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Transesophageal Evaluation of Reconstructive Surgery for Aortic Valve Stenosis

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Abstract

BACKGROUND: With transesophageal echocardiography (TEE), were evaluated morphological characteristics and early hemodynamic parameters of stentless three leaflets pericardial patch in patients with aortic stenosis (AS) undergoing aortic valve (AV) surgery.

AIM: The aim of the study was to point the importance of two-dimensional and three-dimensional TEE imaging intra and early postoperatively.

METHODS: At Zan Mitrev Clinic, 2002–2020, were included 377 patients following the actual guidelines of European Society of Cardiology for valvular disease, whereas patients with dilatation of aortic annulus, rheumatoid arthritis, and chronic program on hemodialysis were excluded from the study. Instead of using a standard prosthesis, we made a reconstructive surgery implanting three new created leaflets using bovine/equine pericardium by replacing destroyed valve cusps. Leaflets were implanted separately, using continuous sutures with two supported stitches and that is how real stentless AV without any stent or sowing ring was created. Intraoperative and post-operative TEE was performed.

RESULTS: 377 pts with aortic valvular disease (211–56% male, and 166–44% female; 82–21, 75% with AS, 32–8, 49% with aortic insufficiency, and 263–69, 76% with combined stenosis and insufficiency) were included in the study. Post-operative TEE showed aortic morphology close to normal AV, average pressure gradient was 8 mmHg. 121 pts got a combination with aortocoronary bypass (2.3 grafts per pts). 4 patients were re-operated. Mortality rate was 12.46% (44 pts). Follow-up period was 18 years.

CONCLUSIONS: Real stentless aortic bioprosthesis is with a close morphology and hemodynamic parameters as a normal valve. TEE such as tool for assessment of AV morphology, anatomy of aortic root, pre-, and intra-operative plays a pivotal role in guiding case selection, surgical planning, and in evaluating procedural success.

Introduction

Aortic stenosis (AS) is the most prevalent valvular disease in developed countries. The incidence rate has a variation from 4% to 7% in patients >65 years of age [1], [2]. Among those patients who are diagnosed with AS, the optimal timing of surgery needed to be clarified based predominantly on the presence of severe stenosis on imaging and clinical symptoms attributable to valvular disease. Echocardiography plays a major role in the diagnosis and management of AS.

Two-dimensional (2D) transthoracic echocardiography (TTE) is the standard method of severity evaluation. Severe AS is historically defined as aortic jet velocity >4.0 m/s, mean Doppler gradient (MG) >40 mmHg, or aortic valve area (AVA) <1.0 cm^2 [2] (Table 1). These cutoffs are based on previous studies of AS without surgical intervention [4], [5], [6]. The last criteria for AS graduation of the European and American Society for echocardiography are presented in the next table (Table 1).

Transesophageal 2D and three-dimensional (3D) evaluations give superior data for aortic valve morphology, as well as dimensions, and help clinicians decide if it is a better option to treat the patient conservatively or with a surgical replacement.

3D versus 2D echocardiographic imaging techniques provide more accurate and adequate 3D images of the valve. Clinician can get space orientation of the position of the aortic valve in correlation with mitral valve, better image of left ventricle outflow tract (LVOT), and its dimensions, as well as ascending aorta and tricuspid valve. 3D dimensions of the AVA and evaluation of the condition of the left chamber are more accurate. All these parameters are of vital importance when making a decision for further patient's treatment [9].

Table 1: Graduation of severity of AS depending of measured pressures, velocity, AVA, and AVA index –indexed AVA /BSA (body surface area)

Echo parameters	Aortic sclerosis	Mild	Medium	Severe
Ao velocity	<2.5 m/s	2.6–2.9 m/s	3.0–4.0 m/s	>4 m/s
Mean pressure gradient (mmHg)		<20 (<30)	20–40 (30–50)	>40
AVA cm^2		>1.5	1–1.5	<1
AVA index (cm^2/m^2)		>0.85	0.6–0.85	<0.6
Velocity ratio		>0.5	0.25–0,5	<0.25

AS: Aortic stenosis, AVA: Aortic valve area.

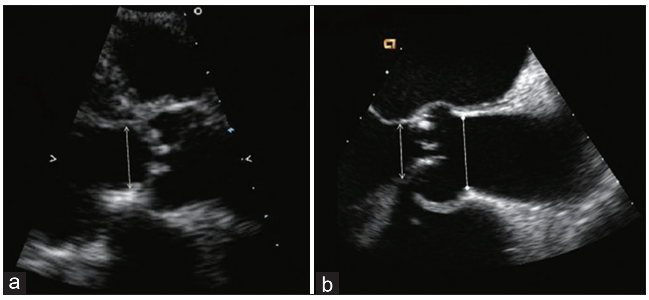

Figure 1: (a and b) Longitude view of the aortic root. (a) Measurement of the left ventricle outflow tract, (b) marked full aortic root with a measurement of sinotubular junction

Subjects and Methods

Study population

The study population consisted of 377 patients with findings of severe AS, referred to Zan Mitrev Clinic between the period of 02/2002 and 06/2020. Patients were included following actual guidelines of the European Society of Cardiology for valvular disease, whereas patients with dilatation of aortic annulus, rheumatoid arthritis, and chronic program on hemodialysis were excluded from the study. All of the patients were older than 18 years and had clinical symptoms for severe AS.

Demographics

Basic demographic data on all subjects were obtained by retrospective review of clinical charts. Patients' available demographics and comorbid conditions included age, gender, and presence of diabetes mellitus, systemic hypertension, hyperlipidemia, coronary artery disease, and chronic kidney disease.

Echocardiography

Transthoracic (TTE) and transesophageal echocardiography (TEE) were performed using one of several commercially available echocardiography systems (Philips IE 33) with standard views and techniques as recommended by the American and by the European Society of Echocardiography (ASE, ESE). The LVOT was imaged in zoom mode in the parasternal long-axis view using harmonic imaging. The gain was adjusted to optimize the blood tissue interface. As recommended [2], LVOT diameter was measured in mid-systole from the inner edge to inner edge just below the insertion of the aortic valve leaflets (Figure 1a). TEE was performed using one of several commercially available echocardiography systems (Philips IE 33) and a 4–7 MHz probe; the LVOT was imaged in zoom mode in the mid-esophageal long-axis view (typically ~ 130 degrees) during mid-systole from the inner edge to inner edge (Figure 1b) [13].

Other available standard B-mode and Doppler measurements were obtained from the existing echocardiography reports. Of note, all Doppler parameters for atrial fibrillation were averaged over 5 to 10 cardiac cycles. Left ventricular EF was based on the TTE study. AVA was measured on a perpendicular image of the valve by 2D and 3D TEE.

Physiologic parameters

Echocardiographic morphological and physiological parameters such is transvalvular energy loss, as an independent predictor for clinical outcome after aortic valvular replacement (AVR), which could help clinicians when making a decision for further treatment. Energy loss index (ELI) can be calculated using the validated equation AVA × Aa/(Aa–AVA)/m^2, where Aa is the aortic area at the level of the sinotubular junction and m^2 is the body surface area [7], [14].

Description of the surgical technique

After median sternotomy and standard pericardial scission, we cannulated the aortic arch and the right atrium according to the protocol for aortic valve surgery, and the patient is connected to the extracorporeal circulation in a condition of mild hypothermia. Using a mild blood (k/mg) cardioplegia, suprannular aortotomy is performed and we extirpate native destructed valve. Using the measurements of AVA, LVOT, aortic annulus, and leaflet dimensions, new created leaflets can be tailored in a semilunar shape, from bovine or equine or matrix pericardium patch. After that, every leaflet is sutured on the aortic annually separately, and at the end, intercommisural junctions have to be created. In the end, we close the aorta and avoid the patient from the extracorporeal machine on a standard way.

Statistical analysis

All analyses were performed using basic demographic analysis. Continuous variables were reported as mean ± standard deviation. Student's t-test and two-way analysis of variance (ANOVA) were used for continuous variables. Pearson's Chi-square contingency test was used to compare categorical variables. Multiple linear regression analysis was used to model the relationship between ≥2 explanatory variables. $p < 0.05$ was considered statistically significant. Data were reported with a 95% confidence interval estimate, and all reported p values were 2-sided.

Results

In our study were included 377 patients, with an average age of 66.3 ± 9.9 years. Two hundred eleven (55.97%) were males and 166 (44.03%) females. One hundred fourteen (30.3%) had severe AS and 263 (69.7%) had combined AS and insufficiency. One hundred (26.5%) had small aortic root. Comorbidities and demographic data of all patients with severe AS are shown in Table 2.

Table 2: Comorbidities and demographic characteristics of patients

Comorbidities	Mail (%)		Female (%)		Mann–Whitney U test
	No	Yes	No	Yes	p-level
Diabetes	161 (76.3)	50 (23.7)	119 (71.7)	47 (28.3)	0.3093
Hyperlipidemia	58 (27.5)	153 (72.5)	46 (27.7)	120 (72.3)	0.9617
Hypertension	14 (6.6)	197 (93.4)	13 (7.8)	153 (92.2)	0.6551
Smoking	175 (82.9)	36 (17.1)	154 (92.7)	12 (7.2)	0.0045*
Obesity	209 (99.1)	1 (0.9)	151 (90.9)	15 (9.1)	0.0001*
COPD	195 (92.4)	16 (7.6)	158 (95.2)	8 (4.8)	0.2758
Renal insufficiency	192 (91.0)	19 (9.0)	156 (94.0)	10 (6.0)	0.2816

In Table 2, we present patient distribution according to sex, as well as patient's comorbidities. There were 16 bicuspid aortic valves and two unicuspid valve. When comparing the comorbidities between male and female patients, we realized that there was no difference according to diabetes, hyperlipidemia, and hypertension between both sexes, but in male patients, smoking and COPD were much more present, whereas female patients were more obese. About 88.5% of the patients were with severe AS of degenerative (calcific) etiology, 5.3% endocarditis, 3.98% rheumatic fever, and 2.12% congenital etiology.

Pre-operative ultrasound measurements were performed by transthoracic ultrasound probe. Mean pressure gradient through the LVOT was measured in a standard left decubitus position through the long axis using a TTE. Velocity measurement of the stenotic valve was done on TTE through apical or right parasternal image. Intraoperatively before the surgery and after surgery, we performed a transesophageal evaluation. Echocardiographic parameters are shown in Table 3.

Mann–Whitney U test analyzes pointed out that female patients with AS had smaller dimensions of the left ventricle, aortic annulus, and more significant hypertrophy of the myocardium with a preserved ejection fraction (EF). According to the performed surgery, we divided estimated patients in four groups (Table 4).

Kruskal–Wallis ANOVA: H = 1.351 p = 0.7170 analyzes showed that there were no significant

Table 3: Echocardiographic parameters

Echocardiographic parameters	Z	p-level	Valid N	Valid N
LVEDD/mm – before operation	7.26060	0.000001	211	166
LVESD/mm – before operation	6.46537	0.000001	211	166
LVEDV/ml – before operation	6.61316	0.000001	210	165
LVESV/ml – before operation	6.07094	0.000001	210	165
IVSd/mm – before operation	−2.26945	0.023241	211	166
LVPWD/mm – before operation	0.32300	0.746698	211	166
SV/ml – before operation	3.97137	0.000071	209	165
EF (%) – before operation	−3.20249	0.001363	210	166
AI –before operation	1.72004	0.085425	210	166
Diameter of annulus/cm – before operation	5.79447	0.000001	211	166
AVA/cm^2 – before operation	2.49591	0.012564	211	165
PG max/mmHg – before operation	−3.88693	0.000102	211	164
PG mean/mmHg – before operation	−3.48179	0.000498	211	164
LVEDD/mm – post operation	7.26060	0.000001	211	166
LVESD/mm – post operation	6.46537	0.000001	211	166
LVEDV/ml – post operation	6.60020	0.000001	210	165
LVESV/ml – post operation	6.05414	0.000001	210	165
SV/ml – post operation	3.94489	0.000080	209	165
EF (%) – post operation	−3.23175	0.001230	210	166
AI – post operation	0.38216	0.702346	209	162
EOA/cm^2 – post operation	5.18396	0.000001	211	166
Diameter of aortic annulus/cm – post operation	7.70445	0.000001	143	115
Transvalvular ELI	−1.16829	0.242693	210	166
PG max/mmHg – post operation	−1.55387	0.120216	211	166
PG mean/mmHg – post operation	−1.65753	0.097413	211	166

Data expressed as n (%) for categorical variables and mean ± standard deviation for continuous variables. TEE: Transthoracic echocardiogram, EF: Ejection fraction, SVI: Stroke volume index, MG: Mean Doppler gradient, AVAI: Aortic valve area index, LVOT: Left ventricular outflow tract, AV: Aortic valve, ELI: Energy loss index. AI: Aortic insufficiency, LVEDD: Left ventricular external end-diastolic diameter, LVESD: Left ventricular end-systolic dimension, LVEDV: Left ventricular end-diastolic volume, LVESV: Left ventricular end-systolic volume, AI: Aortic insufficiency.

differences between the group according to measured dimensions of AVA preoperatively.

The result of Kruskal–Wallis ANOVA: H = 1.351 p = 0.7170 of the pre-operative echocardiographic measurement showed no differences between the groups according to the dimensions of AVA or measured EOA of the new created valve postoperatively (Figures 2 and 3).

Table 4: Patients distribution according to performed surgery and NYHA classification

Group	The NYHA			Total
	Staging II	Staging III	Staging IV	
Reconstructive surgery with replacement of three leaflets (N1)	24 13.33%	145 80.56%	11 6.11%	180
Combined surgery – Reconstructive surgery with replacement of three leaflets and CABG (N2)	7 5.79%	104 85.95%	10 8.26%	121
Combined surgery – Reconstructive surgery with replacement of three leaflets and mitral or tricuspid valv.surg (N3)	1 3.03%	25 75.76%	7 21.21%	33
Combined surgery – Reconstructive surgery with replacement of three leaflets and CABG mitr. And tric surg and aortoplasty (N4)	3 6.98%	30 69.77%	10 23.26%	43
All groups	35	304	38	377

NYHA: New York Heart Association.

Mean measured values of EF% were the lowest in the third group with a performed reconstructive surgery of the stenotic aortic valve in combination with surgery of the mitral and tricuspid one but without any statistical significance.

Kruskal–Wallis ANOVA: H = 18.054 p = 0.0004

Postoperatively, we measured mean and maximal pressure gradient through the new created valve, effective orifice area, and diameter of aortic annulus.

With a Mann–Whitney U test, we calculated that there was significant sex dependent differences. In male patients, we measured bigger dimensions for

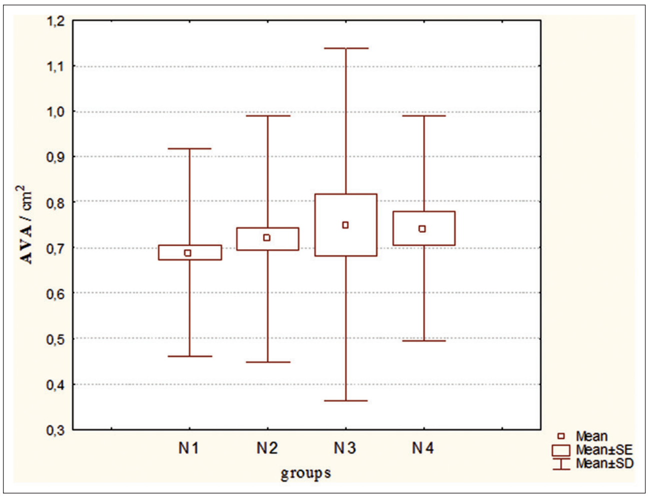

Figure 2: Mean values of AVA in different groups

effective orifice area (post-operative measured opening orifice of new created valve) (Table 3).

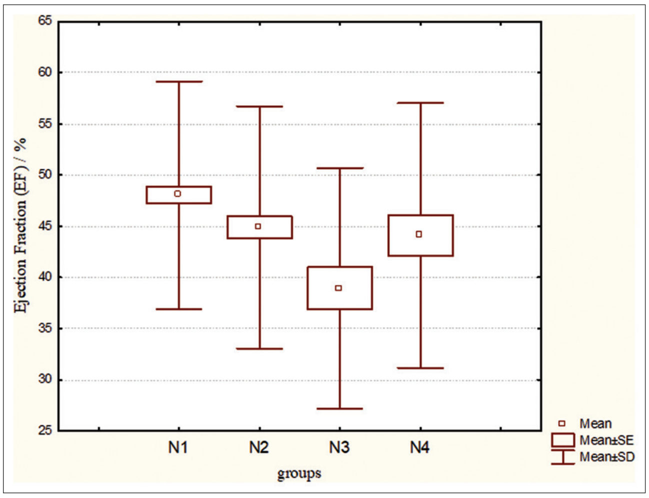

Figure 3: Mean values of EF (%) in different groups

By performing a Kruskal–Wallis ANOVA ($H = 5.654$ $p = 0.1297$), we realized that there was no significant difference in mortality rate between the different surgical groups, and there was also no statistically significant difference in correlation with ELI (Figure 4).

We found a strong correlation between ELI and pre-operative measured AVA dimensions ($r = -96$), whereas there was a weak correlation with the EF ($r = 0.08$) and no correlation with the measured pressure gradients in LVOT (PGmax and PGmean).

The morphology of the new created valve was analyzed on perpendicular view (TEE 45–60°), as well as longitudinal axis (120–130°) with 2D and 3D TEE technique.

With transesophageal 2D and 3D TEE technique, we evaluated the performances of the stenotic and newly created aortic valve. The morphology of the valve was close to the native one, as shown in Figures 5-8. The hemodynamic performances PGmean and PGmax were close to the native normal aortic valve (Table 3).

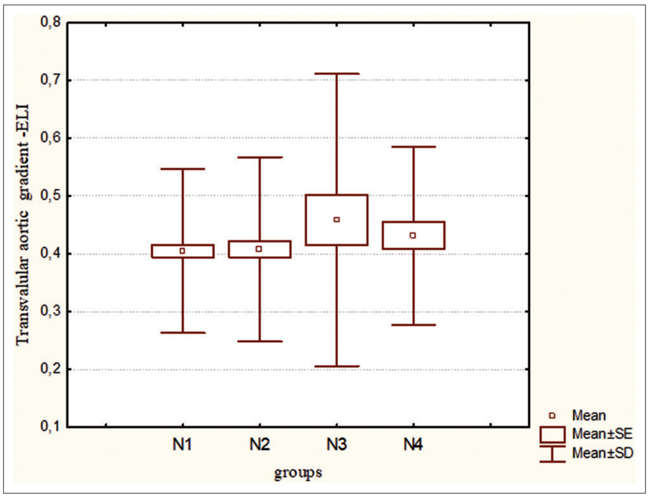

Figure 4: Mean values of transvalvular energy loss index in different groups

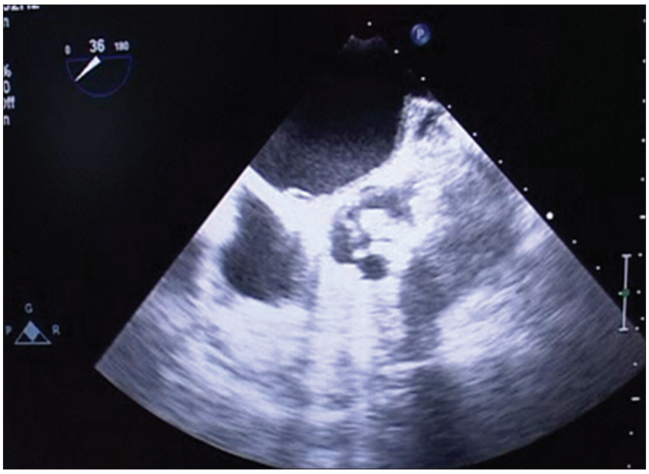

Figure 5: Pre-operative transesophageal image of the stenotic aortic valve – perpendicular view

When analyzing the post-operative clinical outcome, per se, mortality rate, we realized that there was a strong correlation between mortality rate and ELI (Table 5).

Figure 6: Post-operative two-dimensional image of the new created valve

Figure 7: Post-operative three dimensional image of the new created valve

Figure 8: Normal aortic valve

Pearson Chi-squared test (χ^2 = 4.911 df = 1 tp = 0.02669) analyzes pointed that patients with calculated ELI <0.42 cm^2/m^2 have a higher mortality rate (8.7%) in correlation with those one who are with ELI >0.42 cm^2/m^2.

Table 5: Mortality rate in correlation with ELI

Transvalvular aortic gradient (ELI)	Mortality		Total
	Exitus letalis	Alive	
ELI≤ 0.42	33	175	208
	8.7%	92.3%	100%
ELI> 0.42	14	155	169
	3.7%	96.3%	100%
All groups	47	330	377

ELI: Energy loss index.

An ELI of <0.42 cm^2/m^2 is proposed as a cutoff for severe AS [7], and as such, reportedly predicts poor outcomes in patients with severe AS [8]. In the present study, the mean ELI for patients with severe AS was smaller in the group of patients with measured smaller AVA, whereas pressure gradients do not have an influence, and a weak correlation was found with EF. Moreover, Garcia *et al*. got the same conclusions from their trial [7].

Discussion

The main findings of this study can be summarized as follows:

1. TEE – 2D and 3D imaging of the stenotic aortic valve is an important tool which gives important parameters for surgeons on the operative field about severity of the disease and much more that controls the results from the performed surgery
2. The severity of the AS and the clinical outcome does not depend only from the morphological parameters such as measured AVA, the diameter of the aortic annulus, or the measured pressured gradients, and the influence of the whole hemodynamic expressed through the ELI is very important
3. Thus, TEE may be considered before high-risk intervention for severe AS. Despite preserved, EF positive clinical outcome did not always come, and consequently, that is why the physiological parameter ELI was included in this trial [16], [17], [20].

The evaluation of the AS depends from patients technical and physiological parameters. The technical parameters are associated with technical parameters of the ultrasound probe as well as patients general characteristics such are BMI, blood pressure, and heart frequency. Measured pressure gradients are proportionally dependent with systemic patient pressure, whereas increased heart frequency and stroke volume together form a grade separation [18].

There are several physiological parameters such as:

1. The pressure gradient through the LVOT in a longer period results with subendocardial ischemia and fibrosis, which decrease the spiral movements of contraction and elongation of the mitral ring during cardiac cycle. Stroke volume and pressure gradient through the LVOT decrease without any influence on the EF
2. The concentric hypertrophy of the left chamber forces the diastolic left chamber dysfunction and impairment filling of the chamber
3. Transvalvular energy loss, like a parameter, demonstrates the preserved myocardial power

in patients with AS. ELI depends from exchange of static and dynamic power during one heart's cycle, which means that when the aortic valve is stenotic changed, the myocardium spends more energy to push the blood through the valve in the ascending aorta. In a longer period, this can result with a decreased ELI (calculated by ELI equitation). The patient can have a normal EF, but due to morphological changes such as aortic stenos and dilatation of ascending aorta diameter ELI can decrease, so in the post-operative period, we realized that a longer in-hospital stay results with a worse final clinical outcome [19].

4. The mitral valve stenosis or insufficiency, right chamber failure, and constrictive pericarditis are burdensome factors that force the left chamber falling [23], [26].

Although multimodality imaging such as CT scan or magnetic resonance has improved our understanding of LVOT geometry, in any case, the golden standard for diagnosis of AS is echocardiography [3]. Transesophageal ultrasound evaluation ensures much more parameters for the assessment of patomorphology of the AS. Especially 3D imaging technique ensures visualization of the spatial correlation of the aortic valve with mitral and tricuspid one, as well as morphological analyzes of the LVOT tract, systolic anterior movement of the anterior mitral leaflet, and the severity as well geometrics of the left ventricle hypertrophy. Despite the fundamental assumption that the LVOT is circular, differing aortic valve leaflet geometry can lead to variable measurements [11]. Specifically, the ellipticity of the LVOT reportedly results in an underestimation of AVA by echocardiography [11]. Moreover, poor echocardiographic image quality and heavy calcification with secondary acoustic blooming can decrease the accuracy of measurements, which is why 3D TEE images have an advantage when it comes to evaluating these groups of patients [10], [24].

TEE measurements are considered closest to a gold standard on the basis of superior spatial resolution and better correlation of TEE when compared to MSCT and magnetic resonance imaging in prior studies [21], [22]. This does not fully eliminate the risk of misalignment and underestimation of the true cross-sectional area of LVOT. 3D echocardiography was crucial and superior to conventional (2D) techniques for AVA measurement [15], [23].

Immediately postoperatively, 2D and 3D TEE analyzes of estimated patients with reconstructive surgery for aortic valve stenosis showed that new created valve with a separate sutured leaflet on the aortic ring according to the morphology was much closer to the native one. Systolic separation of the leaflets and diastolic closure does not differ from the native normal valve. Basic hemodynamic parameters such are mean and maximal pressure gradients measured in the LVOT tract were in normal values.

Physiologic parameter like ELI was very useful when analyzing post-operative adversative outcomes such as mortality rate. The correlation between ELI and the mortality rate pointed out that patients with severe AS and post-stenotic dilatation of the ascending aorta were with worse prognosis (ELI<0.42). Patients with the same values of measured AVA got different values for ELI depending on the measured diameter of the sinotubular junction of the ascending aorta. Patients with a bigger sinotubular junction had smaller ELI and bigger mortality rate. ELI, like a physiologic parameter, helped us to recognize the level of myocardial reserve for recovery after performed surgery. We realized that the mortality rate even in patients with a small root aorta is not correlated with the dimensions of LVOT, but there is a strong correlation with the calculated ELI [14], [25].

Limitations

This was a single centered study and the study population underwent both TTE and TEE within a short period, pre-operation, and early post-operative. The weakness of the study is that we did not include non-echocardiographic measurements, that is, MSCT or magnetic resonance, which might help us strengthen the conclusion.

Conclusions

Real stentless aortic valve bioprosthesis is with similar morphology and hemodynamic parameters as a normal native valve. The assessment of AV morphology, anatomy of the functional aortic annulus (FAA), and the aortic root with TEE improves the understanding of the mechanisms of AR. Pre- and intra-operative TEE plays a pivotal role in guiding case selection, surgical planning, and evaluating procedural success. Post-operative transthoracic echocardiography is useful to determine long-term success and monitor for recurrence of AR.

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