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Part I

*Right Ventricular Overload in Left Sided Heart Disease*
Chapter 2

*Right Ventricular Dysfunction Affects Survival after Surgical Left Ventricular Restoration*

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Abstract

Background
Several clinical and left ventricular parameters have been associated with prognosis after surgical left ventricular restoration in patients with ischemic heart failure. The aim of this study was to determine the prognostic value of right ventricular function.

Methods
A total of 139 patients with ischemic heart failure (62±10 years; 79% male; left ventricular ejection fraction 27±7%) underwent surgical left ventricular restoration. Biventricular function was assessed with echocardiography before surgery. The independent association between all-cause mortality and right ventricular fractional area change, tricuspid annular plane systolic excursion and right ventricular longitudinal peak systolic strain was assessed. The additive effect of multiple impaired right ventricular parameters on mortality also was assessed.

Results
Baseline right ventricular fractional area change was 42±9%, tricuspid annular plane systolic excursion was 18±3 mm and right ventricular longitudinal peak systolic strain was -24±7%. Within 30 days after surgery 15 patients died. Right ventricular fractional area change (HR 0.93, 95%CI 0.88-0.98, P<0.01), tricuspid annular plane systolic excursion (HR 0.80, 95%CI 0.66-0.96, P=0.02) and right ventricular longitudinal peak systolic strain (HR 1.15, 95%CI 1.05-1.26, P<0.01) were independently associated with 30-day mortality, after adjusting for left ventricular ejection fraction and aortic crossclamping time. Right ventricular function was impaired in 21%, 20% and 27% of patients on the basis of right ventricular fractional area change, tricuspid annular plane systolic excursion and right ventricular longitudinal peak systolic strain, respectively. Any echocardiographic parameter of right ventricular dysfunction was present in 39% of patients. The coexistence of several impaired RV parameters per patient was independently associated with increased 30-day mortality (HR 2.83, 95%CI 1.64-4.87, P<0.01 per additional impaired parameter).

Conclusion
Baseline right ventricular systolic dysfunction is independently associated with increased mortality in patients with ischemic heart failure undergoing surgical left ventricular restoration.

Keywords: heart failure; surgical left ventricular restoration; right ventricular function.
Introduction

Surgical ventricular restoration (SVR) of the left ventricle in addition to coronary revascularization yields a survival benefit compared to revascularization alone, if the predicted postoperative LV end-systolic volume index is ≤ 70 ml/m$^2$. This is the outcome of a substudy of the Surgical Treatment for Ischemic Heart Failure (STICH) trial in which 1000 patients with ischemic heart failure and anterior akinesia or dyskinesia were randomized to coronary artery bypass grafting (CABG) surgery alone or combined with SVR.$^1$ Other factors that may affect outcome in patients undergoing SVR include poor left ventricular (LV) function, high preoperative LV end-systolic volume index and New York Heart Association (NYHA) functional class IV.$^{2-4}$ So far, only limited data are available on the influence of right ventricular (RV) function and dimensions on outcome after SVR.$^5,6$ The reduction in LV volume after SVR may lead to increased LV filling pressures and increased afterload of the right ventricle that may decrease its function. Furthermore, the improvement in LV systolic function after SVR may lead to increased preload of the right ventricle. Preoperative impaired RV systolic function may have a negative impact on outcome after SVR, because the right ventricle may not be able to handle the increased preload and afterload. Therefore, preoperative RV systolic function might be an important variable to consider in the selection of patients with ischemic heart failure who may be candidates for SVR. The purpose of the present study was to assess whether RV function is associated with postoperative survival in heart failure patients undergoing SVR.

Materials and methods

Study population and protocol

The study population comprised 143 consecutive patients who underwent SVR according to the technique described by Dor between January 2006 and January 2014.$^7$ All patients had symptomatic heart failure despite optimal medication and a post-infarction LV aneurysm. The decision to perform SVR was made by the institutional multidisciplinary heart team. Exclusion criteria for the current study were: incomplete follow-up (N=2) and insufficient preoperative transthoracic echocardiographic image quality for the current analysis (N=2). According to the institutional protocol, all patients underwent clinical and echocardiographic evaluation before SVR. Clinical data, including demographic characteristics, medical history, comorbidities and functional status according to the NYHA classification, were prospectively collected in the departmental cardiology information system (EPD-Vision, Leiden University Medical Center, Leiden, the Netherlands) and retrospectively analyzed. Creatinine clearance was estimated using the Cockroft-Gault formula.$^8$ All-cause mortality
was registered during 30 days of follow-up through case record review and the national death registry. The study was conducted in accordance with the declaration of Helsinki. The institutional ethical committee approved this retrospective evaluation of clinically acquired data.

**Transthoracic echocardiography**

In line with the institutional protocol, routine transthoracic echocardiography was performed before SVR. Images were obtained with the patient in the left lateral decubitus and supine position with a commercially available system (Vivid 7 or E9 [General Electric-Vingmed Ultrasound, Horten, Norway]) and digitally stored in cine-loop format. For the present study, measurements were performed by a cardiologist specialized in echocardiography using commercially available software (EchoPAC version 112.0.1; General Electric-Vingmed Ultrasound, Horten, Norway). For the assessment of LV systolic function, LV end-systolic and end-diastolic volumes were measured from the apical 4- and 2-chamber views and LV ejection fraction (LVEF) was calculated using the Simpson’s biplane technique.\(^9\) LV end-systolic volume was indexed for body surface area to obtain LV end-systolic volume index. End-diastolic left atrial volume was measured in the apical 4- and 2-chamber views and indexed for body surface area to obtain left atrial volume index.\(^9\) Peak early diastolic mitral inflow velocity (E) was measured on pulsed-wave Doppler recordings and septal and lateral early diastolic mitral annulus velocities were measured on tissue Doppler imaging of the apical 4-chamber view. Peak early diastolic mitral inflow velocity was divided by the average of septal and lateral annular velocities (E’) to acquire the E/E’ ratio.\(^10\) For comprehensive RV functional assessment, RV end-systolic and end-diastolic areas were traced in the RV apical view to calculate fractional area change (RVFAC). Tricuspid annular plane systolic excursion (TAPSE) was calculated on M-mode recordings of the lateral tricuspid annulus in the RV apical view. Furthermore, speckle-tracking echocardiography of the RV free wall was performed. RV longitudinal peak systolic strain (RV LPSS) was measured in the basal, mid-ventricular and apical segments of the RV free wall and global RV LPSS was calculated as the average of the 3 measurements. Cut-off values for impaired RV functional parameters were derived from the most recent American Society of Echocardiography recommendations for cardiac chamber quantification and assessment of the right heart by echocardiography in adults and were defined as RVFAC <35%, TAPSE <16 mm and RV LPSS >-20%.\(^9,11\) The diameter of the tricuspid valve annulus was measured during diastole on the apical RV view.\(^12\) The maximum tricuspid regurgitant jet gradient was measured from continuous wave-Doppler using the modified Bernoulli equation.\(^11\) Right atrial pressure was estimated as 3, 8 or 15 mmHg on the basis of the diameter and inspiratory collapse of the inferior caval vein in the subcostal view.\(^9\) Systolic pulmonary arterial pressure was calculated by summation of the tricuspid regurgitant jet gradient and right atrial pressure. Pulmonary hypertension was defined as systolic pulmonary arterial pressure > 50 mmHg.\(^13\)
Surgical Left Ventricular Restoration

The details of the SVR procedure according to Dor have been described. All operations were performed using cardiopulmonary bypass, aortic crossclamping and intermittent warm blood cardioplegia. In summary, the left ventricle was opened through the infarcted area and a Fontan-stitch was placed at the transitional zone between viable and scarred myocardium. A mannequin balloon (TRISVR, Chase Medical, Richardson, USA) was used to determine both the new size and shape of the residual LV cavity. For size, the balloon was filled at 55 ml/m² body surface area. The balloon also allowed proper orientation of the neo-apex and the patch used to close the defect, which was sutured in a way directed obliquely at the aortic outflow tract to ensure an elliptical shape and avoid a boxlike or spherical shape. Concomitant procedures were performed when indicated. Non-elective surgery was defined as surgery performed during an urgent admission.

Statistical analysis

Continuous variables are expressed as mean ± standard deviation when normally distributed, or otherwise as median and interquartile range (IQR). Categorical data are presented as frequencies and percentages. Univariable Cox regression analysis was performed to assess the association between 30-day mortality and baseline clinical, surgical and echocardiographic parameters by estimating hazard ratio’s (HR) and 95% confidence intervals (CI). Kaplan Meier survival curves and 95%CI for patients with normal versus impaired echocardiographic indices of RV function were estimated. Significant variables in the univariable analysis were entered in several non-nested multivariable analyses. Regression analysis was performed on 15 events and 1 variable was entered for every 5 events in the multivariable analysis. LVEF and aortic crossclamping time were considered the clinically most relevant variables and were included in the multivariable analysis along with one RV parameter per model. Furthermore, patients were classified as having no, 1, 2, or 3 impaired RV parameters. The association between the number of impaired RV parameters and mortality was assessed using Cox proportional hazard regression models. To define the intraobserver and interobserver variability, measurements for RV functional parameters were repeated for 20 randomly selected patients by the same observer and a second independent observer, both unaware of clinical outcome. Intraobserver and interobserver variability was assessed using Bland-Altman analysis and is expressed as mean difference ± standard deviation. Statistical analysis was performed by using SPSS for Windows (version 23.0, Armonk, New York).
Results

Baseline clinical and echocardiographic data
In total, 139 patients with heart failure (mean age 62±10 years, 79% male) were included. Table 1 summarizes baseline clinical and echocardiographic data. Baseline NYHA functional class was III or IV in 77 (55%) patients and mean LVEF was 27±7%. The median European System for Cardiac Operative Risk Evaluation (EuroSCORE II) was 5% (IQR 3-12%). Nonelective surgery was performed in 29 (21%) patients. Echocardiographic assessment of RVFAC, TAPSE and RV LPSS was feasible in 136 (98%), 137 (99%) and 117 (84%) patients, respectively. Mean RVFAC was 42±9%, mean TAPSE was 18±3 mm and mean RV LPSS was -24±7%. RVFAC was impaired in 29 (21%) patients, TAPSE in 27 (20%) patients and RV LPSS in 31 (27%) patients. In 114 patients all 3 measurements of RVFAC, TAPSE and RV LPSS could be assessed. In this population 44 (39%) patients had 1 or more parameters of impaired RV function. Bland-Altman analysis showed good intraobserver and interobserver agreement. Mean differences were 0.41±2.66 for RVFAC, 0.25±1.29 for TAPSE and 0.07±2.28 for RV LPSS for inter-observer variability and 0.60±2.78 for RVFAC, 0.05±0.69 for TAPSE and 0.10±1.48 for RV LPSS for intraobserver variability.

Surgical data and postoperative survival
At the time of SVR, concomitant CABG, mitral valve surgery and tricuspid valve surgery were performed in 74 (53%), 73 (53%), and 36 (26%) patients, respectively. Ablation for ventricular tachycardia was performed in 58 (42%) patients and included endocardial resection in 11 (8%) patients. Mean aortic crossclamping time was 148±69 minutes. Within 30 days after surgery 15 patients died, yielding a survival rate of 89%. All 15 deaths within the first 30 days were heart failure related and 10 out of 15 (67%) patients clinically experienced postoperative RV failure. In 8 out of 15 (53%) patients mechanical support (intra-aortic balloon pump and/or extra corporeal membrane oxygenation) was used postoperatively to attempt to support cardiac function.

Associates of 30-day survival
Univariable Cox regression analysis revealed that the EuroSCORE II, nonelective surgery, aortic crossclamping time, CABG, LVEF, RVFAC, TAPSE and RV LPSS were associated with 30-day mortality (Table 1). As shown in Figure 1, the 30-day survivals of patients dichotomized on the basis of RVFAC ≥35% or <35% were 94% and 69%, respectively (P<0.01). Likewise, at 30-day follow-up higher survival was observed in patients with TAPSE ≥16 mm compared with patients with TAPSE <16 mm (94% vs
70%, P<0.01) and in patients with RV LPSS ≤-20% compared with patients with RV LPSS >=-20% (94% vs 74%, P<0.01).

Table 1. Baseline characteristics and hazards ratio’s for univariable Cox regression analysis of 30-day mortality.

<table>
<thead>
<tr>
<th>Clinical and surgical characteristics</th>
<th>N = 139</th>
<th>HR</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at operation (years)</td>
<td>62±10</td>
<td>1.02</td>
<td>0.97 - 1.08</td>
<td>0.50</td>
</tr>
<tr>
<td>Male sex (%)</td>
<td>79</td>
<td>1.77</td>
<td>0.40 - 7.83</td>
<td>0.45</td>
</tr>
<tr>
<td>NYHA functional class III or IV</td>
<td>55</td>
<td>3.38</td>
<td>0.95 - 11.97</td>
<td>0.06</td>
</tr>
<tr>
<td>Creatinine clearance (ml/min)</td>
<td>79±28</td>
<td>1.00</td>
<td>0.98 - 1.02</td>
<td>0.92</td>
</tr>
<tr>
<td>EuroSCORE II (%)</td>
<td>5 (IQR 3-12)</td>
<td>1.05</td>
<td>1.02 - 1.08</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Previous sternotomy (%)</td>
<td>12</td>
<td>1.90</td>
<td>0.54 - 6.73</td>
<td>0.32</td>
</tr>
<tr>
<td>Nonelective surgery (%)</td>
<td>21</td>
<td>4.68</td>
<td>1.69 - 12.90</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Aortic cross-clamping time (min)</td>
<td>148±69</td>
<td>1.01</td>
<td>1.00 - 1.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Concomitant procedures (%)</td>
<td>90</td>
<td>23.83</td>
<td>0.02 - 32344.19</td>
<td>0.39</td>
</tr>
<tr>
<td>- CABG (%)</td>
<td>53</td>
<td>3.81</td>
<td>1.07 - 13.50</td>
<td>0.04</td>
</tr>
<tr>
<td>- MV surgery (%)</td>
<td>53</td>
<td>1.86</td>
<td>0.63 - 5.43</td>
<td>0.26</td>
</tr>
<tr>
<td>- TV surgery (%)</td>
<td>26</td>
<td>1.40</td>
<td>0.48 - 4.10</td>
<td>0.54</td>
</tr>
<tr>
<td>- VT ablation (%)</td>
<td>42</td>
<td>0.70</td>
<td>0.24 - 2.04</td>
<td>0.51</td>
</tr>
<tr>
<td>Echocardiographic characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>27±7</td>
<td>0.93</td>
<td>0.87 - 0.99</td>
<td>0.03</td>
</tr>
<tr>
<td>LVESVI (ml/m²)</td>
<td>87±41</td>
<td>1.00</td>
<td>0.99 - 1.01</td>
<td>0.64</td>
</tr>
<tr>
<td>LAVI (ml/m²)</td>
<td>46±18</td>
<td>1.02</td>
<td>0.99 - 1.04</td>
<td>0.23</td>
</tr>
<tr>
<td>E/E’ ratio</td>
<td>18±9</td>
<td>1.02</td>
<td>0.96 - 1.08</td>
<td>0.55</td>
</tr>
<tr>
<td>RVFAC (%)</td>
<td>42±9</td>
<td>0.92</td>
<td>0.88 - 0.97</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>TAPSE (mm)</td>
<td>18±3</td>
<td>0.78</td>
<td>0.65 - 0.94</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RV LPSS (%)</td>
<td>-24±7</td>
<td>1.14</td>
<td>1.04 - 1.24</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>TV annulus (mm)</td>
<td>32±6</td>
<td>1.08</td>
<td>0.99 - 1.17</td>
<td>0.07</td>
</tr>
<tr>
<td>TR grade ≥ 2 (%)</td>
<td>19</td>
<td>1.56</td>
<td>0.50 - 4.89</td>
<td>0.45</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>12</td>
<td>1.89</td>
<td>0.53 - 6.70</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Abbreviations: CABG, coronary artery bypass grafting; EuroSCORE, European System for Cardiac Operative Risk Evaluation; E/E’, peak early diastolic mitral inflow velocity/early diastolic mitral annulus velocity; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; LVESVI, left ventricular end-systolic volume index; MV, mitral valve; NYHA, New York Heart Association; RVFAC, right ventricular fractional area change; RV LPSS, right ventricular longitudinal peak systolic strain; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurgitation; TV, tricuspid valve; VT, ventricular tachycardia.
Figure 1. Kaplan Meier survival curves for baseline normal versus impaired right ventricular function in patients after SVR. A. RVFAC; B. TAPSE; C. RV LPSS.

Abbreviations: RVFAC, right ventricular fractional area change; RV LPSS, right ventricular longitudinal peak systolic strain; SVR, surgical left ventricular restoration; TAPSE, tricuspid annular plane systolic excursion.
Multivariable Cox regression analysis was performed to assess the association between each separate continuous parameter of RV function and 30-day mortality, adjusted for LVEF and aortic crossclamping time. As shown in Table 2, the multivariable analysis revealed that RVFAC (HR 0.93, 95%CI 0.88-0.98, P<0.01), TAPSE (HR 0.80, 95%CI 0.66-0.96, p=0.02) and RV LPSS (HR 1.15, 95%CI 1.05-1.26, p<0.01) remained independently associated with 30-day mortality, after adjusting for LVEF and aortic crossclamping time. Subsequently, the additive effect of multiple impaired RV parameters on mortality was investigated. The 30-day survival rate was 97% in patients with no echocardiographic parameters of impaired RV function, 83% in patients with 1 impaired parameter, 73% in patients with 2 impaired parameters and 40% in patients with 3 parameters of impaired RV function (P<0.01), as shown in Figure 2. On multivariable Cox regression analysis, the coexistence of several impaired RV parameters per patient remained independently associated with increased 30-day mortality (HR 2.83, 95%CI 1.64-4.87, P<0.01 per additional impaired parameter) after adjusting for LVEF and aortic crossclamping time.

Table 2. Multivariable Cox regression analysis of 30-day mortality and right ventricular function.

<table>
<thead>
<tr>
<th>Correlates of 30-day mortality including RVFAC, TAPSE and RV LPSS.</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Univariable analysis</td>
<td>Multivariable analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HR</td>
<td>95%CI</td>
<td>P</td>
<td>HR</td>
</tr>
<tr>
<td>RVFAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>0.93</td>
<td>0.87 - 0.99</td>
<td>0.03</td>
<td>0.91</td>
</tr>
<tr>
<td>Aortic crossclamping time (min)</td>
<td>1.01</td>
<td>1.00 - 1.01</td>
<td>&lt;0.01</td>
<td>1.01</td>
</tr>
<tr>
<td>RVFAC</td>
<td>0.92</td>
<td>0.88 - 0.97</td>
<td>&lt;0.01</td>
<td>0.93</td>
</tr>
<tr>
<td>TAPSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>0.93</td>
<td>0.87 - 0.99</td>
<td>0.03</td>
<td>0.94</td>
</tr>
<tr>
<td>Aortic crossclamping time (min)</td>
<td>1.01</td>
<td>1.00 - 1.01</td>
<td>&lt;0.01</td>
<td>1.01</td>
</tr>
<tr>
<td>TAPSE</td>
<td>0.78</td>
<td>0.65 - 0.94</td>
<td>&lt;0.01</td>
<td>0.80</td>
</tr>
<tr>
<td>RV LPSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>0.93</td>
<td>0.87 - 0.99</td>
<td>0.03</td>
<td>0.95</td>
</tr>
<tr>
<td>Aortic crossclamping time (min)</td>
<td>1.01</td>
<td>1.00 - 1.01</td>
<td>&lt;0.01</td>
<td>1.01</td>
</tr>
<tr>
<td>RV LPSS</td>
<td>1.14</td>
<td>1.04 - 1.24</td>
<td>0.01</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Abbreviations: LVEF, left ventricular ejection fraction; RVFAC, right ventricular fractional area change; RV LPSS, right ventricular longitudinal peak systolic strain; TAPSE, tricuspid annular plane systolic excursion.
Figure 2. Kaplan Meier survival curves for the coexistence of multiple parameters of impaired right ventricular function in patients after SVR. Patients with no, 1, 2 and 3 parameters of impaired right ventricular function.

**Abbreviations:** RV, right ventricular; SVR, surgical left ventricular restoration.

**Discussion**

The main finding of the current study is that preoperative RV dysfunction was an important determinant of postoperative survival in patients with ischemic heart failure undergoing SVR. In particular, reduced RVFAC, TAPSE and RV LPSS as assessed by echocardiography were independently associated with increased 30-day mortality. Furthermore, a higher number of impaired RV parameters per patient was associated with increased mortality.

Impaired RV function, as assessed with a wide variety of parameters, is a well-known risk factor for mortality in the general population with heart failure. Previous studies also demonstrated that RV function is a prognostic marker in patients with heart failure undergoing cardiac surgery. Maslow and colleagues showed that baseline RV dysfunction was associated with poor outcome in patients with severe LV dysfunction undergoing CABG. Furthermore, Dandel and colleagues showed an association between preoperative RV function and outcome in patients undergoing LV assist device (LVAD) implantation and emphasized the additive value of combining RV parameters to quantify RV function.

Conceptually, RV function may also be an important prognostic determinant after SVR. Previous studies reported that SVR enhances LV systolic function, but can also impair LV diastolic properties resulting in elevation of LV filling pressures and increased RV afterload. Furthermore, the more
RV Dysfunction in Surgical Left Ventricular Restoration

spherical LV geometry after SVR alters the position and function of the interventricular septum, which may influence RV geometry and function.\textsuperscript{26,27} Therefore, preoperative assessment of RV function seems an important variable to consider in patient selection for SVR.

Data associating RV function and outcome in patients with ischemic heart failure undergoing SVR are scarce. Kukulski and colleagues examined the prevalence of RV dysfunction and its effect on outcome in a subgroup of 866 patients included in the STICH trial.\textsuperscript{5} RV dysfunction was visually assessed with echocardiography and classified as mild in 12\% of patients and moderate to severe in 9\% of patients. The grade of RV dysfunction was associated with advanced LV remodelling and worse hemodynamic profiles. Patients with moderate to severe RV dysfunction who received CABG and SVR had significant higher mortality and cardiovascular hospitalization rates at long-term follow-up compared to patients who received CABG alone. Kukulski and colleagues concluded that adding SVR to CABG may worsen survival in patients with moderate to severe RV dysfunction. However, it should be noted that visual classification of RV dysfunction is difficult to categorize and may be inaccurate and with poor interobserver agreement.

Furthermore, Garatti and colleagues assessed the relation between RV function and clinical outcome after SVR.\textsuperscript{6} A total of 324 patients underwent SVR and concomitant CABG was performed in 90\% of patients. RV dysfunction, defined as TAPSE $<16$ mm, was present in 21\% of patients and was associated with a higher frequency of so-called low-output syndrome, postoperative inotropic support and intra-aortic balloon pump insertion. In this study no statistically significant difference in 30-day survival was found between patients with and without RV dysfunction, but 5- and 8-year survival and freedom from cardiac events were significantly lower in patients with preoperative RV dysfunction. However, it has to be noted that TAPSE is only an approximate indicator of RV function that does not reflect the complex geometry and function of the right ventricle.

Similarly to these studies, the present study confirmed the association between RV dysfunction and increased mortality after SVR. However, our data extend the insights into this association by adding the assessment of RV function based on myocardial strain. RV LPSS is a novel measurement that assesses free wall deformation independently of the angle of the ultrasound beam.\textsuperscript{9,28} In addition, the use of standardized measuring techniques and generally acknowledged cutoff values make our findings easily reproducible for future patients considered for SVR.\textsuperscript{9,11} Comprehensive echocardiographic assessment of multiple RV functional parameters revealed a higher proportion of patients with any sign of RV dysfunction compared with previous studies (39\% RV dysfunction in the present study versus 21\% in both studies by Kukulski and colleagues and Garatti and colleagues). Our
findings demonstrate for the first time that a higher number of impaired RV parameters per patient had an incremental worse effect on 30-day survival. Furthermore, Kukulski and colleagues showed that RV dysfunction was associated with advanced LV remodelling and proposed that the negative effect of RV dysfunction on outcome after SVR was dependent on this association. The present study is the first to demonstrate that impaired RV function is an independent marker for worse survival in patients undergoing SVR, after adjusting for LVEF. Consequently, the current study increases knowledge on the diagnosis and implications of RV impairment in patients undergoing SVR.

Limitations
First, echocardiographic evaluation of the right ventricle is subject to adequate visualization of its complex 3-dimensional geometry and dependent on the RV preload and afterload. Furthermore, because of the retrospective nature of this study no information is available regarding patients rejected for SVR. Therefore, comparison on survival between operated and non-operated patients with RV dysfunction could not be performed.

Clinical implications
The current study emphasizes the importance of patient selection for SVR, because postoperative mortality is significantly increased in patients with preexistent RV dysfunction. Comprehensive echocardiography using multiple measuring techniques is essential to characterize overall RV function. Patients with RV dysfunction could benefit from additional perioperative measures for RV protection such as the use of inhaled nitric oxide. Otherwise, refraining from SVR should be considered carefully in patients at increased risk for postoperative RV failure. Apart from heart transplant, an alternative treatment option in those patients might even be LVAD implantation because previous studies showed that mechanical unloading of the LV decreases LV filling pressures and thereby reduces RV afterload. Nonetheless, it has to be noted that LVAD implantation brings its own challenges to RV function.

Conclusions
Preexistent RV dysfunction in patients with ischemic heart failure undergoing SVR is frequent and associated with increased postoperative mortality. Comprehensive preoperative echocardiography is essential to characterize RV function and can optimize patient selection for SVR.
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