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Acute left ventricle diastolic function improvement after transcatheter aortic valve implantation

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Aims Data regarding the effects of TAVI on LV after are scarce and conflicting results have been reported immediately after aortic valvuloplasty. This study aimed to determine the acute haemodynamic effects of transcatheter aortic valve implantation (TAVI) in left ventricle (LV) diastolic performance, immediately after aortic valvuloplasty and prosthesis deployment.

Methods and results Sixty-one patients with severe aortic valve stenosis, and preserved LV systolic function submitted to successful TAVI, were included. All procedures were guided through transoesophageal echocardiography, and parameters of diastolic function were evaluated before and minutes after TAVI. The mean age was 83.5 ± 6 years and mean log EuroSCORE was 18.2 ± 9.4. Before the procedure, all patients presented LV diastolic dysfunction. Immediately after TAVI, fewer patients presented a restrictive pattern [27 (44.3%), before the procedure, vs. 20 (34.4%), after TAVI ($P = 0.047$)], and an increase in E wave deceleration time (211.2 ± 75.5 vs. 252.7 ± 102.3 cm/s, $P = 0.001$), in E wave velocity (109.5 ± 41.2 vs. 120.3 ± 43.6 cm/s, $P = 0.025$), and in isovolumetric relaxation time (83 ± 36.5 vs. 97.1 ± 36.0 ms, $P = 0.013$) was observed. On multivariate analysis of covariance (ANCOVA), adjusting to LV systolic function, heart rate, blood pressure, and haematocrit values, the results remained significant. Patients referred to percutaneous approach had invasive haemodynamic data collected, showing a decrease in LV end-diastolic pressure after valve implantation [18.8 ± 5.7 vs. 14.7 ± 4.7, mean difference −4.1 (95% CI: −5.9; −2.9)]. Patients with a restrictive pattern immediately after TAVI presented a smaller decrease in LV end diastolic pressure (−3.3 ± 4.7) than those with diastolic dysfunction grade I or II (−9.5 ± 4.7; $P = 0.017$).

Conclusion This is the first study describing LV diastolic performance during TAVI. Our results show improvement in diastolic function parameters in patients with preserved LV systolic function, immediately after successful TAVI.

Keywords Aortic valve stenosis • Aortic prosthesis • Diastolic dysfunction • Left ventricle (LV) • Transcatheter aortic valve implantation (TAVI)

Introduction

Transcatheter aortic valve implantation (TAVI) techniques have emerged as an alternative treatment for patients with severe aortic stenosis and high surgical risk.[1] Since the first-in-man experience in 2002,[2] thousands of patients have been treated with this technique worldwide with procedural success rates of ~95%.[1,3,4]

Most patients referred for TAVI are elderly and present symptomatic aortic stenosis with heart failure in NYHA classes III and IV,

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in spite of preserved left ventricle (LV) systolic function.[1,5] Myocardial hypertrophy in consequence of cellular hypertrophy and cellular matrix hyperplasia occurs before the development of systolic dysfunction,[6] being diastolic dysfunction the primarily responsible for heart failure symptoms. After aortic valve replacement (AVR), clinical improvement is expected and diastolic stiffness along with relaxation normalization is observed in late follow-up.[7]

In patients submitted to TAVI, several studies have already shown immediate almost complete normalization in afterload and a significant decrease in pressure gradient, between the aorta and the LV, as well as clinical improvement at short term.[4,5,8] At medium-term follow-up, LV mass reduction and improvements in tissue Doppler velocities have been reported,[9] and one study has described early regression of septal hypertrophy 1 month after TAVI.[10] However, so far the acute changes in left ventricular diastolic performance after TAVI and its consequences in patients' clinical outcome are unknown. Conflicting results from invasive haemodynamic measurements after aortic balloon valvuloplasty have been reported and worsening of diastolic indexes was described.[11,12] Nevertheless, the technique applied on TAVI is different, as well as the favourable clinical outcomes,[1] in opposition to the disappointing results after aortic valvuloplasty.[13,14]

This study aimed to determine the acute haemodynamic effects of TAVI in LV diastolic performance, immediately after aortic valvuloplasty and prosthesis deployment.

Methods

Population

Sixty-one patients with severe aortic stenosis (aortic valve area ≤ 1 cm^2) and preserved LV systolic function (ejection fraction $\geq$ 50%), submitted to successful TAVI in one tertiary centre from April 2009 to April 2010, were included. These patients were obtained from a series of 97 consecutive patients who underwent TAVI, after excluding those with LV systolic dysfunction (9 patients), atrial fibrillation or ventricular pacemaker rhythm (7 patients), concomitant moderate to severe mitral valve disease (6 patients), aortic regurgitation (3 patients), and those whose procedure was not totally guided through transoesophageal echocardiography[15] (11 patients). Indications and contraindications for TAVI have been described previously elsewhere.[1,5,16]

Patients were referred for TAVI due to an excessive risk for AVR, which was estimated using the logistic EuroSCORE and/or clinical judgement.[17] Ten (16.4%) elderly patients were considered inoperable on the basis of comorbidities or risk factors such as pulmonary hypertension (defined as a pulmonary systolic pressure >50 mmHg as estimated by Doppler echocardiography or measured by cardiac catheterization) or frailty or porcelain aorta (5, 8.2% patients). No systematic tests were performed for the evaluation of frailty, being its conception based on medical criteria.[18] Porcelain aorta was defined as wide circumferential calcification of the thoracic aorta when assessed by computed tomography and/or fluoroscopy.

Transthoracic echocardiography

On the previous day of the procedure, all patients performed a conventional transthoracic echocardiogram with bidimensional and Doppler assessment, which was completed with three-dimensional (3D) analysis (X4-1 probe, Philips Medical Systems, Andover, MA, USA). The following measurements were obtained in all patients: LV mass calculated with the American Society of Echocardiography (ASE) recommended formula, mean transvalvular gradient calculated with the Bernoulli formula, aortic valve area measured by the continuity equation and early (E') and late (A') diastolic peak velocities from Doppler tissue imaging measured at septal and lateral mitral annulus. Considering the superior accuracy and reproducibility of 3D echocardiography, left atrium (LA) volume, LV systolic and diastolic volumes, and resulting ejection fraction were calculated with direct volumetric analysis.[19] Valvular insufficiencies and diastolic function were graded according to international recommendations.[20,21]

Transcatheter aortic valve implantation

TAVI was performed with fluoroscopy and TEE guidance, under general anaesthesia using techniques described in detail in previous reports.[22,23]

Nineteen patients (31.1%) implanted an Edwards SAPIEN (Edwards Lifesciences, Irvine, CA, USA) aortic valve thought anterograde transapical approach and 42 (68.9%) were submitted to the retrograde transfemoral approach. Among these, a Corevalve (Medtronic CoreValve Percutaneous System, Medtronic CV) was implanted in 23 (54.8%) patients and an Edwards SAPIEN valve in 19 (45.2%). Two valve sizes are available, 23- and 26-mm expanded diameters for Edwards SAPIEN valve and 26 and 29 mm for CoreValve. The aortic prosthesis size was decided according to the annulus diameter, measured with transoesophageal echocardiography.

Transoesophageal echocardiography protocol

During the procedure, data were recorded using TEE with real-time 3D capability (i.e. 33 echocardiography system, X7-2t probe, 7MHz, Philips Medical Systems, Eindhoven, the Netherlands). TEE was performed in the moments previously to intervention and it was repeated few minutes after aortic valve implantation (5.7 ± 2.4 min), for later comparison between TEE results before and after TAVI.

Pulsed wave spectral Doppler was recorded using mid-oesophageal views at four-chamber view, with the sample volume at the leaflet tips for transmitral inflow pattern assessment, and five-chamber view, with the sample volume between leaflet tips and LV outflow tract, for simultaneous imaging of mitral inflow and aortic valve closure clicks. Basal short-axis views were used to assess pulmonary veins flow and at least two pulmonary veins (one left and one right) were recorded. Colour M-mode Doppler in mid-oesophageal four-chamber view was used for recording transmitral flow for later measurement of propagation velocity. Transgastric mid short-axis view of the LV was recorded for LV systolic and diastolic area measurements. Deep transgastric long-axis view was used for continuous Doppler flow assessment through the aortic valve and pulsed Doppler recording at the LV outflow tract in order to calculate the effective aortic valve area before and after TAVI.

Off line analysis of the images captured was performed and using the average measurement of at least three consecutive cardiac cycles, the following measurements were obtained: transmitral E wave and A wave peak velocity, E wave deceleration time, isovolumetric relaxation time (IVRT), isovolumetric contraction time, ejection time (ET), pulmonary venous flow peak systolic velocity (S), peak diastolic velocity (D), peak atrial reversal (Ar) velocity and duration (Adur), and colour M-mode flow propagation velocity (Vp). Mean and maximum transvalvular gradients were calculated with the Bernoulli formula and the aortic valve area measured by the continuity equation. Subsequently, the E/A ratio, S/D ratio, and LV fractional area change were calculated. The latter was chosen for LV systolic function

estimation because of the best convenience at the acute scenario, using transoesophageal echocardiography. The probe used presents 3D echocardiography capabilities, which were regularly employed for guiding the procedure, but it has no tissue Doppler software included, consequently tissue Doppler measurements were not available during the procedure.

After aortic valve deployment, the presence of complications such as aortic regurgitation, cardiac effusion or cardiac tamponade, LV dysfunction or wall motion abnormalities, mitral valve damage or prosthesis misplacement were described.[20]

In order to evaluate diastolic function from the beginning to the end of the procedure, modified ASE recommendations with the exclusion of tissue Doppler parameters were used.[21] Mild diastolic dysfunction was defined by mitral *E/A* ratio <0.8 and DT >200 ms or *E/A* ratio <0.8 and IVRT ≥ 100 ms, along with predominant systolic flow in pulmonary venous flow ($S > D$); moderate diastolic dysfunction by mitral *E/A* ratio from 0.8 to 1.5 along with diastolic predominance in pulmonary venous flow ($S < D$) with at least one of the following: DT from 160 to 200 ms, IVRT <90 ms or Ar velocity >35 cm/s. Severe diastolic dysfunction/restrictive pattern was defined by *E/A* ratio ≥ 2 with DT ≤ 160 ms, or with IVRT ≤ 60 ms, along with diastolic predominance in pulmonary venous flow ($S < D$).[24]

Data expected to interfere in diastolic function parameters namely heart rate, systolic and diastolic blood pressure, and haematocrit value were evaluated when starting the procedure and few minutes after valve implantation.

Invasive haemodynamic data

Patients referred for the percutaneous approach ($n = 42$) had invasive haemodynamic measurements performed. For the purpose of this study, LV end diastolic pressure measured immediately before and after implantation was considered.

This protocol was approved by the local ethics committee and all patients gave written informed consent for participation.

The authors are solely responsible for the design and conduct of this study, analyses, and its final contents.

Statistical analysis

Categorical variables were expressed as percentages and continuous variables as mean (SD) unless otherwise specified. Continuous variables were compared between groups using an unpaired *t*-test (for normally distributed variables) or the Mann–Whitney *U*-test (for non-normally distributed variables). Multivariate regression analysis of covariance (ANCOVA) was used to compare continuous variables and categorical variables relation with major outcomes. The confounders shown to present significant variation in univariate analysis (systolic and diastolic blood pressure, heart rate, haematocrit, and fractional area change of LV) were sequentially included in the model executed for each outcome variable.

For assessing the level of agreement, Cohen's kappa was used for categorical variables. All reported probability values are two-tailed, and $P < 0.05$ was considered statistically significant. Analyses were performed with the SPSS statistical software package (version 16.0) (SPSS Inc, Chicago, IL, USA).

Results

Patient characteristics

Among the 61 patients included in this prospective study, the mean age was 83.5 ± 6 years and mean log EuroSCORE was 18.2 ± 9.4. LV concentric hypertrophy was present in 44 (72%) patients, 45 (73.8%) had LA volume ≥ 34 mL/m^2 and 29 (47.5%) had *E/E'* ratio >15. Only patients with preserved LV systolic function were included, but all patients presented LV diastolic dysfunction. Thirty-one (50.8%) showed a restrictive pattern when using the ASE recommendations[20] and 27 (44.3%), when the classification is modified, excluding tissue Doppler parameters (Cohen's kappa level of agreement $= 0.679$). Overall, and according to intervention, baseline patients' characteristics and echocardiography data are presented in *Table 1*. Most characteristics were similar in both groups, but patients referred to transapical approach were younger (78 ± 8 vs. 85 ± 4, $P = 0.001$), presented more commonly dyslipidemia (89.5 vs. 50%, $P = 0.004$), peripheral vascular disease (63.2 vs. 14.3%, $P < 0.001$), and renal impairment (47.4 vs. 21.4% $P = 0.041$).

Echocardiographic haemodynamic parameters immediately after transcatheter aortic valve implantation

In the few minutes immediately after prosthesis deployment, mean aortic pressure gradient decreased to normal parameters (8 ± 3 mmHg). Mild aortic regurgitation, central or perivalvular was present in 30 (49.2%) patients after the procedure, but none ended with moderate or severe aortic regurgitation. There was a decrease in ET and an increase in E wave maximum velocity, E wave deceleration time, *E/A* ratio and IVRT. In spite of all patients having preserved LV systolic function, LV fraction area change significantly increased [difference of means 8.1 (95% CI: 4.4–11.8)] after the procedure. No significant variation was found in the comparative analysis of grade I or II of LV diastolic function (*Figure 1*); nevertheless, there was a significant reduction in a restrictive pattern after TAVI, as 27 (44.3%) patients presented a restrictive pattern before the procedure vs. 20 (34.4%) after TAVI ($P = 0.047$). Comparative results from univariate analysis of TEE and clinical parameters during TAVI are presented in *Table 2*. A significant decrease in blood pressure, heart rate, and haematocrit, as well as an increase in LV fractional area change, was observed after aortic valve implantation (*Table 2*).

Using the ANCOVA, we assessed the modification of the intervention effect on primary outcome variables and confounders during TAVI in the overall population. The results presented in *Table 3* showed the absence of significant differences according to the type of procedure. However, a tendency for a smaller decrease in ET [percutaneous: -28.8 (95% CI: -46.5; -11.1) vs. transapical: -6.3 (95% CI: -27.5; -14.9)] and for a larger reduction in Vp slope [percutaneous: -0.095 (95% CI: -16.9; -16.8) vs. transapical: -10.8 (95% CI: -20.7; -0.97)] after prosthesis deployment could be observed in the transapical subgroup.

Subsequently, a multivariate ANCOVA was performed in order to assess the effect of potential confounders in main outcome variables variation. The modifications in the diastolic function parameters observed remained significant when adjusted in the multivariate models performed (*Table 4*). We found a significant increase in the E wave deceleration time [41.5 (95% CI: 18.0–65.1)] in the global population; however, the multivariate analysis with the ANCOVA model showed that it occurred mainly in

Table 1 Baseline characteristics of the study population

Variables	Overall ($n = 61$)	Percutaneous ($n = 42$)	Transapical ($n = 19$)	*P*-value
Age (years)	83 (6)	85 (4)	78 (8)	0.001
Female [*n* (%)]	38 (62.3)	29 (69.0)	9 (47.4)	0.154
Log EuroSCORE (%)	18.2 (9.4)	18.1 (7.8)	18.4 (12.4)	0.930
Body surface area (m^2)	1.6 (0.2)	1.7 (0.19)	1.9 (0.15)	0.680
Hypertension [*n* (%)]	52 (85.2)	36 (85.7)	16 (84.2)	1.0
Diabetes [*n* (%)]	15 (24.6)	8 (19.9)	7 (36.8)	0.199
Dyslipidemia [*n* (%)]	38 (62.3)	21 (50.0)	17 (89.5)	0.004
Coronary artery disease [*n* (%)]	22 (36.1)	15 (37.5)	7 (36.8)	1.0
Previous PCI or prior CABG [*n* (%)]	16 (26.2)	9 (21.4)	7 (36.8)	0.224
NYHA functional class				0.853
II	5 (8.2)	4 (9.5)	1 (5.3)	
III	53 (86.9)	36 (85.7)	17 (89.5)	
IV	3 (4.9)	2 (4.8)	1 (5.3)	
COPD [*n* (%)]	24 (39.3)	16 (38.1)	8 (42.1)	0.784
Renal impairment	18 (29.5)	9 (21.4)	9 (47.4)	0.041
Creatinine (mg/dL)	1.3 (0.7)	1.2 (0.7)	1.5 (0.7)	0.199
Peripheral vascular disease	18 (29.5)	6 (14.3)	12 (63.2)	<0.001
Nt-ProBNP (pg/mL)[a]	3208 (1794–6318)	3721 (2034–6529)	3200 (1319–8692)	0.739
Pulmonary hypertension	9 (14.8)	8 (25.0)	1 (14.3)	1.0
Mean aortic pressure gradient (mmHg)	54 (14)	56 (16)	51 (10)	0.221
Aortic peak pressure gradient (mmHg)	90 (22)	91 (24)	87 (20)	0.610
Aortic valve area (cm^2)	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)	0.167
LV EF (%)	63 (9)	62 (10)	63 (9)	0.621
LA index volume (mL/m^2)	47 (24)	49 (28)	43 (12)	0.322
LV mass index (g/m^2)	132 (42)	137 (44)	121 (35)	0.197
E/*E*′ ratio	21 (13)	23 (13)	17 (10)	0.210
Diastolic dysfunction				
Grade I	22 (36.1)	15 (35.7)	7 (36.8)	0.452
Grade II	8 (13.1)	3 (7.1)	5 (26.3)	0.212
Grade III	31 (50.8)	24 (57.1)	7 (36.8)	0.321

CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; LA, left atrium; LV, left ventricle; log EuroSCORE, logistic European System for Cardiac Operative Risk Evaluation; Nt-ProBNP, NT portion B-type natriuretic peptide; PCI, percutaneous coronary intervention.
[a]Presented as median and interquartile range.

patients in whom the haematocrit value remained stable. In those with an important decrease in the haematocrit minutes after TAVI, the E wave deceleration time remained constant.

The baseline demographic and clinical characteristics presented in *Table 1*, as well as the type or size of prosthesis were individually tested for each diastolic parameter and confounders, but none had significant effect on the results obtained after the intervention.

Invasive haemodynamic parameters immediately after transcatheter aortic valve implantation

In the group of patients submitted to the percutaneous approach ($n = 42$), invasive haemodynamic measurements were performed and significant decrease in LV end-diastolic pressure, after valve implantation was found [18.8 ± 5.7 vs. 14.7 ± 4.7, mean difference -4.1 (95% CI: -5.9; -2.9)]. Patients with a restrictive pattern immediately after TAVI had a smaller decrease in LV end diastolic pressure (-3.3 ± 4.7) than those presenting diastolic dysfunction grade I or II after the procedure (-9.5 ± 4.7; $P = 0.017$).

Discussion

This is the first study describing acute haemodynamic changes regarding diastolic function parameters during TAVI. We present a representative group of patients among those being currently submitted to TAVI.[25] These elderly patients with degenerative aortic stenosis have severe heart failure symptoms, several comorbidities, high EuroSCORE, and multiple cardiovascular risk factors. The ones submitted to transapical approach have been considered by others as a particular group with more comorbidities and higher Logistic EuroScore.[25] Our patients referred to transapical approach had more frequently renal impairment and peripheral

vascular disease; however, they were younger and the mean Logistic EuroSCORE was similar to those referred to TAVI through percutaneous approach. This might be explained by the number of patients referred to transapical approach for porcelain aorta (5; 26.3%), which were younger and with fewer comorbidities, but still being refused for AVR.

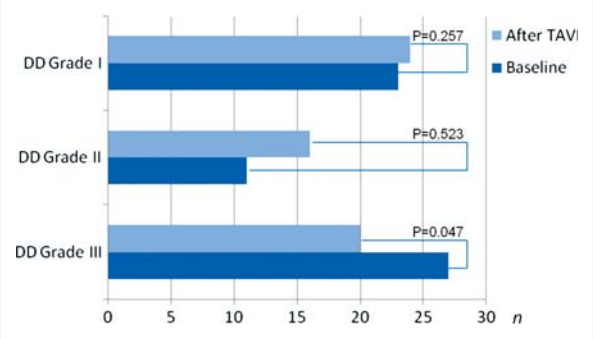

Figure 1 Patients' diastolic dysfunction classification at baseline and after transcatheter aortic valve implantation. Diastolic dysfunction[21] definition according ASE recommendations modified by the exclusion of tissue Doppler parameters.

Left ventricle remodelling in severe aortic stenosis

In this study, the population was restricted to patients with preserved LV systolic function, which in fact represents most of the patients treated with TAVI.[1,5] These patients, in addition to the age-related changes in diastolic function parameters, with increased passive stiffness and abnormal relaxation, also present LV hypertrophy, LA dilatation, and myocardium fibrosis in result of the chronic pressure overload.[26,27] During the LV remodelling process, the myocytes and fibroblasts proliferation initially result in asymptomatic abnormal tissue Doppler velocities and diastolic dysfunction, in spite of normal ejection fraction. However, in the absence of treatment, global systolic dysfunction and/or symptoms eventually develop, leading to death unless the valve is replaced.[28]

Immediate left ventricle diastolic response after transcatheter aortic valve implantation

Severe LV diastolic dysfunction prevailed at baseline, but it significantly improved after the procedure (*Figure 1*). This result was supported by the invasive measurement of LV end diastolic pressure. Analysing echocardiographic parameters, fewer patients presented severe LV diastolic dysfunction after the procedure, mostly because of the E wave deceleration time increase, which may be the result of increased relaxation and compliance and

Table 2 Overall univariate analysis of transoesophageal echocardiography and clinical parameters during transcatheter aortic valve implantation ($n = 61$)

Variables	Data at baseline	Data minutes after TAVI	Difference of means (95% CI)	*P*-value
Mean aortic pressure gradient (mmHg)	54 (14)	8 (3)	−46.4 (−50.3; −42.6)	<0.001
Aortic peak pressure gradient (mmHg)	90 (22)	16 (6)	−73.9 (−79.9; −68.1)	<0.001
E wave (cm/s)	109.5 (41.2)	120.3 (43.6)	10.5 (1.4; 20.2)	0.025
A wave (cm/s)	100.6 (40.7)	96.1 (38.9)	−3.7 (−14.3; −6.8)	0.482
E wave/A wave	1.2 (0.8)	1.5 (1.1)	0.29 (0.01; 0.57)	0.040
E wave deceleration time (ms)	211.2 (75.5)	252.7 (102.3)	41.6 (17.2; 65.9)	0.001
IVRT (ms)	83 (36.5)	97.1 (36.0)	14.1 (3.2; 25.1)	0.013
ET (ms)	314.9 (32.2)	293.1 (46.5)	−21.8 (−35.6; −8.0)	0.002
S/D	1.1 (0.8)	1.2 (0.5)	0.36 (−0.29; 0.37)	0.817
Ar (cm/s)	25.1 (11.1)	22.9 (10.5)	3.1 (1.2; 5.4)	0.092
Adur (ms)	124.3 (29.9)	121.8 (51.1)	2.9 (0.9; 6.8)	0.438
Vp (cm/s)	62.1 (20.0)	57.4 (28.9)	−4.6 (−14.9; −5.6)	0.366
LV diastolic area (cm^2)	17.9 (3.9)	17.8 (4.1)	−0.07 (−1.1; −0.9)	0.880
LV systolic area (cm^2)	8.4 (3.5)	7.0 (3.4)	−1.4 (−2.3; −0.5)	0.002
LV fractional area change (%)	54 (14)	62 (14)	8.1 (4.4; 11.8)	<0.001
Clinical parameters				
HR (b.p.m.)	79 (16)	75 (14)	−4.0 (−7.9; −0.07)	0.046
BP systolic (mmHg)	130 (19)	122 (17)	−7.9 (−13.2; −2.6)	0.004
BP diastolic (mmHg)	67 (11)	59 (11)	−8.5 (−11.1; −5.8)	<0.001
Haematocrit (%)	35.4 (4.7)	33.1 (3.8)	−2.5 (−3.8; −1.3)	<0.001

BP, blood pressure; *D*, pulmonary venous flow peak diastolic velocity; ET, ejection time; HR, heart rate; IVRT, isovolumetric relaxation time; LV, left ventricle; *S*, pulmonary venous flow peak systolic velocity; Vp, colour M-mode flow propagation velocity.

Table 3 Analysis of the intervention effect on primary outcome variables and confounders during transcatheter aortic valve implantation in the overall population ($n = 61$)

Variables	Difference of means (95% CI)		*P*-value
	Percutaneous ($n = 42$)	Transapical ($n = 19$)	
E wave (cm/s)	12.4 (0.6; 24.2)	7.3 (−9.4; 24.1)	0.624
E wave/A wave	0.3 (−0.05; 0.7)	0.3 (−0.21; 0.78)	0.954
E wave deceleration time (ms)	44.0 (15.6; 72.4)	36.2 (−14.9; 87.3)	0.770
IVRT (ms)	13.1 (−1.7; 28.0)	16.4 (1.5; 31.2)	0.788
ET (ms)	−28.8 (−46.5; −11.1)	−6.3 (−27.5; −14.9)	0.132
Vp slope (cm/s)	−0.095 (−16.9–16.8)	−10.8 (−20.7; −0.97)	0.303
LV fractional area change (%)	9.6 (4.9; 14.2)	4.8 (−1.4; 11.1)	0.232
HR (bpm)	−3.4 (−8.5; −1.7)	−5.4 (−11.7; −0.87)	0.630
BP systolic (mmHg)	−5.0 (−10.8; −0.79)	−14.2 (−25.5; −2.8)	0.108
BP diastolic (mmHg)	−7.8 (−11.0; −4.6)	−9.8 (−14.9; −4.7)	0.486
Haematocrit (%)	−2.2 (−3.7; −0.7)	−3.3 (−5.6; −1.0)	0.414

BP, blood pressure; ET, ejection time; HR, heart rate; IVRT, isovolumetric relaxation time; LV, left ventricle; Vp, colour M-mode flow propagation velocity.

Table 4 Analysis of covariance multivariate analysis of transoesophageal echocardiography and clinical parameters during transcatheter aortic valve implantation in the overall population ($n = 61$)

Variables	Baseline[a]	Minutes after TAVI[a]	Difference of means (95% CI)	*P*-value
E wave (cm/s)	109.5 (98.9; 120.1)	120.3 (109.2; 131.5)	10.8 (1.4; 20.2)	0.025[b]
E wave/A wave	1.2 (0.9; 1.4)	1.5 (1.2; 1.8)	0.30 (0.03; 0.56)	0.002
E wave deceleration time (ms)	211.2 (191.7; 230.6)	252.7 (226.8; 278.7)	41.5 (18.0; 65.1)	<0.001
IVRT (ms)	83.0 (73.8; 92.8)	97.1 (87.9; 106.4)	14.2 (3.3; 25.0)	0.003
ET (ms)	314.9 (306.6; 323.2)	294.8 (284.2; 305.3)	−20.2 (−32.8; −7.5)	0.026

ET, ejection time; LV, left ventricle; IVRT, isovolumetric relaxation time; Vp, colour M-mode flow propagation velocity.
[a]Data presented as adjusted mean (95% CI).
[b]Univariate—none of the confounders had a significant effect on the mean E wave variation during the procedure.

LV end diastolic pressure reduction. Accordingly, the IVRT increase after TAVI suggests a significant reduction in LA pressure. In patients with major decline in the haematocrit during the procedure, the haemodynamic response with transient tachycardia in consequence of acute preload reduction may have constrained the deceleration time increase.

The increase in E wave maximum velocity may be explained by alterations in preload or in LV relaxation. During the intervention, the indirect parameters of preload evaluation were LV diastolic area, which remained constant, and haematocrit value, which did not significantly affect E wave velocity increase. Thus, we consider that the augmented LA LV pressure gradient during early diastole is consequence of an ameliorated LV relaxation, in response of immediate, complete, and sustained afterload release.

The diastolic function parameters presented similar results whether the procedure was performed by transapical or percutaneous approach. However, in patients submitted to TAVI through transapical approach, the Vp slope decline was evident (*Table 3*). This parameter has limitations in patients with preserved LV systolic function, but it represents LV suction force and its slowing is consistent with an apical suction reduction.[21] This is in accordance with the technical procedure, where the LV apex puncture is performed. Possibly, the reduced sample size of patients submitted to transapical approach may explain the absence of statistic difference in Vp slope between both groups. Therefore, this result should be expected in those patients and it should not be interpreted as lone criteria of abnormal LV filling pressures.

The acute improvement in diastolic function parameters found in our study is in agreement with the results obtained in patients with hypertrophic obstructive cardiomyopathy after septal ablation. In those patients, it was described an immediate improvement of diastolic function along with LV outflow tract pressure gradient reduction. However, after septal ablation, there is a reduction in systolic function, in opposition to LV ejection fraction improvement usually observed after TAVI.[15] After aortic valvuloplasty, the immediate load-dependent responses reported have been inconsistent,[11,12] which is not surprising given the limited and

often unsustained enlargement of aortic valvular area and the large variability of response after aortic valvuloplasty.[11] In contrast, almost complete normalization of afterload was found to occur after TAVI, without significant variability among patients.[4,5,8] In what concerns to patients referred to AVR, limited assumptions can be made. Normalization of LV diastolic function[7] and benefits in ejection fraction, volumes, and hypertrophy are seen at long-term follow-up,[29] but short-term results are limited by the effects of extracorporeal circulation, positive inotropic drugs administration, and the presence of a paradoxical septum.

TAVI represents a unique opportunity of LV diastolic function evaluation immediately after afterload release and the observed improvement is in concert with the expectations from the Frank–Starling law. Whether these results are persistent or transient is unknown and should be assessed in further studies.

Our results are in agreement with the study of Bauer *et al.*[30] that described improvement in myocardial velocities and strain, 24 h after aortic valve percutaneous implantation in a population of 19 patients. Gotzmann *et al.*[9] have described diastolic function improvement at 6 months follow-up in patients with CoreValve prosthesis implanted by percutaneous approach. Even so, additional studies with longer follow-up regarding the different types of prosthesis and both techniques of implantation are needed, in order to clarify the relation of the acute changes in diastolic function with clinical outcomes among patients submitted to TAVI.

Limitations

The only form of comparison of degrees of diastolic dysfunction during TAVI was based on an adapted definition; however, an acceptable correlation between both classifications was found, allowing the assumption of an appropriate modified classification.

During the procedure, systolic function was assessed using fractional area change. This method has the limitation of measurement in one single plane, being its accurate assumption restricted to patients with symmetrically contracting ventricles. In this study, it may be considered an acceptable method since only patients with preserved LV systolic function were included, but in the eventual presence of wall motion abnormalities, it may have been misleading.

During TAVI, rapid pacing is performed, which may transiently change the diastolic properties of the LV. Consequently, echocardiography data were only acquired after rhythm stabilization in order to minimize the possible effect of the transient ventricular tachycardia.

Conclusion

Our results show the improvement of LV diastolic function in patients with preserved LV systolic function, immediately after successful TAVI. These results might corroborate to explain the remarkable clinical improvements in heart failure symptoms reported shortly after TAVI.

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IMAGE FOCUS

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Right coronary artery–coronary sinus fistula demonstrated by transthoracic echocardiography

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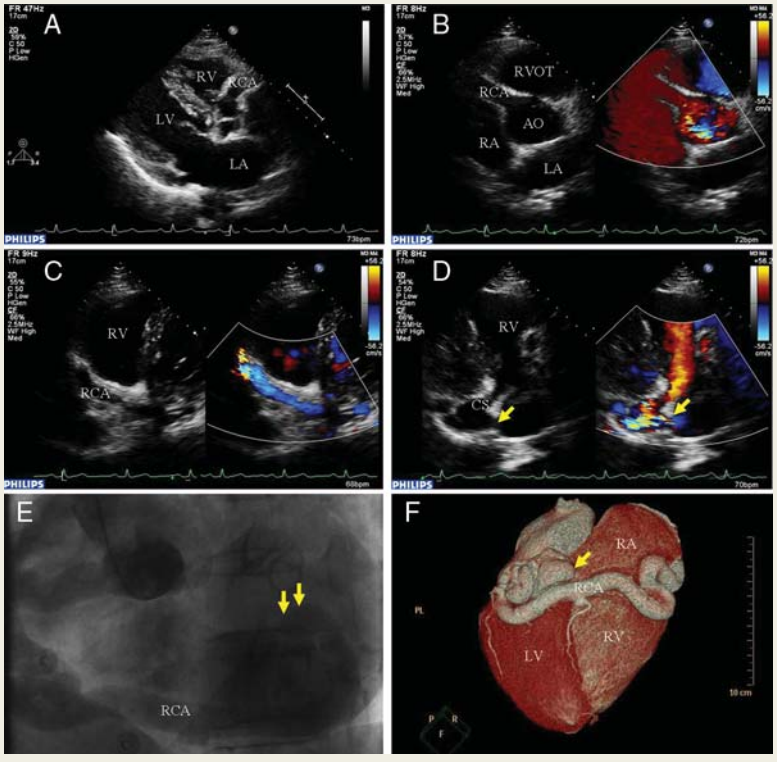
A 61-year-old man presented with 1-month history of chest pain on exertion. Two-dimensional transthoracic echocardiography showed a dilated right coronary artery (RCA) and coronary sinus (CS) in a parasternal long-axis view (*Figure A*). The diameter of the RCA was 14 mm at the origin, the middle and the distal part of the RCA in the atrioventricular groove was preserved as well (*Figures B* and *C*). In addition, the CS was apparently dilated, and the drainage site was identified. Colour Doppler echocardiography showed a turbulent flow into the right atrium from the CS (*Figure D*, arrow). Continuous Doppler echocardiography revealed a continuous-wave flow with a maximal velocity of 4.2 m/s at the drainage site.



Right coronary angiography confirmed a large and tortuous RCA, and a distal fistula was identified (*Figure E*, arrows). Three-dimensional cardiac computed tomographic scanning demonstrated a dilated RCA and a fistula between the RCA and the CS (*Figure F*, arrow). The patient underwent surgical treatment; in addition to close the fistula site with polypropylene sutures, the RCA prior to the posterior descending coronary artery was resected, and the posterior descending coronary artery was bypassed with the saphenous vein graft. He did well post-operatively.

Supplementary data are available at *European Journal of Echocardiography* online.