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Original Article

The Reduction in Right Ventricular Longitudinal Contraction Parameters Is Not Accompanied by a Reduction in General Right Ventricular Performance During Aortic Valve Replacement: An Explorative Study

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Objective: The aim of the present study was to identify whether the decrease of longitudinal parameters after cardiothoracic surgery (ie, tricuspid annular systolic plane excursion [TAPSE] and systolic excursion velocity [S']) is accompanied by a reduction in global right ventricular (RV) performance.
Design: Prospective, observational study.
Setting: Single-center explorative study in a tertiary teaching hospital.
Participants: The study comprised 20 patients who underwent aortic valve replacement with or without coronary artery bypass grafting.
Interventions: During cardiac surgery, simultaneous measurements of RV function were performed with a pulmonary artery catheter and transesophageal echocardiography.
Measurements and Main Results: TAPSE and S' were reduced significantly directly after surgery compared with the time before surgery (TAPSE from 20.8 [16.6-23.4] mm to 9.1 [5.6-15.5] mm; $p < 0.001$ and S' from 8.7 [7.9-10.7] cm/s to 7.2 [5.7-8.6] cm/s; $p = 0.041$). However, the reduction in TAPSE and S' was not accompanied by a reduction in RV performance, as assessed with the TEE-derived myocardial performance index (MPI) and pulmonary artery catheter–derived RV ejection fraction (RVEF). Both remained statistically unaltered before and after the procedure (MPI from 0.52 [0.43-0.58] to 0.50 [0.42-0.88]; $p = 0.278$ and RVEF from 27% [22%-32%] to 26% [22%-28%]; $p = 0.294$).
Conclusions: In the direct postoperative phase, the reduction of echocardiographic parameters of longitudinal RV contractility (TAPSE and S') were not accompanied by a reduction in global RV performance, expressed as MPI and RVEF. Solely relying on a single RV parameter as a marker for global RV performance may not be adequate to assess the complex adaptation of the right ventricle to aortic valve replacement.

Key Words: right ventricle; right ventricular function; pulmonary artery catheter; transesophageal echocardiography; tricuspid annular systolic plane excursion; systolic excursion velocity; cardiac surgery; right ventricular ejection fraction

OVER THE years, the prognostic value of right ventricular (RV) function in cardiac surgery increasingly has been recognized. RV dysfunction is associated with morbidity and mortality both in patient populations with well-known risk factors for RV dysfunction and in more general cardiac surgery populations.[1-5]

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Clinical assessment of RV dysfunction remains a topic of debate.[6,7] With longitudinal shortening as the main contributor for RV contraction, longitudinal echocardiographic parameters, such as tricuspid annular systolic plane excursion (TAPSE) and systolic excursion velocity (S'), are considered to represent the systolic function of the right ventricle.[8-10] In the noncardiac surgery setting, TAPSE and S' were associated with reduced right ventricular ejection fraction (RVEF). In addition, TAPSE was most predictive for survival in a variety of patient groups.[11-13]

However, in postcardiac surgery patients, the relationship between the well-established decrease in these longitudinal echocardiographic parameters and actual RV performance is unknown. Moreover, the etiology of this decrease remains unclear.[14-16] A variety of factors, including the opening of the pericardium, have been suggested as contributors to this phenomenon.[17-20] Another theory is that the longitudinal contraction is reduced, whereas the transversal contraction is increased. This would result in a stable RV function with diminished longitudinal parameters.[21]

The aim of this study was to assess ultrasound-derived RV parameters simultaneously with pulmonary artery catheter (PAC)−derived variables of RV function to identify whether the decrease of longitudinal echocardiographic parameters is accompanied by a reduction in global RV performance.

Methods

Study Population

A single-center, prospective, observational explorative study in a tertiary teaching hospital was performed. Twenty patients with significant aortic stenosis (aortic valve area <1 cm^2 or a mean aortic valve pressure gradient >40 mmHg) who were scheduled for aortic valve replacement (AVR) with or without coronary artery bypass grafting (CABG) were prospectively included.

Exclusion criteria were the following: age <18 years, preoperative tricuspid valve regurgitation, atrial fibrillation, nonelective surgery, significant stenosis in the right coronary artery, a preoperative left ventricular ejection fraction $<55\%$, and a previous history of cardiac surgery. According to institutional protocol, intraoperative monitoring for the aforementioned procedures consists of transesophageal echocardiography (TEE) and a PAC, enabling continuous measurements of RV performance. The study was approved by the local ethical and scientific committee, and the need for informed consent was waived in accordance with applicable laws (Regionale Toetsingscommissie Patiëntgebonden Onderzoek Leeuwarden, nWMO 220). The study was registered before patient enrollment at ClinicalTrials.gov (NCT03183414).

Data Collection

Simultaneous TEE and PAC measurements were performed during the following 6 separate time points: (1) after general anesthesia, before sternal opening; (2) after sternal opening; (3) after pericardial opening; (4) after weaning of cardiopulmonary bypass (CPB) (ie, 5 min after removal of cannulae); (5) after pericardial approximation or closure; and (6) after sternal closure. None of the variables was considered as the absolute reference value (gold standard).

PAC

Hemodynamic variables were derived from a PAC (7.5 F continuous cardiac output/mixed venous oxygen saturation [SvO_2]/continuous end diastolic volume [CEDV]-pulmonary artery catheter, model 774F75; Edwards Lifesciences, Irvine, CA), which interfaced with a computerized monitoring system (Vigilance continuous cardiac output/SvO_2/CEDV monitor; Edwards Lifesciences). This catheter is equipped with a thermal filament that generates heat pulses in a random on/off pattern for continuous thermodilution cardiac output measurements, which is repeated every 60 seconds. The change in blood temperature is measured downstream throughout the entire respiratory cycle. Based on this pattern, a relaxation thermodilution waveform is generated. The RVEF is computed by the exponential slope of this thermodilution waveform curve and the continuous averaged heart rate.[22] In addition to the RVEF, this catheter enables continuous measurements of the cardiac output and cardiac index, SvO_2, end-diastolic volume index (EDVi), pulmonary artery pressures, and central venous pressure. The PAC was placed immediately after induction of anesthesia via the right jugular vein. Positioning of the PAC was performed according to instructions of the manufacturer based on waveforms and pressure characteristics. Measurements started directly after placement of the PAC. During CPB, measurements were paused and were restarted immediately after the patient was weaned from CPB.

TEE

Two-dimensional (2D) TEE measurements were performed with the Philips IE33 transesophageal echocardiography system (Philips Medical Systems; Amsterdam, The Netherlands) with a X7-2t TEE probe (Philips Medical Systems). After induction of general anesthesia and PAC placement, the TEE probe was placed and data were acquired directly after placement. All patients were in the zero degrees supine position. All measurements of the right ventricle were performed with the probe in the modified (deep) transgastric position at 0 degrees.[23,24]

Image acquisition was obtained by a single echocardiographer (IB). In each acquired image, 3 cardiac cycles were recorded. The RV function was analyzed using M-mode and pulsed wave tissue Doppler imaging (TDI). The ultrasound line was aligned at the RV free wall at the level of the lateral tricuspid annulus to measure both TAPSE and velocities with pulsed wave tissue Doppler imaging (PW TDI). PW TDI represents the time to peak velocity of S', early diastolic myocardial relaxation and active atrial contraction in late diastole. The myocardial performance index (MPI) as a global index of myocardial function was measured with PW TDI. M-mode is defined as a monodimensional view of the ultrasound wave along a chosen ultrasound line. The ultrasound line was aligned at the lateral annulus of the tricuspid valve to measure

TAPSE. All images were analyzed using Philips IntelliSpace Cardiovascular 2.3 software. Criteria for readability of the images were defined as a clear delineation of the lateral tricuspid annulus and traceable envelopes of PW TDI. The reliability of the TEE measurements was evaluated by calculating intraobserver and interobserver variability. Offline postprocessing data analysis of measurements was performed postoperatively by 2 experienced operators (IB and FdL) in a blinded manner and in random order to test the interobserver variability. The second operator was not directly involved in the image acquisition and is American Society of Echocardiography Board–certified. For assessment of intraobserver variability, offline analysis of all measurements was repeated by the same observer in a blinded manner and in random order.

Perioperative Details

Anesthesia was administered to all patients in the same manner according to local protocol. Induction of anesthesia was established with sufentanil 3 to 7 µg/kg, rocuronium 0.6 mg/kg, and midazolam 0.1 mg/kg. For maintenance, sevoflurane and sufentanil were used. All patients received tranexamic acid 2 g, and if a patient was younger than 75 years, 1 mg/kg dexamethasone was administered. CPB was performed at a continuous blood flow (2.2-3.0 L/min/m^2) during normohypothermia or mild hypothermia (>34°C). The CPB hardware consisted of an HL-30 heart-lung machine, HCU-30 heater-cooler, and inline blood analysis monitor (CDI 500; Terumo Cardiovascular Group, Ann Arbor, MI). The CPB circuit consisted of a Rotaflow centrifugal pump (Maquet, Cardiopulmonary AG, Hirrlingen, Germany) a Quadrox-D membrane oxygenator (Maquet Cardiopulmonary AG, Hirrlingen, Germany) a Quart arterial filter (Maquet Cardiopulmonary AG, Hirrlingen, Germany), a JVR 1900 collapsible venous reservoir (Maquet Cardiopulmonary AG, Hirrlingen, Germany), and a BCR 3500 cardiotomy reservoir (Jostra Bentley Corp. Irvine, Calif). The components are Bioline-coated, except for the venous reservoir, which has a Safeline coating (Maquet Cardiopulmonary AG, Hirrlingen, Germany). Heparinization started with an initial bolus of 300 IU/kg heparin (LEO Pharma BV, Amsterdam, The Netherlands), which was replenished until the Celite activated clotting time test exceeded 480 seconds (Hemochron Response, Edison, NJ). The CPB priming solution (1,400 mL) contained 7,500 IU heparin. After termination of extracorporeal circulation, heparin was reversed with protamine sulfate (Meda Pharma BV, Amstelveen, The Netherlands). A cell saver was used during full heparinization of the patient. Surgical procedures were performed per local protocol. Cardioplegia was administered continuously (blood) or intermittently (St Thomas) every 45 minutes, by surgical preference.

By protocol, all patients received temporary pacemaker leads and subsequently were paced 90 beats per minute. The pacing wires were placed on the atrial and ventricular epicardial surface before the patient was weaned from CPB. Preferably, pacemakers were programmed in the AAI mode (atrium paced, atrium sensed, and pacemaker inhibited in response to ...nsed atrial beat). In case of an abnormal supraventricular ...hm, the pacemaker was set to VVI mode. (ventricle paced, ventricle sensed, and pacemaker inhibited in response to a sensed ventricular beat). Patients in VVI mode were excluded from assessment of early diastolic myocardial relaxation/ active atrial contraction in late diastole and MPI. Throughout theprocedure, patients were ventilated in a pressure-regulated, volume-controlled mode, and positive end-expiratory pressure settings remained unaltered.

Statistical Analysis

Statistical analyses were performed with SPSS, Version 25 for Windows (IMB Corp, Armonk, NY). Data are described as median with interquartile range unless stated otherwise. Because of the small sample size, nonparametric tests were applicable. Comparison between 2 measurements in time of a single variable were performed with the Wilcoxon signed rank test. Correlation coefficients are expressed as Spearman R_s^2. All results were

Table 1
Perioperative Characteristics

Demographic characteristics (n = 20)	
Age (y)	69 [65-76]
Male (%)	45
Comorbidities (%)	
Diabetes mellitus	15
Vessel disease	30
COPD	0
Cardiac status	
Recent myocardial infarction (<90 d) (%)	0
Previous cardiac surgery (%)	0
Unstable angina (%)	0
NYHA class III or IV (%)	45
EuroSCORE II	1.4 [1.1-1.8]
Left ventricular function (%)	
Preoperative LVEF >55%	100
Postoperative LVEF >55%	95
Moderate or severe LV hypertrophy	12
Dilated LV	0
Preoperative status	
Preoperative serum creatinine	79 [69-92]
Preoperative pulmonary hypertension (%)	4
Intraoperative characteristics	
Aortic cross-clamp time (min)	78 [60-94]
ECC time (min)	100 [82-121]
Use of norepinephrine after CPB (%)	15
Use of phenylephrine after CPB (%)	75
Use of dobutamine after CPB (%)	0
Procedure (%)	
CABG + AVR	20
Isolated AVR	80
Postoperative characteristics (%)	
Myocardial infarction	5
Redo surgery	10
• Tamponade	5
• Bleeding	5
Ischemic cerebrovascular accident	5

NOTE. Data are presented as median [interquartile range] unless stated otherwise.
Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; CPB, cardiopulmonary bypass; ECC, extracorporeal circulation; LV, left ventricular; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; EuroSCORE, European System for Cardiac Operative Risk Evaluation.

Table 2
Transesophageal and Hemodynamic Measurements of All Participants During Surgical Procedure

Time point	1	2	3	4	5	6	p Value
Transesophageal measurements							
TAPSE (mm)	20.8 [16.6-23.4]	20.4 [13.8-24.0]	15.4 [13.5-18.9]	13.5 [9.6-16.8]	10.0 [8.9-13.1]	9.1 [5.6-15.5]	< 0.001
S' (cm/s)	8.7 [7.9-10.7]	9.4 [8.3-10.3]	9.3 [8.1-10.2]	8.5 [7.3-10.6]	6.7 [5.9-8.4]	7.2 [5.7-8.6]	0.041
E' (cm/s)	7.4 [6.3-9.3]	7.6 [6.6-9.3]	6.2 [5.7-8.1]	6.9 [5.7-8.1]	5.3 [4.3-5.9]	5.1 [4.2-5.9]	0.023
A' (cm/s)	10.2 [8.1-13.0]	10.9 [9.1-12.5]	11.9 [8.8-13.9]	9.9 [8.9-12.0]	8.3 [6.9-10.6]	6.9 [5.5-9.9]	0.023
E'/A'	0.71 [0.58-0.90]	0.72 [0.58-0.84]	0.55 [0.48-0.6]	0.64 [0.49-0.84]	0.63 [0.54-0.69]	0.75 [0.57-0.89]	0.442
MPI	0.52 [0.43-0.58]	0.44 [0.36-0.55]	0.49 [0.37-0.58]	0.63 [0.45-0.82]	0.71 [0.49-0.84]	0.50 [0.42-0.88]	0.278
Hemodynamic measurements							
SvO_2 (%)	77 [76-79]	77 [75-81]	79 [76-82]	76 [72-82]	74 [69-80]	73 [69-79]	0.040
CCI (L/min/m^2)	2.4 [1.7-2.8]	2.1 [2.0-2.5]	2.4 [2.1-2.8]	3.1 [2.8-3.5]	3.2 [2.7-3.4]	2.9 [2.4-3.4]	0.009
EDVi (mL/m^2)	136 [112-153]	134 [119-150]	125 [113-146]	122 [107-154]	135 [118-148]	129 [110-137]	0.444
RVEF (%)	27 [22-32]	24 [19-27]	26 [22-33]	29 [25-34]	27 [25-29]	26 [22-28]	0.294
SVi (mL/beat/m^2)	37 [31-42]	31 [28-37]	31 [28-35]	35 [33-41]	36 [31-41]	34 [28-40]	0.024
HR (beat/min)	60 [55-67]	66 [60-70]	65 [60-79]	90 [86-90]	90 [90-90]	90 [90-90]	< 0.001
Mean ABP (mmHg)	69 [62-78]	71 [66-82]	62 [55-66]	59 [54-66]	61 [56-69]	66 [60-70]	0.350
CVP (mmHg)	13 [9-14]	9 [8-11]	8 [6-11]	8 [7-13]	11 [8-14]	13 [10-15]	0.775
Mean PAP (mmHg)	22 [19-24]	21 [20-23]	19 [18-21]	20 [17-26]	21 [18-23]	23 [21-24]	0.812
sPAP (mmHg)	32 [27-36]	29 [25-32]	29 [23-33]	29 [23-34]	28 [23-32]	30 [28-32]	0.150
dPAP (mmHg)	16 [13-19]	15 [13-17]	14 [12-17]	16 [12-20]	16 [14-19]	18 [15-20]	0.268

NOTE. Data are presented as median [interquartile range]. Measurement points are as follows: 1, after general anesthesia, before sternal opening; 2, after sternal opening; 3, after pericardial opening; 4, after weaning from cardiopulmonary bypass; 5, after pericardial approximation or closure; and 6, after sternal closure. The p values were calculated over the difference between the individual time points 1 and 6.

Abbreviations: A', late diastolic excursion velocity; ABP, arterial blood pressure; CCI, continuous cardiac index; CVP, central venous pressure; dPAP, diastolic pulmonary artery pressure; E', early diastolic excursion velocity; EDVi, end-diastolic volume index; HR, heart rate; MPI, myocardial performance index; PAP, pulmonary artery pressure; RVEF right ventricular ejection fraction; S', systolic excursion velocity; sPAP, systolic pulmonary artery pressure; SVi, stroke volume index; SvO_2, mixed venous oxygen saturation; TAPSE, tricuspid annular plane systolic excursion.

considered significantly different if the p value was < 0.05. Because of the explorative nature of the study, a power calculation was impossible. In accordance with similar studies, a sample size of 20 patients was deemed sufficient. Bland-Altman analysis was used to obtain interobserver and intraobserver variability among echocardiographic measurements. For both intraobserver and interobserver variability, the intraclass correlation coefficient was calculated, using the 2-way random model and absolute agreement among measurements.

Results

Between July 2017 and July 2018, 121 patients underwent AVR with or without CABG in the authors' institution. Major reasons for exclusion were significant right coronary artery stenosis (n = 41), logistical reasons (n = 30), and atrial fibrillation (n = 6). Baseline characteristics are listed in Table 1. Preoperative left ventricular ejection fraction was >55% in all patients. In 6 patients, the postoperative quality of the PW TDI signal was either insufficient, or VVI pacing rendered the measurement of MPI impossible. None of the patients had a mitral regurgitation exceeding grade 1 out of 4.

RV Function Measurements

TEE measurements of all participants during surgical procedure are shown in Table 2. TAPSE was reduced significantly from the time before the surgical procedure to sternal closure (from 20.8 [16.6-23.4] mm to 9.1 [5.6-15.5] mm; p < 0.001) (Fig 1).

Representation over time shows that this reduction was not limited to the pericardial opening but appeared to be a gradual reduction, even after partial pericardial closure (Fig 2, A). In addition, S' also decreased over time (from 8.7 [7.9-10.7] cm/s to 7.2 [5.7-8.6] cm/s; p = 0.041) (Fig 3, A). The overall reduction in TAPSE and S' was not accompanied by a reduction in actual RV performance; MPI remained constant before and after the procedure (from 0.52 [0.43-0.58] to 0.50 [0.42-0.88]; p = 0.278) (Fig 3, B). In addition, PAC-derived RVEF also was unaltered after the procedure (from 27% [22%-32%] to 26% [22%-28%]; p = 0.294) (Fig 2, B and Fig 3, C). Simultaneously, the continuous cardiac index increased over time (from 2.4 [1.7-2.8] L/min/m^2 to 2.9 [2.4-3.4] L/min/m^2; p = 0.009 (Fig 3, D). There was no change in central venous pressure or pulmonary artery pressure (see Table 2).

The correlation coefficient between the change in TAPSE over time and the change in RVEF over time was insignificant (Fig 4; $R_s^2 = 0.02$; p = 0.37)

The interobserver and intraobserver variability showed very good reproducibility for all echocardiographic measurements (Supplemental Table S1 and Supplemental Figs S1 and S2).

Discussion

The present study makes clear that longitudinal parameters of RV contraction (ie, TAPSE and S') were significantly reduced between the start of and after cardiothoracic surgery. This reduction was not limited to the opening of the pericardium. However, the decline in longitudinal parameters in RV function was not

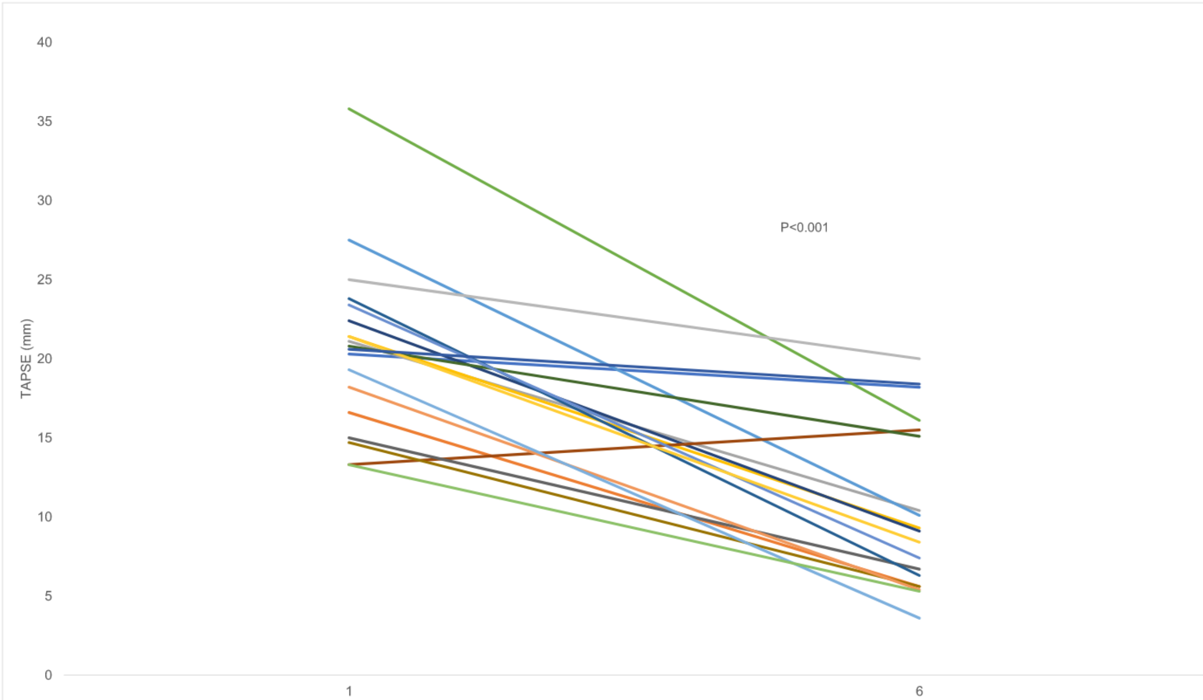

Fig 1. Individual measurements of tricuspid annular plane systolic excursion, measured with transesophageal echocardiography before sternal opening (1) and after sternal closure (6).

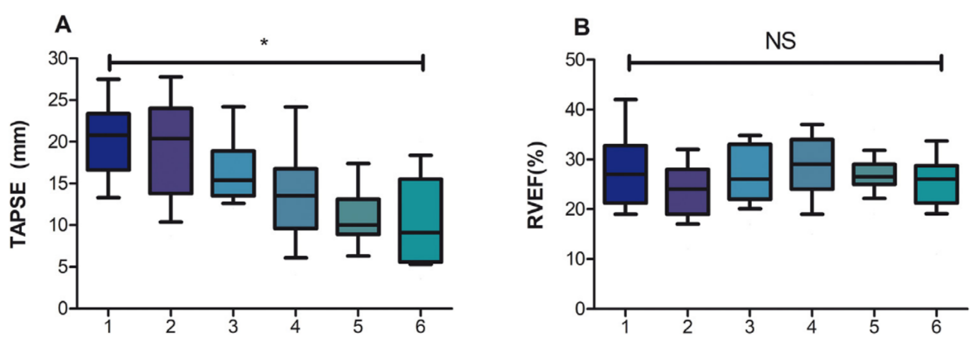

Fig 2. Evaluation of right ventricular function. Measurement points: 1, after general anesthesia; 2, after sternal opening; 3, after pericardial opening; 4, after weaning from cardiopulmonary bypass; 5, after pericardial approximation or closure; and 6, after sternal closure. (A) Tricuspid annular systolic plane excursion measured with transesophageal echocardiography. (B) Right ventricular ejection fraction measured with pulmonary artery catheter. *p < 0.05. p values were calculated over the difference between time point 1 and 6. RVEF, right ventricular ejection fraction; TAPSE, tricuspid annular systolic plane excursion.

accompanied by a decrease in global RV performance, as expressed by TEE-derived MPI and PAC-derived RVEF and cardiac index. Consequently, a correlation could not be established between the change over time in TAPSE and RVEF. Assessment of the multiple changes of RV performance during cardiac surgery therefore should not be limited to a single measurement. Whether that includes a combination of ultrasound-derived longitudinal parameters and PAC or a more complex echocardiographic evaluation seems to be setting- and operator-dependent.

Several studies have reported a significant reduction in TAPSE or S' after cardiothoracic surgery.[8,17,18,25,26] In general, opening of the pericardium and weaning from CPB have been identified as pivotal time points for this reduction.[14,17,19,27,28] In addition, the authors were unable to confirm this previously reported critical influence of the opening of the pericardium on RV function. This is in accordance to on-pump CABG patients without valve repair.[29] Data on the change of RVEF during cardiothoracic surgery are not fully unequivocal. In accordance with the present study's data, a significant reduction in TAPSE was not accompanied by a reduction in 3D transthoracic echocardiographic (TTE)– or PAC-derived RVEF in patients with CABG surgery[30] or mitral valve repair.[15,19,31] Similarly, both PAC-derived and 3D TEE–derived RVEF remained unaltered during CABG, but simultaneous measurement of TAPSE and S' were lacking in that study.[32]

In addition, in a recent study with TEE-derived 3D echocardiography among CABG patients, RVEF remained unchanged, whereas peak longitudinal strain of the RV lateral and inferior walls, TAPSE, and S' declined significantly after the procedure.[33]

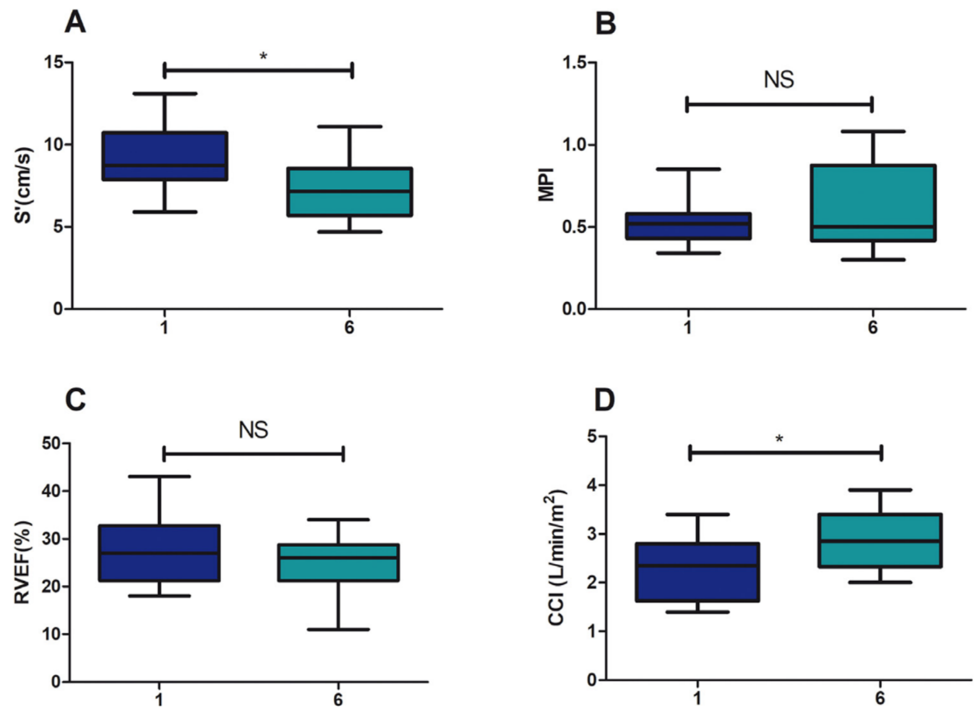

Fig 3. Comparison between preoperative measurements before sternal opening (point 1) and postoperative measurement after sternal closure (point 6). (A) Systolic excursion velocity was measured with transesophageal pulsed wave tissue Doppler. (B) Myocardial performance index was measured with transesophageal echocardiography. (C) Right ventricular ejection fraction was measured with a pulmonary artery catheter. (D) The continuous cardiac index was measured with a pulmonary artery catheter. *$p < 0.05$. CCI, continuous cardiac index; MPI, myocardial performance index; NS, nonsignificant; RVEF, right ventricular ejection fraction; S', systolic excursion velocity.

However, the present study's data seem to be conflicting with the establishment of a significant correlation between ultrasound-derived TAPSE and PAC-derived RVEF in a mixed group of cardiothoracic patients.[25] Despite the use of an identical method to assess RVEF, the referred study was restricted to a single postoperative measurement. Moreover, a comparison between preoperative and postoperative performance of the right ventricle was not included. In other words, the observed correlation between TAPSE and RVEF suggests that both variables reflect RV function to some extent. This also has been illustrated by the observed relationship between adverse outcome and variables.[34,35] However, the observations from the present study indicate that they are not interchangeable and are clearly markers of different processes. A reduction in RV longitudinal contractions, as reflected by TAPSE and S', may be compensated for by radial shortening of the right ventricle, enabling preservation of global RV performance.[21] Vice-versa, in long-term exercise-induced changes of RV mechanics, longitudinal contractions are more profoundly involved with a concomitant decreased importance of free wall radial motion, underlining the noninterchangeable contribution of the 2 contractile mechanisms in various conditions.[36] Clearly, the design of the present study precluded the exploration of underlying mechanisms of changes in RV performance. However, on the basis of the present study's results, it becomes clear that preload (as reflected by EDVi) and afterload (as reflected by mean pulmonary artery pressures and positive end-expiratory pressure settings) did not change over time. This was accompanied by a reduction in stroke volume index, compensated for by an increase in heart rate.

The present study has several limitations. Inclusion criteria included patients specifically scheduled for aortic valve surgery with a preserved left ventricular function, in the absence of significant right coronary artery stenosis, in order to avoid the influence of left ventricular systolic impairment and RV ischemia on the results. Whether the study's data thus are applicable to different settings of cardiothoracic surgery remains a topic for future studies. It becomes clear that the type of assessment of RV parameters may be of substantial influence on the results. TEE and TTE both deal with specific challenges to obtain reliable measurements of RV performance. Even the positioning of the TEE probe may be of influence on measurements of the same parameters.[37] Guidelines

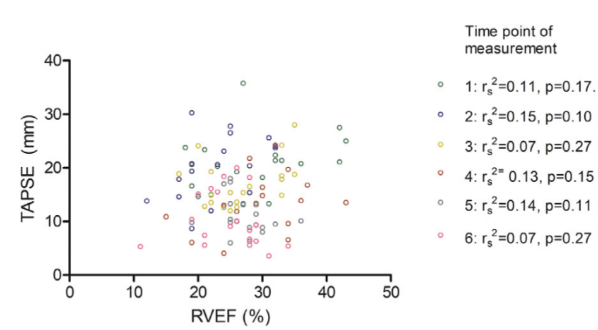

Fig 4. Correlation between the change in tricuspid annular systolic plane excursion over time and the change in right ventricular ejection fraction over time. Measurement points: 1, after general anesthesia; 2, after sternal opening; 3, after pericardial opening; 4, after weaning of cardiopulmonary bypass; 5, after pericardial approximation or closure; and 6, after sternal closure. RVEF, right ventricular ejection fraction; TAPSE, tricuspid annular plane systolic excursion.

on echocardiography of the right ventricle focus on TTE, whereas TEE predominantly is used in the perioperative setting. Because of a lack of normal values and validation studies, extrapolation to TEE measurements from the TTE methods remains cumbersome.[38-41] Because the method used throughout the study protocol did not change over time, the authors believe that the changes over time are represented adequately. This is especially true because the transgastric view allowed for the reproduction of TAPSE and S' with minimum change in angle. This is of particular importance because there seems to be a lack of consistency in the echocardiographic assessment of the right ventricle and the definition of RV dysfunction in the current guidelines.[38,39,42,43] Unlike the left ventricle, the complex anatomy of the right ventricle does not allow for any geometric assumptions, which makes a reliable echocardiographic assessment of size and volume difficult.[38] The most recent guideline for chamber quantification recommends to include RV and right atrial size and a measure of RV systolic function, as assessed by at least 1 or a combination of the following: fractional area change, S′, TAPSE, and MPI, each with its own advantages and limitations.[42] In a large worldwide survey, TAPSE appeared to be the most commonly used parameter in daily practice, followed by S'.[44] Although both parameters seem to correlate well with RV function in both normal participants and in different disease states, validated against radionuclide angiography and magnetic resonance imaging, the current study underlines the complexity of a full assessment of RV function in specific settings.[34] In particular, the assessment of MPI appeared to be cumbersome. In 6 of 20 patients in the present study, MPI measurements were unable to be performed, resulting in a potential of bias.

In addition to echocardiography, the PAC also might play an important role in the bedside evaluation of the RV function, despite its invasive character.[40,45,46] The latest version of the PAC, as used in this study, enables continuous bedside assessment of the RVEF, EDVi, cardiac index, and SvO_2.

Assessment of thermodilution-derived RVEF correlates well with magnetic resonance imaging– and angiography-derived RVEF.[35,47,48] Furthermore, RVEF is associated with survival in different clinical settings, including cardiac surgery.[4,49] Notwithstanding the criticism on the use of a PAC, the device still is widely used in the perioperative setting during cardiac surgery and measurements are not operator dependent.[46,50]

Conclusion

During aortic valve surgery, the reduction of echocardiographic parameters of RV longitudinal contraction (ie, TAPSE and S') generally is not accompanied by a reduction in global RV performance, as established with TEE and PAC. Such reduction may rather serve as a marker of geometric adaption. Solely relying on a single RV parameter as a marker for global RV performance may not be adequate to assess the complex adaptation of the right ventricle to AVR. In addition, study investigators were unable to confirm the previously reported critical influence of the opening of the pericardium on RV function.

Conflict of Interest

None.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2020.01.012.

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