV's reserve precluding hemodynamic

Table 2
Univariate analysis for prolonged length of inotropic agent support.

	Inotropic support >24 h		*p*
	No (n = 46)	Yes (n = 22)	
Preoperative echo data			
LVEF (%)	58.2 ± 15.0	56.4 ± 15.2	0.656
Left atrium (mm)	43.0 ± 8.0	49.1 ± 13.7	0.066
LVEDD (mm)	52.1 ± 8.6	53.7 ± 10.4	0.517
LVESD (mm)	35.4 ± 10.0	36.8 ± 11.0	0.592
Mitral E/A	1.2 ± 0.5	1.2 ± 0.6	0.799
Intraoperative data			
Stage 1 (before sternotomy)			
RVFAC (%)	38.6 ± 8.9	36.1 ± 8.9	0.297
RVS' (cm/s)	5.6 ± 2.4	4.9 ± 1.5	0.090
RVMPI	0.52 ± 0.10	0.50 ± 0.07	0.559
TAPSE (mm)	13.9 ± 4.1	12.6 ± 3.6	0.208
RVGLS (%)	−20.7 ± 5.2	−17.9 ± 5.5	0.048*
LVEF (%)	46.7 ± 11.2	46.4 ± 10.9	0.907
CCO (L/min)	3.6 ± 1.5	3.1 ± 1.3	0.151
Stage 2 (after sternal closure)			
RVFAC (%)	37.8 ± 7.7	39.9 ± 9.8	0.340
RVS' (cm/s)	4.3 ± 1.7	4.3 ± 1.6	0.948
RVMPI	0.55 ± 0.11	0.58 ± 0.13	0.361
TAPSE (mm)	9.2 ± 2.5	8.6 ± 2.8	0.429
RVGLS (%)	−18.7 ± 4.7	−15.4 ± 5.6	0.013*
LVEF (%)	48.5 ± 8.2	47.8 ± 9.4	0.757
CCO (L/min)	5.1 ± 1.3	5.3 ± 3.0	0.866
Change			
RVFAC (%)	−0.7 ± 8.7	3.8 ± 10.6	0.066
RVS' (cm/s)	−1.3 ± 2.7	−0.5 ± 1.9	0.119
RVMPI	0.03 ± 0.12	0.10 ± 0.13	0.204
TAPSE (mm)	−4.7 ± 4.3	−3.9 ± 3.6	0.467
RVGLS (%)	2 ± 5.3	2.5 ± 5.9	0.712

The change in RV index was calculated as values in stage 2 subtracting values in stage 1.
CCO = continuous cardiac output, GLS = global longitudinal strain, Mitral E/A = mitral inflow ratio of rapid early filling peak velocity to atrial contraction peak velocity, MPI = myocardial performance index, LVEDD = left ventricular end diastolic diameter, LVEF = left ventricular ejection fraction, LVESD = left ventricular end systolic diameter, RVFAC = right ventricular fractional area change, RVS' = peak systolic tricuspid annular velocity, TAPSE = tricuspid annular plane systolic excursion.

instability and prolonged inotropic agent support in postoperative critical care. This observation also highlights the important contribution of RV function in maintaining clinical compensation. Moreover, we explored some characteristics within these RV indices measured by perioperative TEE. The longitudinal RV variables worsened in the postoperative stage while only RVGLS remained predictive of the outcome, which supplemented previous findings in other works.[12−15]

The superiority of RVGLS over other RV measurements can be explained by a global assessment of RV longitudinal function and less angle-dependent characteristics using the speckle tracking approach.[16] In addition, based on findings in congenital heart surgeries,[17−19] it appeared that RVGLS was more susceptible to increased wall tension derived from geometric changes of RV than other measured RV variables. For the pulmonary hemodynamics that RV confronted, RVGLS showed better correlations with MPAP and PVR in stage 1 than others in this study; the higher the pulmonary hemodynamic data were, the more constrained RVGLS was, which was consistent with the results of Fukuda et al.[20] Although the correlations were lost in stage 2, we presumed that RVGLS in stage 2 better reflected RV geometric changes after cardiac surgery than pulmonary circulation.

RV dysfunction can lead to circulatory failure after cardiac surgery, which in turn has been associated with the need for inotropic agent administration.[3,4] After adjusting for confounding factors, including concurrent CCO, LVEF, and/or CPB time, we demonstrated that RVGLS in either stage 1 or stage 2 was the variable most strongly associated with prolonged duration of postoperative inotropic agent use. This result is consistent with that of Ternacle et al.'s study,[21] and indicates that identification of RV dysfunction should be performed with an accurate method due to its strong impact on patient outcome. The detection of severe RV dysfunction could inform surgeons or intensivists of the need to modify the medical strategy and postoperative management in advance. Verhaert and colleagues[9] reported that RVGLS could respond subtly to the medical therapy in the heart failure population.

Table 3
Multivariable logistic regression analysis of separate models for prolonged inotropic agent use.

	Stage 1			Stage 2			Change		
	OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
RVFAC (%)	0.98	0.92 to 1.05	0.637	1.07	0.99 to 1.16	0.072	1.07	1.00 to 1.15	0.057
RVS' (cm/s)	0.81	0.59 to 1.12	0.206	1.39	0.91 to 2.13	0.133	1.22	0.98 to 1.51	0.074
RVMPI	0.96	0.90 to 1.03	0.239	1.01	0.96 to 1.08	0.653	1.03	0.99 to 1.09	0.177
TAPSE (mm)	0.94	0.80 to 1.10	0.434	0.93	0.72 to 1.20	0.556	1.03	0.88 to 1.20	0.743
RVGLS (%)	1.11	1.01 to 1.22	0.048*	1.15	1.02 to 1.28	0.018*	1.03	0.92 to 1.16	0.569
RVGLS > -13.5%	3.72	0.77 to 17.97	0.102	7.37	1.46 to 37.36	0.016*			

Each cell of the odd ratio column represents a model including one RV index adjusting for a set of clinical confounders.
In stage 1, one RV index was adjusted for age, gender, hypertension, diabetes mellitus, chronic kidney disease, coronary artery disease, previous heart surgery, concurrent CCO, and concurrent LVEF.
In stage 2 and change models, one RV index was adjusted for age, gender, hypertension, diabetes mellitus, chronic kidney disease, coronary artery disease, previous heart surgery, concurrent CCO, concurrent LVEF and cardiopulmonary bypass time.
The change in RV index was calculated as values in stage 2 subtracting values in stage 1.
"*" denotes p value < 0.05.

Therefore, this study used the mean RVGLS of −13.5%, which was reported in their subgroup with adverse events in the follow-up, as a cutoff point. We found that RVGLS > −13.5% after sternal closure was highly predictive of the outcome, which indicates that if RV is poorly reserved and had a negative response from the medical therapy, prognosis may be poor.

As a conventional measurement of RV function, RVFAC was highly correlated with RVGLS in the perioperative stages in this study, although it was not a significant predictor of the outcome. In the aforementioned study,[21] the sensitivity of RVFAC < 35% for prolonged postoperative inotropic agent use was 18.29%. However, the specificity was 97.62% and the positive likelihood ratio was 7.68 (95% CI 2.63 to 22.42), which suggested that RVFAC < 35% could be considered to rule in patients' prolonged postoperative inotropic agent use when speckle tracking imaging was not available.

Parameters related to RV longitudinal movement were involved in the phenomenon becoming impaired after sternal closure in the present study. Previous studies[12,14] demonstrated that RVS′ declined by 43.0 ± 17.0% within the first 3 min after the pericardium was cut open, and even lasted for 1 y after surgery. Due to the time sequence, the researchers concluded that loss of pericardium support was the fundamental cause contributing to reduction of RV long axis.[14] In contrast, RVFAC was little affected after cardiac surgery in our study, possibly because it includes both radial and longitudinal components of RV function.[13]

Interestingly, it has been questioned whether these measurements of RV longitudinal movement can still be used to assess RV function in the postoperative state.[15] We assume it is the capacity of RV longitudinal indices on outcome analysis that should be converged on. Although previous studies[12,14] did not record all the RV indices beat-by-beat intraoperatively, we speculated that the falling patterns of RV indices were quite different among themselves. RVS′ may be the index reacting most instantly to the insult of pericardiotomy, while RVGLS was the least influenced by the insult and maintained the property of RV myocardial tracking throughout the perioperative period well.

As for the speckle tracking measurement of RV, there is currently no guideline[5,8] on whether RV should be divided into three segments in the lateral wall or into six segments including the interventricular septum. Although the method of three segments in the lateral wall of RV is considered more exclusive to the native function of RV, there remains 40% of the RV systolic function pertaining to the septum[22] and should not be ignored. Hence, we adopted the method tracking six segments of the entire RV wall. Concerning the aspect influenced by LV systolic function, we included the concurrent LVEF into the multivariate analysis in both stages, which made the results more convincible. However, since the lateral movement of RV, such as TAPSE and RVS′, were not significantly different between the study groups, future solicitation of RV free wall longitudinal strain and LVGLS may be needed to explore the importance of RV septal motion.

4.1. Limitations

In this research, we enrolled consecutive patients undergoing cardiac surgery of a range. According to previous studies,[1,2,21] RV indices are acknowledged as outcome predictors broadly applied in either pure CABG or combined with valvular heart surgery. Likewise, patients with prolonged inotropic agent support did not show significant tendency toward having undergone specific types of cardiac surgery in our study. Though tricuspid ring annuloplasty occurred in six patients (8.8%), the severity of tricuspid regurgitation (TR) was severe in two patients and no more than moderate grading in others. Moreover, we did not observe a correlation between any RV indices and TR severity using Spearman rank correlation. As we excluded patients with atrial fibrillation at study enrollment, and to justify the generalization of the study findings, it is a potential topic to explore the difference of RV measurements between patients with sinus rhythm and those with atrial fibrillation using either averaging beats or indexed beat method. Our study adopted models adjusting for left systolic function (using LVEF). Although LVEF may be considered by some to be insensitive to present overall LV function, it was a predictor of death after cardiac surgery in a prestigious scoring system.[23] Because of the significant correlation between MPAP and RVGLS ($r = 0.49$, $p < 0.001$), we did not use MPAP in the regression models in consideration of the effect of collinearity. A previous study[20] proved that RV indices could reflect the severity of pulmonary hypertension; however, it was not our intent to discuss the causes of RV dysfunction. We did not apply cutoff values to each of the RV indices in our study because most of the cutoff values were validated by precordial echocardiography,[5] which was deemed unsuitable for our situation. Moreover, the cutoff value of −13.5% for RVGLS from a previous study[9] may differ for study populations. Despite the small sample size, the effect size of our sample was 0.66, and we had a power of 92% to detect presence of such predictors as RVGLS > −13.5% in stage 2 at the double-sided *p*-valve of 0.05.

In conclusion, assessment of RV function is essential for outcome prediction in patients undergoing cardiac surgery. As the operation alters RV's geometry, RV indices consequently change. Among various RV systolic measurements, RVGLS in the perioperative period is a reliable method to predict the hemodynamic instability following cardiac surgery, which substantially helps in directing patients' further care in the ICU.

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