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Global and regional myocardial function and outcomes after transcatheter aortic valve implantation for aortic stenosis and preserved ejection fraction

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Aim **To investigate the effects of transcatheter aortic valve implantation (TAVI) on early recovery of global and segmental myocardial function in patients with severe symptomatic aortic stenosis and preserved left ventricular ejection fraction (LVEF) and to determine if parameters of deformation correlate with outcomes.**

Methods **The echocardiographic (strain analysis) and outcome (hospitalizations because of heart failure and mortality) data of 62 consecutive patients with preserved LVEF (64.54 ± 7.97%) who underwent CoreValve prosthesis implantation were examined.**

Results **Early after TAVI (5 ± 3.9 days), no significant changes in LVEF or diastolic function were found, while a significant drop of systolic pulmonary artery pressure (PAP) occurred (42.3 ± 14.9 vs. 38.1 ± 13.9 mmHg, *P* = 0.028). After TAVI global longitudinal strain (GLS) did not change significantly, whereas significant improvement in global mid-level left ventricular (LV) radial strain (GRS) was found (−16.71 ± 2.42 vs. −17.32 ± 3.25%; *P* = 0.33; 16.57 ± 6.6 vs. 19.48 ± 5.97%, *P* = 0.018, respectively). Early significant recovery of longitudinal strain was found in basal lateral and anteroseptal segments (*P* = 0.038 and 0.048). Regional radial strain at the level of papillary muscles [*P* = 0.038 mid-lateral, *P* < 0.001 mid-anteroseptum (RSAS)] also improved. There was a significant LV mass index reduction in the late follow-up (152.42 ± 53.21 vs. 136.24 ± 56.67 g/m^2, *P* = 0.04). Mean follow-up period was 3.5 ± 1.9 years. Parameters associated with worse outcomes in univariable analysis were RSAS pre-TAVI, LV end-diastolic diameter after TAVI, relative wall thickness, and mitral *E* and *E/A* after TAVI.**

Conclusion **Global and regional indices of myocardial function improved early after TAVI, suggesting the potential of myocardium to recover with a reduced risk for clinical deterioration.**

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Introduction

Transcatheter aortic valve implantation (TAVI) has been established as a promising procedure for patients with severe symptomatic aortic stenosis who are not suitable candidates for surgery.[1–6] The procedure has been shown to be well tolerated and feasible in the short- and mid-term follow-up period.[7,8] In patients with severe aortic stenosis, because of chronic pressure overload, compensatory mechanisms lead to geometry and functional changes: left ventricular (LV) hypertrophy, diastolic dysfunction, fibrosis and global systolic dysfunction. Myocardial strain, especially longitudinal strain, is a sensitive tool for detecting subtle intrinsic myocardial function damage, even when standard indices of myocardial performance, that is, ejection fraction, are still preserved.[9,10] Acute changes in myocardial function may be seen immediately after TAVI partly because of pressure unloading.[11] In the mid-term follow-up, occurrence of geometrical changes known as reverse remodelling, that is, LV mass and volume regression,[12,13] can be detected with conventional transthoracic echocardiography (TTE). Global longitudinal strain (GLS) improvement after TAVI correlates with symptomatic improvement after intervention.[9] Patients with reduced LV ejection fraction benefit the most in terms of longitudinal reverse remodelling,[14–16] although impaired LVEF itself is associated with adverse outcomes.[15] However, the impact of elevated afterload is not the same in all LV segments according to the Laplace's law. Whether regional LV deformation is associated with outcomes remains unknown. We sought to investigate the effects of TAVI on early recovery of global and segmental myocardial function and mechanics in

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patients with severe aortic stenosis and preserved LVEF, and to determine if parameters of deformation correlate with prognosis. We hypothesized that after TAVI, regional longitudinal strain in basal LV segments and also regional radial strain measured at the level of the papillary muscles improve because of acute pressure unloading and that those changes are associated with prognosis.

Methods

Study population

A single-centre retrospective longitudinal study was performed using hospital charts and digitally stored standard TTE protocols. Consecutive patients with severe symptomatic aortic stenosis who underwent CoreValve (Medtronic, Minneapolis, Minnesota, USA) implantation at the University Hospital of Liège, Belgium in the period 2008–2014 and met inclusion criteria were enrolled. Inclusion criteria were: severe aortic stenosis with preserved LVEF (>50%), high calculated operative risk or contraindication for surgery, available comprehensive TTE protocol before and early after TAVI. Exclusion criteria were: reduced LVEF, unresolved coronary artery disease, signs of scared myocardium and poor quality of echocardiographic images.

Echocardiography

TTE was performed using Vivid 9 echocardiographic ultrasound system (GE Vingmed Ultrasound, Horton, Norway). All TTE studies conducted prior to TAVI, in the early postprocedural period (mean 5 ± 3.9 days), and, if available, after 1-year follow-up were analysed using offline software (EchoPAC-PC, GE Vingmed Ultrasound). LVEF and LV volumes were calculated according to Simpson's biplane method from apical two-chamber and four-chamber views. LV dimension and mass were measured in the long parasternal view. LV mass was then indexed to body surface area. Data concerning diastolic function were collected from apical four-chamber view using pulse wave Doppler on tips of mitral leaflets and tissue Doppler pulse wave Doppler on septal and lateral part of the mitral annulus – simplified approach for patients with preserved ejection fraction was used according to recommendations.[17] Right ventricular function was estimated from apical four-chamber view using tricuspid annulus systolic excursion, fractional area change and tissue Doppler velocity of the tricuspid annulus. Left and right atrial volumes were measured from apical four-chamber and two-chamber views at end systole. Maximum and mean aortic valve gradients were measured from continuous wave Doppler and the aortic valve area was calculated using the continuity equation.

Two-dimensional speckle-tracking strain analysis

Speckle-tracking strain analysis was performed offline using EchoPAC-PC software according to recommendations.[18,19] Two-dimensional views were obtained from the apical (four-chamber, two-chamber and three-chamber views) and parasternal papillary muscle view. Three consecutive cardiac cycles of each view were acquired during a breath hold. Special care was taken to avoid foreshortening in apical views. Peak systolic longitudinal strain was analysed from apical three-chamber, two-chamber and four-chamber views. GLS was measured automatically using an 18-segment model. Segmental longitudinal strain and strain rate (Sr) were measured from six LV basal segments. Radial strain and Sr and circumferential strain and Sr were measured at the mid-ventricular level in short-axis view (papillary muscle level) from six segments because radial strain in basal LV segments is an inaccurate measure because of reduced spatial resolution in this tracking direction. Global radial (GRS) and global circumferential strain (GCS) were calculated manually as an average value from these mid-ventricular six segments.[18] Global right ventricular longitudinal strain (RVLS) was measured from apical four-chamber view. After manual careful tracing of the endocardial borders, epicardial borders were automatically traced by the software. Tracing quality and derived curves were visually checked and manual adjustment was performed when necessary. Timing of aortic valve closure was set manually. The region of interest width was adjusted in order to get optimal tracing. Only segments with satisfactory tracking were used for further analysis. Image quality was checked for each examination and only cine-loops with 2D frame rate greater than 50 fps were used. Global and regional deformation indices were recorded. Intraobserver variability was within 5% measured on 10 randomly chosen patients, whereas interobserver variability was less than 10%, which is in concordance with previously reported data.

Outcomes

Data concerning functional status and outcomes (hospitalizations because of heart failure and death) were collected by direct patients' interview, telephone interview with patients, their physicians or next of kin, or review of hospital or autopsy records and death certificates. Functional status was estimated according to New York Heart Association (NYHA) class. Mean time of follow-up after TAVI to telephone interview was 3.5 ± 1.9 years.

Statistical analysis

Data are reported as mean ± standard deviation for continuous variables or percentages of individuals for categorical variables. Comparisons among patient groups before and after TAVI were performed using appropriate statistical tests, depending on data types and distributions (paired *t*-test, Wilcoxon signed-rank test, or McNemar's test). Paired sample correlations among different variables before and after TAVI were also measured. Survival and outcome analysis was performed using Kaplan–Meier curves, log-rank test and Cox regression. The results were

Table 1 Baseline patients' characteristics and comorbidities

	Number of patients	Percent
Sex (men)	23	37
Arterial hypertension	44	71
Percutaneous coronary intervention	16	26
Coronary arterial bypass grafting	12	19
Hyperlipidaemia	35	56
Pulmonary hypertension	20	32
Atrial fibrillation	17	27
Diabetes	16	26
Chronic obstructive pulmonary disease	14	23
Pacemaker	13	21
Peripheral arterial disease	10	16
Porcelain aorta	10	16
Renal failure	13	21
Stroke/transitory ischemic attack	10	16
Valve surgery	4	6
Carotid disease	3	5

considered statistically significant with a P value of 0.05 or less. Statistical analysis was done using IBM SPSS version 21-software.

Results

Patients' characteristics

Out of all 156 TAVI procedures performed during the period 2008–2014, a total of 62 patients who underwent successful TAVI and met inclusion criteria were enrolled in the study (39 women, mean age 84.5 ± 6.6 years). Patients' baseline characteristics and comorbidities are shown in Table 1. Twenty-eight patients had undergone coronary artery revascularization prior to TAVI (percutaneous in 16, surgical in 12), but had no signs of myocardial scar on TTE.

Procedural data

Mean dimension of the CoreValve implanted was 28.2 ± 2.2 mm. Transfemoral approach was used in the majority of patients (88.7%), subclavian in six patients (9.7%) and carotid in one patient (1.6%). Complications after the procedure included: eight pacemaker implantations early after the procedure, four lesions of the femoral artery, one tamponade requiring surgical drainage, three valves re-sheathed and three recaptured, two strokes, two transitory ischemic attacks and blood transfusion because of bleeding in two patients.

Conventional echocardiographic measurements

Echocardiographic data acquired prior and within 1 week after TAVI revealed no changes in either the LVEF, LV diastolic function, or in the cavity dimensions and volumes (Table 2). As expected, a significant drop in aortic pressure gradients and maximal jet velocity as well as an increase in the aortic valve area was observed (Table 2). Postprocedural aortic regurgitation was found in two-thirds of the patients [trace aortic regurgitation in 32 (52%); mild in 7 (11%); and moderate aortic regurgitation in 2 patients (3%)]. At baseline, transmitral Doppler parameters revealed severely impaired myocardial relaxation, elevation of filling pressures (E/e' 17.7 ± 7.5), left atrial dilatation and concomitant pulmonary artery hypertension. Early after the procedure, no change in either the diastolic parameters, left atrial dimensions or in the right ventricular function was observed, whereas a significant drop in the pulmonary artery pressure occurred ($P = 0.028$) (Table 2).

Table 2 Changes in echocardiographic parameters in the early follow-up

	Before TAVI	Early after TAVI	P value
LVEF (%)	64.54 ± 7.97	66.18 ± 8.42	0.124
LVIDd index (cm)	39.96 ± 15.79	38.56 ± 18.15	0.657
RWT	0.49 ± 0.15	0.45 ± 0.10	*0.023**
LV mass index (g/m^2)	152.4 ± 53.2	136.2 ± 56.7	*0.046**
LVEDV (ml)	73.3 ± 29.5	71.7 ± 26.2	0.435
LVESV (ml)	26.7 ± 13.3	25.3 ± 12.6	0.190
E wave (m/s)	1.02 ± 0.37	1.09 ± 0.34	0.101
E/A	1.08 ± 0.71	0.97 ± 0.57	0.228
e' septal	0.05 ± 0.01	0.05 ± 0.01	0.234
e' lateral	0.06 ± 0.02	0.02 ± 0.07	0.186
E/e'	17.76 ± 7.44	18.64 ± 6.09	0.367
Left atrial volume (ml)	88.9 ± 40.9	87.6 ± 35.7	0.734
PAP (mmHg)	42.3 ± 14.9	38.1 ± 13.9	*0.028**
Maximum aortic PG (mmHg)	75.7 ± 28.9	15.25 ± 9.6	*<0.001**
Mean PG (mmHg)	46.8 ± 17.3	7.8 ± 4.7	*<0.001**
AVA (cm^2)	0.77 ± 0.21	1.93 ± 0.69	*<0.001**
AVA/BSA (cm^2/m^2)	0.43 ± 0.13	1.12 ± 0.42	*<0.001**
TAPSE (mm)	19.8 ± 4.3	19.2 ± 3.8	0.265
FAC (%)	63.1 ± 11.6	60.7 ± 10.4	0.343
RV s' (m/s)	0.10 ± 0.02	0.11 ± 0.02	0.185

AVA, aortic valve area; BSA, body surface area; E', early myocardial tissue velocity at septal mitral annulus; E, early transmitral velocity; FAC, fractional area change; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume; LVIDd, left ventricular internal diameter diastole; PAP, pulmonary artery pressure; PG, pressure gradient; RV, right ventricle; RWT, relative wall thickness; TAPSE, tricuspid annular plane systolic excursion. * $P < 0.05$.

Two-dimensional speckle-tracking strain analysis

Changes in the global and regional longitudinal strain and strain rate early after TAVI are shown in details in Table 3. Before TAVI, the global indices of LV deformation (GLS, GRS) were significantly reduced, with a mild insignificant change in GLS and significant improvement in GRS early after TAVI. Significant regional improvement in longitudinal strain was found in the basal lateral and basal anteroseptum segments, whereas a nonsignificant improvement in the regional basal longitudinal strain was observed in all the other segments. Interestingly, LSr increased significantly after TAVI in almost all basal LV segments. Radial strain and RSr at the mid-ventricular segments also showed a trend of improvement. However, significant changes in the mid-anteroseptum and mid-lateral radial strain were observed. Right ventricular longitudinal deformation did not change significantly after TAVI.

Outcome clinical data

Survival rate 30 days after TAVI was 100%, with a significant improvement in the functional status at the early follow-up period: 20 were in NYHA I (41%), 15 in NHYA II (31%), 7 in NYHA III (14%) and 7 in NYHA IV (14%), whereas before TAVI there were 23 in NYHA II

Table 3 Global and regional strains before and early after transcatheter aortic valve implantation

	Before TAVI	Early after TAVI	*P* value
Global strain			
GLS (%)	−16.71 ± 2.42	−17.32 ± 3.25	0.333
GRS (%)	16.57 ± 6.96	19.48 ± 5.97	*0.018**
GCS (%)	−25.59 ± 5.29	−24.75 ± 6.13	0.508
RVLS (%)	−19.30 ± 5.50	−18.60 ± 5.20	0.558
Regional basal longitudinal strain and strain rate			
LS basal septum (%)	−9.90 ± 4.84	−11.09 ± 4.11	0.105
LSr basal septum (s^{-1})	−0.61 ± 0.28	−0.74 ± 0.29	*0.007**
LS basal lateral (%)	−12.09 ± 4.57	−14.64 ± 7.41	*0.038**
LSr basal lateral (s^{-1})	−0.82 ± 0.29	−1.13 ± 0.46	*<0.001**
LS basal inferior (%)	−12.60 ± 5.75	−13.22 ± 5.05	0.471
LSr basal inferior (s^{-1})	−0.81 ± 0.05	−1.01 ± 0.06	*0.008**
LS basal anterior (%)	−12.85 ± 3.77	−14.02 ± 6.63	0.245
LSr basal anterior (s^{-1})	−0.80 ± 0.31	−0.97 ± 0.43	*0.017**
LS basal posterior (%)	−13.85 ± 4.79	−15.20 ± 5.39	0.237
LSr basal posterior (s^{-1})	−1.03 ± 0.32	−1.24 ± 0.56	0.064
LS basal anteroseptum (%)	−14.07 ± 4.48	−16.43 ± 5.39	*0.048**
LSr basal anteroseptum (s^{-1})	−0.92 ± 0.35	−1.05 ± 0.38	0.129
Regional mid-ventricular radial strain and strain rate			
RS septum (%)	21.07 ± 11.16	19.53 ± 10.49	0.634
RSr septum (s^{-1})	1.48 ± 0.57	1.81 ± 1.52	0.341
RS lateral (%)	16.05 ± 6.75	21.24 ± 11.38	*0.038**
RSr lateral (s^{-1})	1.51 ± 0.52	1.91 ± 0.62	*0.041**
RS inferior (%)	18.10 ± 9.52	18.27 ± 10.33	0.937
RSr inferior (s^{-1})	1.53 ± 0.58	1.60 ± 0.62	0.796
RS anterior (%)	10.51 ± 5.40	15.85 ± 8.53	0.068
RSr anterior (s^{-1})	1.24 ± 0.45	1.70 ± 0.91	0.075
RS posterior (%)	20.08 ± 16.17	23.03 ± 15.45	0.121
RSr posterior (s^{-1})	1.47 ± 0.49	1.69 ± 0.74	0.181
RS anteroseptum (%)	11.08 ± 5.73	17.25 ± 8.15	*<0.001**
RSr anteroseptum (s^{-1})	1.09 ± 0.51	1.46 ± 0.57	*0.025**

GCS, global circumferential strain; GLS, global longitudinal strain; GRS, global radial strain; LS, longitudinal strain; LSr, longitudinal strain rate; RS, radial strain; RSr, radial strain rate; RVLS, right ventricular longitudinal strain. * $P < 0.05$.

(37%), 35 in NYHA III (56%) and 4 patients in NYHA IV (7%) functional status. In the late follow-up period of 3.5 years, 28 patients (45%) died and 6 were lost from the final following-up. Among patients who died, 21% ($N = 6$) suffered from cardiac-related death. Concerning hospitalizations, there were altogether 10 hospitalizations (16%) because of heart failure. Echocardiographic measurements before and early after TAVI (5 ± 3.9 days) were analysed in correlation with mortality and composite outcomes (mortality and hospitalizations because of heart failure) (significant correlations are shown in Table 4). Diastolic function was found to correlate with mortality. Abnormal relaxation ($E < A$) early after TAVI was found to have better prognosis compared with patients with more severe diastolic dysfunction (*E*/*A* 0.78 vs. *E*/*A* 1.23, $P = 0.038$; $\rho = 0.300$, $P = 0.041$). Concerning composite outcomes, higher *E* wave velocity before (i.e. worse diastolic function, abnormal relaxation and increase in diastolic filling pressures) correlated with worse composite outcomes (0.93 ± 0.34 vs. 1.14 ± 0.38; $P = 0.041$, $\rho = 0.29$, $P = 0.033$). Also, early after TAVI, E wave velocity and *E*/*A* ratio were found to correlate with composite outcomes: higher *E* wave velocity (0.99 ± 0.31 vs. 1.20 ± 0.36; $P = 0.028$; $\rho = 0.36$, $P = 0.008$) and higher *E*/*A* ratio (0.77 ± 0.20 vs. 1.20 ± 0.81, $P = 0.045$; $\rho = 0.370$, $P = 0.022$) was associated with worse prognosis. Kaplan–Meier survival curves showed worse long-term outcomes (both mortality and composite outcomes) in patients with *E*/*A* ratio higher than 1.5 (Fig. 1). Noncompromised RV function and significant postprocedural PAP reduction did not show an effect on survival. Concerning deformation indices, lower segmental radial strain values in the mid-LV anteroseptal region (RSAS) before TAVI significantly correlated with mortality (17.53 ± 7.90 vs. 12.26 ± 6.11%; $P = 0.031$; $\rho = -0.351$, $P = 0.036$); it also showed a trend towards worse composite outcomes (17.50 ± 8.15 vs. 12.56 ± 6.08%, $P = 0.045$; $\rho = -0.312$, $P = 0.064$). Kaplan–Meier curves (Fig. 2) show that patients with RSAS less than 18% had higher morbidity and mortality than patients with better radial strain in this segment

Follow-up echocardiographic data

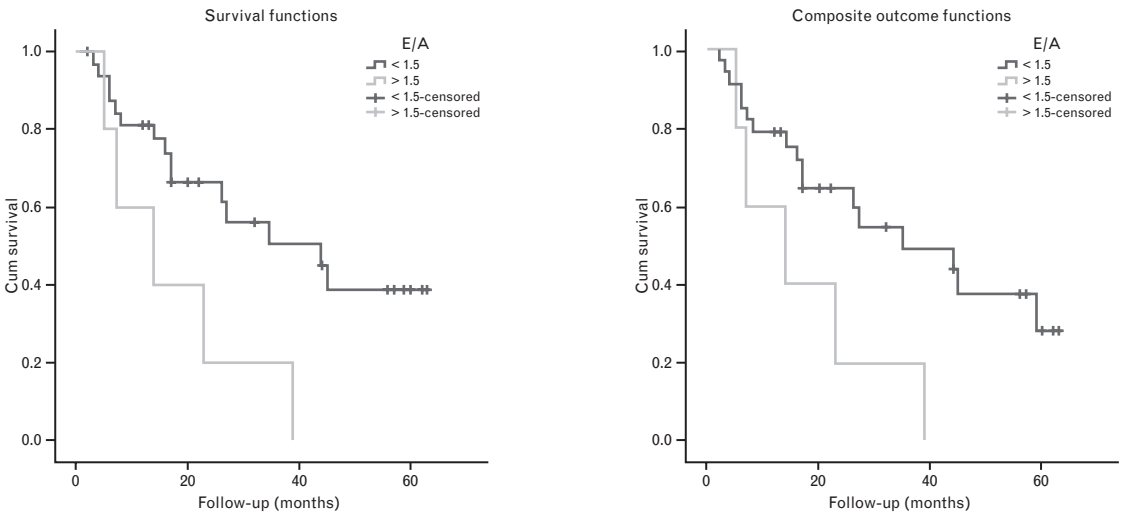
After 1-year follow-up, 21 patients had a complete TTE. Only a few significant differences were found when compared with preprocedural and early postprocedural TTE data. A significant reduction in LV mass index was found (152.4 ± 53.2 pre-TAVI vs. 136.2 ± 56.7 g/m^2 post-TAVI, $P = 0.04$), whereas relative wall thickness, LV volumes and dimensions showed no significant changes. Function of the valve prosthesis was well preserved after 1 year, with no significant changes in maximal ($P = 0.75$) and mean pressure gradients ($P = 0.85$) or in the valve area ($P = 0.86$). There was a nonsignificant improvement in GLS and mid-LV GRS. Improvement in NYHA status was found to significantly correlate only with regional improvement in longitudinal strain of basal interventricular septum ($r = 0.446$, $P = 0.015$).

Table 4 Univariable predictor analysis of mortality and composite outcomes

Outcome	*E* Pre-TAVI	RSAS Pre-TAVI	LVIDd After TAVI	RWT After TAVI	*E* After TAVI	*E*/*A* After TAVI
Mortality	$\rho = 0.260$	$\rho = -0.351$	$\rho = -0.348$	$\rho = 0.376$	$\rho = 0.252$	$\rho = 0.365$
	$P = 0.060$	$P = 0.036$*	$P = 0.009$*	$P = 0.009$*	$P = 0.069$	$P = 0.024$*
	Exp (*B*) = 3.821	Exp (*B*) = 0.892	Exp (*B*) = 0.970	Exp (*B*) = 742.965	Exp (*B*) = 3.978	Exp (*B*) = 12.915
	$P = 0.096$	$P = 0.038$*	$P = 0.073$	$P = 0.038$*	$P = 0.131$	$P = 0.042$*
Composite outcome	$\rho = 0.294$	$\rho = -0.312$	$\rho = -0.344$	$\rho = 0.344$	$\rho = 0.360$	$\rho = 0.370$
	$P = 0.033$*	$P = 0.064$	$P = 0.009$*	$P = 0.018$*	$P = 0.008$*	$P = 0.022$*
	Exp (*B*) = 5.489	Exp (*B*) = 0.902	Exp (*B*) = 0.962	Exp (*B*) = 322.015	Exp (*B*) = 9.556	Exp (*B*) = 16.721
	$P = 0.051$	$P = 0.058$	$P = 0.045$*	$P = 0.066$	$P = 0.036$*	$P = 0.042$*

E, E wave on transmitral flow; *E*/*A*, *E* wave/*A* wave ratio on transmitral flow; LVIDd, left ventricular internal diastolic diameter; RSAS, radial strain of anteroseptum; RWT, relative wall thickness; TAVI, transcatheter aortic valve implantation.

Fig. 1



Kaplan–Meier analysis according to *E/A* ratio early after transcatheter aortic valve implantation: poorer survival and composite outcomes in patients with *E/A* greater than 1.5 (green line) than in patients with *E/A* less than 1.5 (blue line) ($P = 0.022$ and $P = 0.033$).

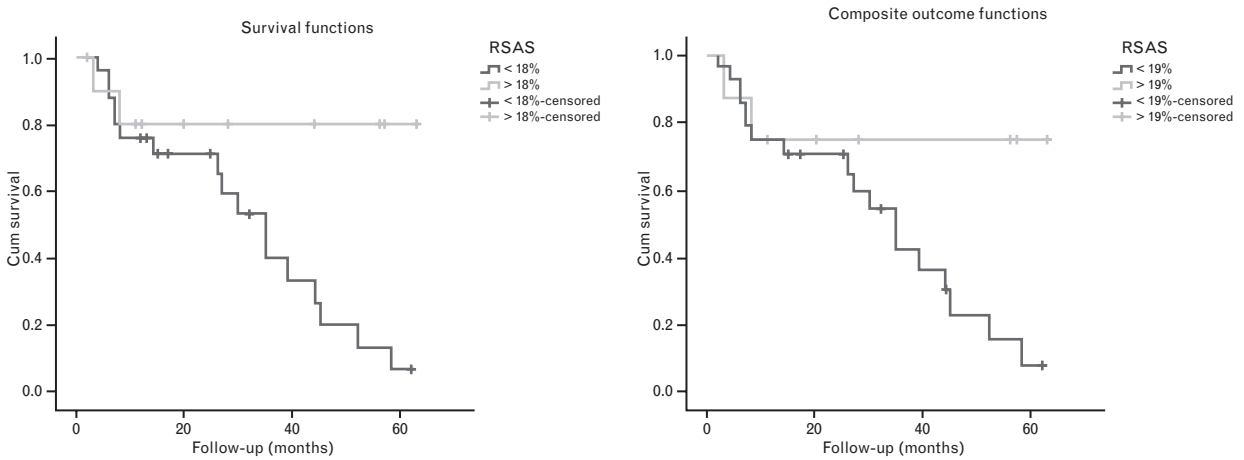
Discussion

We hypothesized that after TAVI, regional longitudinal and radial strain improve because of acute pressure unloading and that those changes are associated with prognosis. The main findings of our study are as follows: LV systolic function as assessed by radial mid-LV GRS and regional longitudinal basal strain of LV anteroseptum and lateral segments improved early after TAVI procedure; radial strain of mid-LV anteroseptum and diastolic dysfunction were associated with a worse prognosis; neither right ventricular function nor the changes in pulmonary pressures after TAVI predicted individual outcome. Those results support given hypothesis.

Left ventricular remodelling in aortic stenosis

In aortic stenosis, the chronically increased afterload results in progressive LV remodelling.[20,21] Early in this compensatory phase, afterload mismatch implies that myocardial contractility is not irreversibly depressed, and that after pressure unloading, recovery of the LV function will be allowed.[22] LVEF measured by conventional means of echocardiography will be preserved even

Fig. 2



Kaplan–Meier analysis according to mid-anteroseptum radial strain before transcatheter aortic valve implantation: RSAS less than 18% implicates worse survival rates ($P = 0.035$) and RSAS less than 19% is associated with worse composite outcomes ($P = 0.084$) (green lines).

at this point, although progressive stepwise impairment of longitudinal and radial deformation can be detected by 2D strain.[23] In our study, LVEF was preserved, whereas GLS and GRS were reduced. So, early signs of subnormal LV function can be reliably detected by 2D strain imaging,[24] as a potential surrogate marker of the presence and severity of myocardial fibrosis, and of likelihood for progression to heart failure. Strain imaging is superior to LVEF in the assessment of latent LV dysfunction.[22] Global indices of longitudinal strain were shown to be a predictor of worse outcomes in both asymptomatic and symptomatic aortic stenosis with preserved LVEF.[25–27] Although the increase in LV wall thickness is a compensatory mechanism that reduces systolic wall stress, it can result in impaired LV relaxation, reduced LV compliance and increased metabolic demands. These early hemodynamic changes can be detected by quantification of LV diastolic function, which is known to have an important role in the progression of symptoms and development of heart failure.[22] In the present study, we showed that prior to TAVI, myocardial relaxation was severely impaired, left atrium was significantly enlarged, and pulmonary artery pressures markedly increased.

Pressure unloading, left ventricular function and outcomes

After TAVI, the so-called 'reverse remodelling' often occurs.[11] We found no change in LVEF measured by conventional echocardiography in the early postoperative period, which is in concordance with previous studies.[28] LV mass and relative wall thickness deceased in the early and late stages after TAVI and predicted individual outcome, suggesting that the vulnerable myocardium can still recover.[10,21]

Diastolic dysfunction may persist in various degrees for a longer period of time[22,24,29] after TAVI. In our study, although diastolic parameters did not change significantly in the early postimplantation period, they were associated with the outcome. Diastolic function both prior to and after TAVI showed positive correlations with mortality and composite end-points. Hypertrophied LV with reduced compliance, impaired relaxation and consequently elevated filling pressures implies pulmonary arterial hypertension even with normal right ventricular function. Such a normal functioning right ventricle may worsen after surgical aortic valve replacement because of unsatisfactory cardioprotection.[30] After TAVI, as we have shown, RV function remained normal, suggesting that the drop in pulmonary pressure was mainly because of LV filling pressure reduction.

Strain is known to be a more sensitive measure of LV function and mechanics.[23] In previous studies, longitudinal strain was mostly analysed. In our study, we also extended the analysis of deformation parameters to regional radial strain and strain rate. Călin *et al.*[22] have demonstrated that longitudinal fibres are most prone to damage during pressure overload, whereas radial and circumferential functions determined by mid-LV fibres are capable of compensating and preserving LVEF for a longer period of time. Radial deformation is normally expressed more, so changes could be easier to detect. Early after TAVI, there was a slight immediate improvement in GLS and in GRS (Table 3). Moreover, segmental strain also showed significant improvement in some segments. Due to acute pressure unloading, significant improvement in regional longitudinal strain was recorded in basal LV anteroseptal and lateral segments. Intriguingly, we did not observe early improvement in longitudinal strain in the region of basal interventricular septum, known to be the most prone to pressure overload.[31] Absolute longitudinal strain values were the worst in this segment before TAVI, not related to outcomes. This could be because of patient's age and longstanding hypertension in more than two-thirds of our patient population (71%), both factors known to influence the function of this segment, leading to more permanent damage (fibrosis).[32–34] Also the low implantation of the prosthesis in some patients might have played a role. On the other hand, early significant improvement in global radial strain and regional radial strain was also detected in mid-LV anteroseptal and lateral segments. Before TAVI, anteroseptum radial strain was found to be associated with outcomes in our population. The better the anteroseptum radial strain prior to the procedure, the more extended was the recovery after TAVI and better was the outcome. Altogether, these changes in strain advocate the presence of an early 'reverse remodelling' phenomenon[10] or 'reverse function'.

Clinical implications

The assessment of LV global and regional function in patients with aortic stenosis has shown to be associated with individual patient outcome. After surgical aortic valve replacement, the extent of improvement in the myocardial deformation parameters reflects the magnitude of LV reverse remodelling and of functional reserve recruitment. In the present study, we extended these observations to TAVI patients showing additionally that LV segmental strain improvement was not uniform. Moreover, we also found that some specific segments were not only improving more than others after TAVI but also they are associated with outcomes. Interestingly, only segments that improved most significantly in longitudinal and radial directions early after intervention showed correlations with prognosis. According to our results, the assessment of anteroseptal LV segment function was of most interest. Impairment in its radial strain identified patients with a worse prognosis. Remarkably, this segment had the highest potential to improve its function early after TAVI. As already described, the use of strain rate was also more sensitive to these changes than strain parameters in our study. So the longitudinal strain rate may thus be a more specific tool to measure the

impact on the LV of pressure unloading in the damaged myocardium. Furthermore, regular assessment of radial strain in the anteroseptal mid-LV segment might be used as a signal to select patients for earlier intervention.

Limitations

The main limitation of our study is its relatively small size with the inclusion of a heterogeneous group of patients concerning comorbidities. As age and comorbidities per se are one of the indications for TAVI, it is hard to obtain a homogenous population with, for example, no coronary artery disease or hypertension. It would be interesting to follow up this population for a longer period of time and to compare our results with magnetic resonance estimation of fibrosis. Also, the results of this hypothesis-generating only study should be cautiously interpreted and confirmed by further investigations on larger populations.

Conclusion

The improvement in LV regional (longitudinal and radial) function early after TAVI, suggesting the potential of the myocardium to recover, is associated with a reduced risk for clinical deterioration. So, not only global but also indices of segmental LV function before and early after TAVI may affect patient prognosis. Diastolic dysfunction before TAVI represents a major outcome determinant after intervention. Altogether, predictors of worse outcomes for composite end-points according to our study are: more hypertrophied, smaller and more stiffened LV with worse diastolic function and decreased radial deformation in the mid-LV anteroseptum segment.

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Conflicts of interest

There are no conflicts of interest.

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