ОРИГИНАЛЬНАЯ СТАТЬЯ

THREE-DIMENSIONAL TRANSESOPHAGEAL ECHOCARDIOGRAPHY IN THE DIAGNOSIS OF MITRAL VALVE DISEASE

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The aim of the study was to estimate the significance of intraoperative transesophageal 3D-echocardiography (3D-TEE) in determination of possibility, expected volume, complexity and efficacy of mitral valve (MV) surgery in patients with different origin of the mitral regurgitation (MR).

Materials and methods. The study included 64 patients with significant mitral MR (degenerative, arrhythmogenic and ischemic origin): 49 (77%) patients underwent MV repair and 15 (23%) patients - MV replacement. The mean age was 52,2 ± 13,2 years. Twenty patients without MV pathology were included in the control group (12 men and 8 women), mean age was 58 ± 13 years. For all patients undergoing MV repair the valve geometry was assessed intraoperatively using 3D-TEE with Mitral Valve Quantification (MVQ) software before the main stage of the surgery and compared with data in patients of the control group.

Results. comparing the data of patients with MR and patients of the control group, we obtained the following results: myxomatous degeneration is characterized by MV vertical and horizontal deformation and leaflets prolapse into LA; arrhythmogenic MR is associated with dilatation of MV; ischemic MR is characterized by loss of saddle-shaped of MV.

Conclusion. Real-time (RT) 3D-TEE with MVQ software allow to determine the specific changes in MV geometry depending on the MR etiology, to select optimal surgical technique, to predict complexity of surgery for each patient in the operating room and to evaluate the efficiency of procedure.

Keywords: mitral valve, mitral valve insufficiency, mitral valve prolapse, real-time three-dimensional transesophageal echocardiography, Mitral Valve Quantification.

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ТРЕХМЕРНАЯ ЧРЕСПИЩЕВОДНАЯ ЭХОКАРДИОГРАФИЯ В ДИАГНОСТИКЕ ЗАБОЛЕВАНИЙ МИТРАЛЬНОГО КЛАПАНА

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Цель исследования - оценить значимость интраоперационной чреспищеводной 3D-эхокардиографии (3D-TEE) в определении возможности, ожидаемого объема, сложности и эффективности операции на митральном клапане (МК) у пациентов с митральной регургитацией (МР) различного происхождения.

Материалы и методы. В исследование были включены 64 пациента со значимым уровнем МР (дегенеративным, аритмогенным и ишемическим генезом): 49 (77%) пациентам выполнена репарация МК и 15 (23%) - замена МК. Средний возраст составил 52,2 ± 13,2 года. В контрольную группу вошли 20 пациентов без патологии МК (12 мужчин и 8 женщин), средний возраст составил 58 ± 13 лет. У всех пациентов, перенесших реконструкцию МК, геометрию клапана оценивали интраоперационно с помо-

щью программы 3D-TEE with Mitral Valve Quantification (MVQ) перед основным этапом операции и сравнивали с данными у пациентов контрольной группы.

Результаты. Сравнивая данные пациентов с МР и пациентов контрольной группы, мы получили следующие результаты: миксоматозная дегенерация характеризуется вертикальной и горизонтальной деформацией МК и пролапсом листков в ЛП; аритмогенная МР связана с дилатацией МК; ишемическая МР характеризуется потерей седловидной формы МК.

Заключение. Real-time (RT) 3D-TEE с программным обеспечением MVQ позволяют определить конкретные изменения геометрии МК в зависимости от этиологии МР, выбрать оптимальную хирургическую технику, спрогнозировать сложность операции для каждого пациента в операционной и оценить эффективность процедуры.

Ключевые слова: митральный клапан, недостаточность митрального клапана, пролапс митрального клапана, трехмерная чреспищеводная эхокардиография в реальном времени, количественное определение митрального клапана.

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Introduction.

Diagnosis and treatment options of mitral valve (MV) diseases is one of the most pressing problems in cardiology and cardiac surgery. Nkomo VT et al. (2006) considers that mitral regurgitation (MR) is the most common valve disease after aortic stenosis [1]. Thomas Buck et al. (2015) presents data suggesting that hemodynamically significant MR (moderate and severe) was detected in 2-3% of the general population [2].

Hemodynamically significant regurgitation often requires surgical correction: MV repair or replacement. According to ESC, EACTS and AHA/ACC (2014) guidelines MV repair should be the preferred technique when it is expected to be durable. It should be noted that there is no clear recommendations for the planning and evaluation of the possible results.

In most cases, the severity of MR assessed only according to its degree, but the origin and the geometry of MV is no less important. In particular these morphological characteristics of the valve have a direct prognostic value in determining the indications for surgery and the evaluation of its effectiveness. Intraoperative real-time three dimensional transesophageal echocardiography (RT 3D TEE) with Mitral Valve Quantification (MVQ) allows to get detailed MV morphology and its subvalvular apparatus [5,6]. The first attempts to obtain a three-dimensional image of the heart belong to M. Matsumoto and refer to the end of the 70s [7].

MVQ presents a method of constructing three-dimensional MV models, which provides insight of fibrous ring shape and also allows to estimate the parameters of the leaflet geometry and chordal apparatus [8-13].

Our study includes the analysis of intraoperative evaluation of patients with hemodynamically significant MR of various origin: myxomatous degeneration, arrhythmogenic and ischemic MR operated at A.N. Bakoulev Scientific Center for Cardiovascular Surgery. from 2012 to 2017.

The aim of the study was to evaluate the significance of intraoperative three-dimensional transesophageal echocardiography to determine the feasibility, the expected volume, complexity and efficiency of cardiac surgery in patients with different origin of the mitral regurgitation (MR).

Methods.

Study population and design.

Prospective single-center study included 64 patients with hemodynamically significant MR: 49 pts (77%) underwent MV repair and 15 pts (23%) – MV replacement. The mean age was 52,2 ± 13,2 years. Twenty subjects without MV pathology according to TTE and TEE were included in the control group (12 men and 8 women, the mean age was 58 ± 13 years)

Inclusion criteria was hemodynamically significant MR requiring surgical intervention. Exclusion criteria were decompensation of comorbidities contradicting the surgery, infective endocarditis, acute MR, multivalvular heart disease.

The study design was approved by the Ethics Committee of the Bakoulev center. All patients

Table №1. Clinical and echocardiographic characteristics of patients

	MV repair			MV replacement (n=15)	Control group (n=20)	
	Degenerative MR (n=22)	Arrhythmogenic MR (n=14)	Ischemic MR (n=13)			
Age	56,2±14,5	58,7±6,3	62,7 ± 4,2	60,4±4,5	58,1±13	0,
Male, n (%)	12 (55%)	10 (71%)	8 (62%)	9 (60%)	12 (60%)	0
BMI, kg/m^2	26,2	27,5	26,7	25,9	26,7	0
Hypertension, n (%)	10 (45%)	8 (57%)	8 (62%)	7 (46%)	10 (50%)	0,
Standard TTE parameters						
LA dimension, cm	4,8±0,2	5,2±0,2	4,7±0,2	4,9±0,2	3,7±0,3	**0,**
LV EDS/BSA (cm/m2)	2,8±0,3	2,6±0,3	2,7±0,1	2,6±0,4	2,57±0,3	0
LV ESS/BSA (cm/m2)	1,8±0,2	1,9±0,3	1,9±0,1	1,9±0,3	1,68±0,1	0
LV EDV/BSA (ml/m2)	80,7±15,4	78,6±14,8	79,2±5,3	80,2±13,6	73,2±10,3	0
LV ESV/BSA (ml/m2)	35,2,3±7,6	31,3±14	31,3±10,8	30,5±9,2	27,5±7,8	0,
LV EF, %	61,3±5	56,9± 9,4	59,2±4,1	58,1±4,5	57,2±3,5	0,

Categorical data are presented as frequencies and percentages. Continuous data are presented as mean±standard deviation.

MV – mitral valve; MR – mitral regurgitation; BMI – body mass index; TTE – transthoracic echocardiography; LA – left atrium; LV – left ventricle; EDS – end-diastolic size; ESS – end-systolic size; BSA – body surface area; EDV – end-diastolic volume; ESV – end-systolic volume; EF –ejection fraction.

provided a written informed consent.

Methods.

All patients underwent physical examination, electrocardiography, Holter ECG monitoring, transthoracic echocardiography, coronary angiography, intraoperative two- and three-dimensional TEE. Echocardiographic studies were performed intraoperative using ultrasound machine Philips iE 33 and Philips CX 50 with TE transducer X7-2t (Bothell, WA, USA).

During the intraoperative evaluation a detailed assessment of the affected valve morphology, prolapse localization and rupture of the chordae tendineae was assessed. The obtained data were processed using Mitral Valve Quantification (MVQ) software. We evaluated the following parameters of the MV annulus: antero-posterior and commissural diameter, annulus circumference and area, anterior and posterior leaflets angle, non-planar leaflets angle, mitral leaflet tenting height and volume, prolapse height and volume, aorto-mitral annulus angle, anterolateral and posteromedial chord length. In patients who underwent MV replacement, the valve geometry was assessed before implantation and after procedure was compared with repair procedures group to identify parameters affecting surgery tactics.

Statistical analysis.

Statistical analysis was carried out with SPSS 21.0 (SPSS, Chicago, Illinois). Categorical data were presented as frequencies and percentages. Continuous variables were presented as mean ± SD and for categorical data frequencies and percentages were used. A p value of <0.05 was considered statistically significant.

Results.

All patients with MR (n=64) were divided into 3 groups.

The first group (n=37) included 25 men and 12 women with degenerative MR (MV myxomatosis). The mean age was 56,2 ± 14,5 years. The second group (n=14) included 10 men and 4 women with arrhythmogenic MR due to persistent atrial fibrillation. The mean age was 58,7±6,3 years. The third group was presented by 13 patients with ischemic MR due to stable coronary artery disease

Table №2. MVQ data in patients with degenerative MR before repair surgery and in patients of control group.

Parameters	Pts with degenerative MR (n=37)	Control group	P
Antero-posterior annular diameter, mm	40,1 ± 3,7	34,2 ± 1,12	**0,0001**
Commissural diameter, mm	40,7 ± 4,5	33,5 ± 1,51	**0,0001**
Annular height, mm	9,0 ± 1,1	6,4 ± 1,287	**0,0001**
Annular perimeter, mm	144,3 ± 19,1	115,39 ± 4,49	**0,0001**
Annular area, mm^2	1482 ± 380,3	967,08 ± 129,3	**0,0001**
Anterior mitral leaflet angle, degree	24,4 ± 11,5	22, 25 ± 7,8	0,392
Posterior mitral leaflet angle, degree	20,5 ± 9,0	19,84 ± 6,3	0,78
Non planar leaflet angle, degree	143,2 ±25,9	132,19 ± 10,3	**0,001**
Prolapse height, mm	6,4 ± 2,3	1,01 ± 0,443	**0,0001**
Prolapse volume, ml	1,2 ± 1,3	0,07 ± 0,22	**0,0001**
Tenting height, mm	7,6 ± 3,9	5,86 ± 1,4	0,67
Tenting volume, ml	2,6 ± 1,7	1,72 ± 2,0	0,102
Aortic-mitral angle, degree	120,28 ± 8,3	117,105 ±3,14	0,127
Antero-lateral chord length, mm	26,5 ± 2,7	24, 99 ± 2,43	0,258
Postero-medial chord length, mm	27,0 ± 3,1	25,2 ± 1,79	0,643

Data are presented as mean ± standard deviation. MR – mitral regurgitation

(SCAD) according to the results of coronary angiography. The mean age was 62,7±4,2 years.

Clinical and echocardiographic characteristics of patients presented in Table 1.

All patients who underwent MV replacement had a myxomatous MV degeneration. According to clinical and standard TTE parameters there were no significant differences between the groups before surgery (p>0,05), excluding the left atrium size (p=0,041).

Intraoperative 2D-and 3D-echocardiography was performed in all patients before the main stage of the surgery. All MV parameters were compared with control group to identify regular variations in MV geometry in patients with different etiology of MR.

Mitral valve characteristic in patients with degenerative mitral regurgitation before and after surgery.

The myxomatous MV degeneration group included 22 patients. All patients had grade 3 MR (regurgitation flow reached the LA roof) and according to colour Doppler mean vena contracta was 7.2±1 mm, while mean regurgitation volume was 32±2,7 ml.

Comparing the MV characteristics patients with myxomatous degeneration and control group, we obtained following significant differences in geometry: antero-posterior diameter (p=0.001), commissural diameter (p=0.001), annular height (p=0.001), annular perimeter (p=0.001) and annular area (p = 0.0001), non-planar angle prolapse height (p = 0.0001) and volume (p = 0.0001). Other words, myxomatous valve exposed horizontal and vertical deformation and leaflets prolapse into LA. (Figure 1, Table 2).

Mitral valve characteristic in patients with atrial fibrillation and arrhythmogenic mitral regurgitation before surgery and in patients of control group

The arrhythmogenic MR group included 14 patients (mean age was 58,7±6,3 years). All patients had persistent atrial fibrillation (AF).

Reduced systolic function and left ventricular ejection fraction (LVEF) about 45-54% recorded in 2.5% of patients. According to colour Dop-

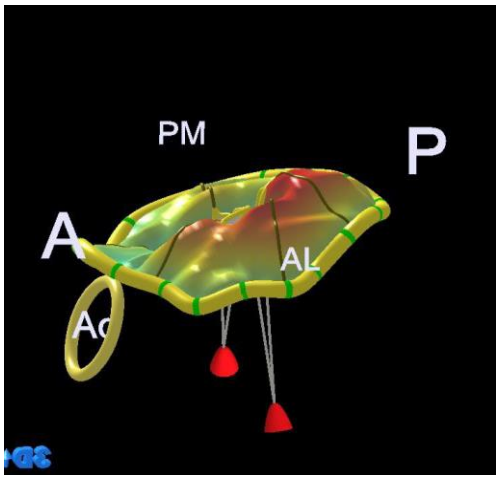

Fig. 1 a (Рис. 1 а)

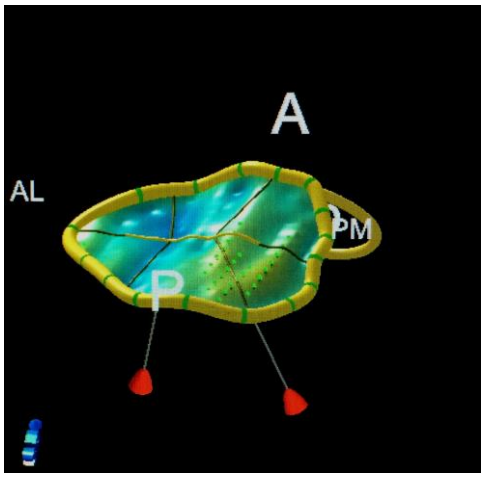

Fig. 1 b (Рис. 1 б)

Fig. 1. 3D model of MV.

a - patient with degenerative mitral regurgitation before MV repair (Posterior leaflet prolapse)

b - patient without MV pathology (MV without pathology)

MV – mitral valve; MR – mitral regurgitation; AL – antero-lateral; PM – postero-medial; A – anterior, P – posterior; Ao – aortic valve

Рис. 1. 3D-модель МК.

а - пациент с дегенеративной митральной регургитацией перед восстановлением МК (пролапс задней створки)

б - пациент без патологии МК (МК без патологии)

MV - митральный клапан; MR - митральная регургитация; AL - переднебоковая; PM – заднебоковая; A - передняя, P – задняя; Ao – аортальный клапан.

pler the mean preoperative vena contracta was 5,2±1 mm and the mean regurgitation volume according to PISA (proximal isovelocity surface area) was 25±0,5 ml.

MV geometry in patients with arrhythmogenic MR had no substantial differences compared to control group and significant differences were obtained only in following parameters: commissural and antero-posterior annular diameters, annular perimeter and area (p=0,0001) (Table 3, Figure 2).

Thus, arrhythmogenic MR due to long-term atrial fibrillation is characterized by minimal MV leaflets changes and annular dilation.

Mitral valve characteristic in patients with ischemic mitral regurgitation before surgery and and in patients of control group

The ischemic MR group included 13 patients with MR grade 3 and hemodynamically significant ctsurgerypatients.orgcoronary artery disease (CAD).

Degenerative changes in MV were excluded using TTE and TEE. According to color Doppler the regurgitation jet reached the LA roof, mean vena contracta was 7,0±1,0 mm, mean regurgitation volume according to PISA was 28±0,5 ml.

All patients before surgery had preserved systolic function and no LV aneurysm. Compared with the control group following changes were revealed:

- annulus dilatation due to anterior-posterior (p=0,0001) and commissural diameter (p=0,0001);
- loss of MV saddle shape, which is associated with a decrease of non-planar leaflet angle (p=0.039);
- increase of tenting volume (p=0.0001) and height (p=0.039), due to ischemia of papillary muscles and left ventricle (Table 4, Figure 3)

Discussion.

The main issue in MV surgery remains the choice of surgical technique for the benefit of repair or replacement. The introduction of three-dimensional echocardiography in our practice provide so-called «surgical view»-as it can be.

Biaggi et al. used a 3D reconstruction in mitral valve prolapse to predict surgical anatomy and the complexity of MV repair [14]. Grewal J et al. assessed MV annulus and leaflets comparing myxomatos and other cause of MR using RT 3D TEE in operating room [12]. Jin, Salgo et al. revealed that anatomic intelligence in 3D TEE image can provide accurate, reproducible, and rapid quantification of the mitral valve anatomy [19].

Table №3. MVQ data in patients with arrhythmogenic MR before repair surgery and and in patients of control group.

Parameters	Pts with arrhythmogenic MR (n=14) before surgery	Control group	P
Antero-posterior annular diameter, mm	38,9 ± 2,8	34,2 ± 1,12	**0,0001**
Commissural diameter, mm	40,6 ± 2,8	33,5 ± 1,51	**0,0001**
Annular height, mm	7,5 ± 1,44	6,4 ± 1,28	0,025
Annular perimeter, mm	136,1 ± 16,6	115,39 ± 4,4	**0,0001**
Annular area, mm^2	1301 ± 256,7	967,08 ± 72,73	**0,0001**
Anterior mitral leaflet angle, degree	23,5 ± 6,2	22,25 ± 7,8	0,642
Posterior mitral leaflet angle, degree	20,5 ± 5,2	19,84 ± 6,3	0,724
Non planar leaflet angle, degree	126,3 ± 9,12	132,19 ± 10,3	0,247
Prolapse height, mm	1,44 ± 1,5	1,01 ± 0,44	0,319
Prolapse volume, ml	0,25 ± 0,43	0,07 ± 0,22	0,597
Tenting height, mm	6,6 ± 1,4	5,86 ± 1,4	0,173
Tenting volume, ml	3,03 ± 1,58	1,72 ± 2,0	0,235
Aortic-mitral angle, degree	120,4 ± 8,4	117,1 ±3,14	0,127
Antero-lateral chord length, mm	26,0 ± 2,2	24, 99 ± 2,43	0,258
Postero-medial chord length, mm	25,5 ± 1,7	25,2 ± 1,79	0,643

Data are presented as mean±standard deviation. MR – mitral regurgitation

In our study, we also observed the most MV deformation in degenerative group.

Chikwe J. et al demonstrated that the 3D TEE parameters prolapsing height, multisegment involvement, bileaflet prolapse and anterior leaflet surface area were strong predictors of repair complexity. [15]. Authors conclude that quantitative MV assessment is simple, reproducible and reliable method that allows us to choose surgical tactics.

Previous studies have shown that significant ischemic MR is a predictor of poor outcome in patients with CAD. Prifti E et al. assessed the feasibility of MV surgery along with coronary artery bypass grafting (CABG) in patients with ischemic MR grade II-III and LV dysfunction. [16]. A comparison of MV characteristics in CAD patients with ischemic MR and the control group revealed the loss of its physiological saddle shape due to LV remodeling and subvalvular apparatus destruction. Increase in tenting height and volume are specific changes in MV geometry. Ryan L. et al demonstrated that increase of tenting height and volume is associated with more severe valve impairment in CAD patients with ischemic MR [17,18].

Currently, many studies are focused on the analysis of mitral valve geometry in functional mitral regurgitation. Cong T and al. in their study showed that patients with significant MR had a larger size of left atrium, a more dilated mitral annulus, a reduced annular height to commissural width ratio , indicating flattening of the annular saddle shape, and greater leaflet surfaces compared to patients without MV pathology [20]. In recent study Tolstikhina A. et al. following MV geometry characteristics in patients with atrial fibrillation were observed: annulus dilatation, coaptation defect and nearly intact leaflets [13].

Chen et al. analyzed geometric changes in

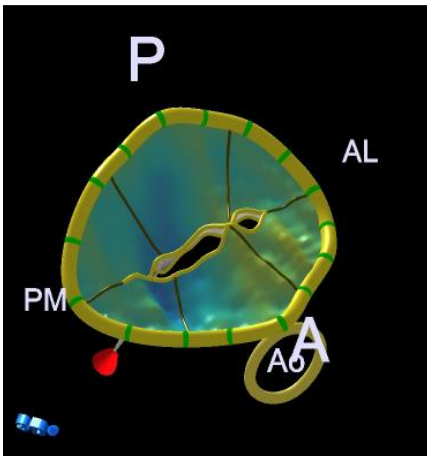

Fig. 2 a (Рис. 2 а)

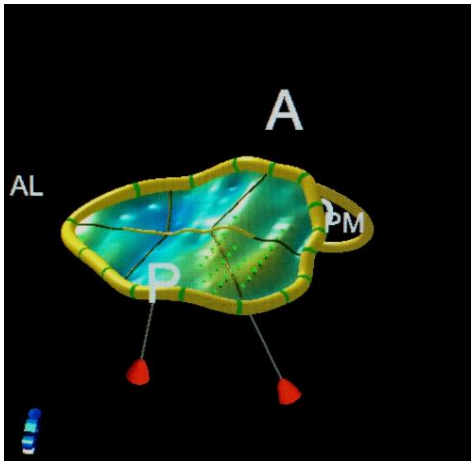

Fig. 2 b (Рис. 2 б)

Fig. 2. 3D model of MV.

a - patient with arrhythmogenic MR before MV repair (MV annulus dilatation and coaptation disturbance)

b - patient without MV pathology (MV without pathology)

MV – mitral valve; MR – mitral regurgitation; AL – antero-lateral; PM – postero-medial; A – anterior, P – posterior; Ao – aortic valve

Рис. 2. 3D-модель МК.

а – пациент с аритмогенной МР перед операцией на МК

б – пациент без патологии МК

MV - митральный клапан; MR - митральная регургитация; AL - переднебоковая; PM – заднебоковая; A - передняя, P – задняя; Ao – аортальный клапан.

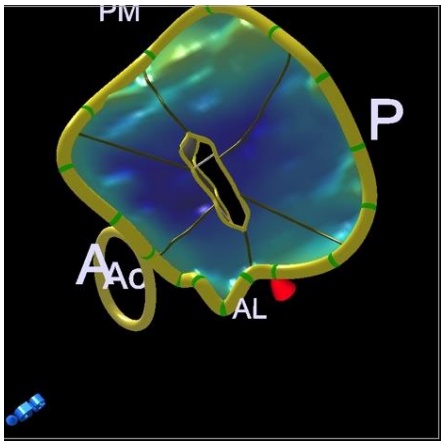

Fig. 3 a (Рис. 3 а)

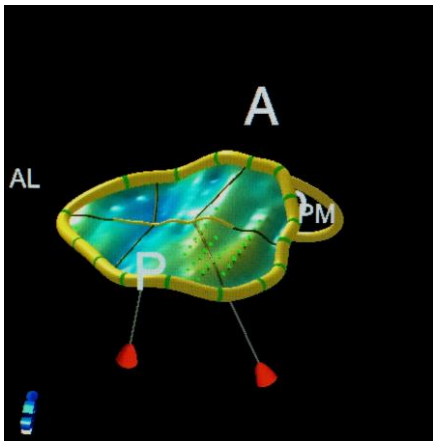

Fig. 3 b (Рис. 3 б)

Fig. 3. 3D model of MV.

a - patient with ischemic MR before MV repair (Valve is dilated and flattened)

b - patient without MV pathology (MV without pathology)

MV – mitral valve; MR – mitral regurgitation; AL – antero-lateral; PM – postero-medial; A – anterior, P – posterior; Ao – aortic valve

Рис. 3. 3D-модель МК.

а – пациент с ишемической формой МР перед операцией на МК

б – пациент без патологии МК

MV - митральный клапан; MR - митральная регургитация; AL - переднебоковая; PM – заднебоковая; A - передняя, P – задняя; Ao – аортальный клапан.

Table №4. MVQ data in patients with ischemic MR before repair surgery and and in patients of control group.

Parameters	Pts with ischemic MR (n=13) before surgery	Control group	P
Antero-posterior annular diameter, mm	41,2 ± 1,5	34,2 ± 1,12	**0,0001**
Commissural diameter, mm	39,7 ± 2,1	33,5 ± 1,51	**0,0001**
Annular height, mm	6,92 ± 1,7	6,4 ± 1,28	0,641
Annular perimeter, mm	151,2 ± 3,9	115,39 ± 4,4	**0,0001**
Annular area, mm^2	1476,8 ± 77,3	967,08 ± 72,73	**0,0001**
Anterior mitral leaflet angle, degree	42,8 ± 2,4	22,25 ± 7,8	**0,003**
Posterior mitral leaflet angle, degree	25,4 ± 0,6	19,84 ± 6,3	**0,04**
Non-planar leaflet angle, degree	119,6 ± 7,1	132,19 ± 10,3	**0,03**
Prolapse height, mm	1,02 ± 0,8	1,01 ± 0,44	0,408
Prolapse volume, ml	0,075 ± 0,05	0,07 ± 0,22	1,000
Tenting height, mm	11 ,9 ± 1,9	5,86 ± 1,4	**0,039**
Tenting volume, ml	7,7 ± 0,5	1,72 ± 2,0	**0,0001**
Aortic-mitral angle, degree	114,8 ± 3,2	117,1 ±3,14	0,188
Antero-lateral chord length, mm	21,3 ± 1,4	24, 99 ± 2,43	0,251
Postero-medial chord length, mm	22,4 ± 1,5	25,2 ± 1,79	0,05

Data are presented as mean±standard deviation. MR – mitral regurgitation

mitral annular and/or leaflets spatial conformation in patients with atrial fibrillation complicated with severe mitral regurgitation using real-time 3-dimensional transesophageal echocardiography [21].

Conclusion.

Intraoperative RT 3D-TEE with MVQ technique allows to determine the characteristic of MV geometry in each patient group according to MR origin.

- myxomatous degeneration is characterized by MV vertical and horizontal deformation and leaflets prolapse into LA.

- arrhythmogenic MR is associated with dilatation of MK:

increase of commissural and antero-posterior annular diameters, annular perimeter and area

- ischemic MR is characterized by loss of saddle-shaped of MV, increase of the tenting height and tenting volume

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