COMPARATIVE ANALYSIS OF CARDIAC ARRHYTHMIAS BY AUTOMATIC CARDIOREGISTRATION IN PATIENTS AFTER SURGICAL TREATMENT OF ATRIAL FIBRILLATION, CORRECTION OF VALVULAR PATHOLOGY AND SYMPATHETIC DENERVATION OF THE PULMONARY ARTERIES

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Abstract. Objectives: to analyze early postoperative arrhythmias in patients after surgical treatment of atrial fibrillation, correction of valvular pathology and sympathetic denervation of the pulmonary arteries in order to correct high pulmonary hypertension. Materials and methods: the study included patients with diagnosed mitral valve disease complicated by atrial fibrillation and high-grade pulmonary hypertension (40 mm Hg or more). All studied patients underwent mitral valve replacement, Maze IV biatrial surgery. In contrast to the patients in the study group, pulmonary artery denervation was not performed in the control group. On the first day after transfer to the ward from the intensive care unit, patients were fitted with a wearable cardiorecorder, which provides continuous ECG recording of one lead with automatically machine analysis with the formation of a pre-medical conclusion. Results: In all studies, a mechanism was implemented for remote ECG transmission of data in the «real time» mode for evaluation by a cardiologist. The study group demonstrated the best recovery and preservation of sinus rhythm in the early postoperative period. 92% of the patient had sinus rhythm, while in the control group this indicator was – 81% ($p = 0.05$). Radiofrequency denervation of the pulmonary arteries is a safe and effective method for correcting high pulmonary hypertension and helps to maintain sinus rhythm after the concomitant Maze IV procedure ($p = 0.05$). The use of automatic cardiac screening has demonstrated the feasibility of detecting early arrhythmias in automatic mode with the possibility of timely personalized correction of antiarrhythmic therapy and treatment tactics in general.

Keywords: secondary pulmonary hypertension, pulmonary artery denervation, cardiac monitoring, machine diagnostic methods.

List of Abbreviations

AF – atrial fibrillation
PA – pulmonary arteries
PAH – pulmonary arterial hypertension
mPAP – mean pulmonary artery pressure
PADN – pulmonary arteries denervation

Introduction

Diseases of the circulatory system remain the most common cause of death in the population (Boitsov *et al*., 2021). A comprehensive examination of a patient is impossible without the use of instrumental diagnostic methods and systems; a doctor has to analyze a huge amount of data, including those received in electronic form (Vorobyev, 2016; Moskalenko *et al*., 2019).

Telemedicine is a modern embodiment of the use of information and telecommunication technologies for the provision of medical care. It has been developed and improved for several decades in various fields of medicine, including cardiac surgery (Echahidi *et al*., 2014; Bokeria & Shengelia, 2014).

A team of authors tested a software and hardware complex (HSC) for automatic registration and analysis of electrocardiograms, which allows you to work within the information chain: «patient – mobile monitoring room - doctor – patient» and solves the problems of diagnostics and optimization in the field of cardiology practice (Moskalenko *et al*., 2019; Rodionov *et al*., 2022).

Rhythm disturbances in the form of AF in patients with severe valvular heart disease occur in up to 84% of cases. The presence of this arrhythmia significantly reduces the effectiveness of surgical treatment of valvular pathol-

ogy, contributes to an increase in the risk of thromboembolic complications, an increase in heart failure and, as a result, a decrease in the quality of life and an increase in the mortality of patients (Echahidi *et al*., 2014; Trofimov *et al.*, 2019). Surgical correction of mitral valve disease in such patients contributes to the restoration of sinus rhythm in only 8.5–20.0% of cases, which requires additional efforts to eliminate AF. One of the significant factors in the pathogenesis of AF is an increase in pressure in the cavity of the left atrium, which expands over time; the morphological and electrical properties of the myocardium change, which causes the appearance of areas of slow and fast conduction of impulses with the formation of pathological circles of re-entry (Trofimov *et al.*, 2019).

An increase in pressure in the left atrium causes an increase in PAH with subsequent structural changes in the wall of the PA and, as a result, an overload of the right heart (Avdeev *et al*., 2021; Briongos Figuero *et al*., 2016). An increase in pressure in the pulmonary circulation also contributes to the appearance of tricuspid insufficiency and, as a result, an increase in heart failure, the development of comorbid pathology, a decrease in the quality of life and an increase in mortality in this group of patients (Simonneau *et al., 2013*). In this regard, surgical correction of valvular dysfunction is the main pathogenetic task in the surgical treatment of AF (Gaine, 2000). The treatment of secondary pulmonary hypertension is currently one of the urgent tasks of medicine. Drug therapy in this case is not effective enough and is associated with the use of expensive drugs. The first studies of sympathetic regulation of the vascular tone of the pulmonary arterioles and the precapillatory bed of the pulmonary circulation were performed in 1962 by a group of authors led by J. Osorio (Osorio & Russek, 1962). The presence of sympathetic nerve plexuses in the adventitia of the pulmonary trunk and the orifices of the PA was proved, which caused a contraction of smooth muscle cells and subsequently a spasm of the pulmonary arterioles, followed by an increase in pressure in the pulmonary circulation. Surgical correction of secondary pulmonary hypertension was first proposed in 2013 by a group of authors led by S.L. Chen (Chen *et al.,* 2013). Works on endovascular radiofrequency denervation of sympathetic ganglia in the trunk and ostia of the PA also demonstrated the effectiveness of the technique (Porodenko *et al.,* 2014). A method for the surgical correction of pulmonary hypertension under cardiopulmonary bypass with simultaneous surgical intervention on the mitral valve, which consists in radiofrequency ablation of the anterior wall of the trunk and pulmonary artery orifices using a monopolar electrode, is presented in the work of A.V. Bogacheva-Prokofiev et al. (Bogachev-Prokofiev *et al.,* 2016). Despite the presented data, there is currently no generally accepted method of surgical treatment of patients with mitral valve dysfunction complicated by AF and high pulmonary hypertension, which determines the need for further search for an algorithm for complex surgical correction of this pathology. In addition, there are no data on the effect of surgical treatment of high PAH on the safety and efficacy of the procedure Maze IV and maintenance of sinus rhythm in the postoperative period.

Objective: to analyze early postoperative arrhythmias in patients with mitral valve dysfunction complicated by AF and high PAH after surgical treatment of AF, correction of valvular pathology, and sympathetic PADN in order to correct high PAH.

Materials and Methods

The study has been approved by the local ethical committee. All the studied patients before the operation, without fail, were informed about the upcoming additional procedure PADN, which was planned to be performed with the main stage of surgical correction, signed informed voluntary, according to the principles of clinical practice (Good Clinical Practice – GCP), in accordance with the Helsinki Declaration (2013), voluntary informed consents were signed.

The study included 68 patients, 42 (62%) male patients aged 49 to 71 years, 26 (38%) female patients aged 55 to 73 years. Surgical

treatment was carried out in connection with paroxysmal and persistent forms of AF, EHRA 2 ct with a history of verified paroxysms of arrhythmia. All patients were diagnosed with mitral malformation complicated by AF and high-grade PAH (40 mm Hg or more). The study group consisted of 35 patients (32 patients with severe mitral stenosis and 3 with mitral valve insufficiency of the 4th degree). Patients in the study group underwent mitral defect correction (35 valve prostheses), the Maze IV biatrial procedure using the AtriCure bipolar ablator (ATRICURE Inc., USA), and additionally PADN procedure. The control group consisted of 33 patients who also had a mitral valve defect (33 valve prostheses), AF and PAH according to mPAP of more than 40 mm Hg. However, unlike the patients of the study group, PADN procedure was not performed in the control group.

The criteria for inclusion in the experiment were the presence of mitral valve defect, AF; high-grade PAH (40 mmHg or more); absence of hemodynamically significant coronary artery damage, absence of pulmonary embolism and chronic obstructive pulmonary disease with severe respiratory insufficiency in the anamnesis.

The study group and the control group were comparable in terms of the main clinical and demographic indicators (Table 1).

Table 1

Clinical and demographic characteristics of study groups before surgery (M ± m)

Indicators	Study group (n = 35)	Control group (n = 33)	p Mann–Whitney criterion
Sex (man/fam.)	22/13	20/13	0.102
Age, years	53.4 ± 4.2	54.2 ± 6.1	0.005
Nosology, % – chronic rheumatic heart disease – infective endocarditis – connective tissue dysplasia syndrome	 26 10 3	 25 8 4	 0.072 0.072 0.657
Type of atrial fibrillation, % – long-term persistence – persistent – paroxysmal	 5 8 22	 6 8 19	 0.412 0,110 0,144
Duration of arrhythmia, years	2.60 ± 1.12	2.75 ± 1.24	0.582
Atrial flutter, %	5	6	0.245
Atherosclerosis of brachiocephalic vessels with stenoses over 50%, %	9	7	0.710
Risk of adverse outcome according to the EuroSCORE scale, points (Me [Q1;Q3])	5 [4;8]	4 [3;6]	0.004
Cardiopulmonary bypass time, min (Me (min-max))	105 (87-128)	128 (118-150)	<0.001
Aortic clamping time, min (Me (min-max))	79 (67-99)	102(92-128)	<0.001
Chronic heart failure NYHA class	III	III	0.052
End-diastolic size of the left ventricle, cm	5.78 ± 0.20	5.62 ± 0.45	0.014
Left ventricular ejection fraction, %	54.15 ± 4.23	56.32 ± 4.72	<0.001
End-systolic size of the left atrium, cm	5.38 ± 0.28	5.44 ± 0.52	0.5
Pulmonary hypertension, mm Hg	48.12 ± 6.47	44.56 ± 5.12	0.016

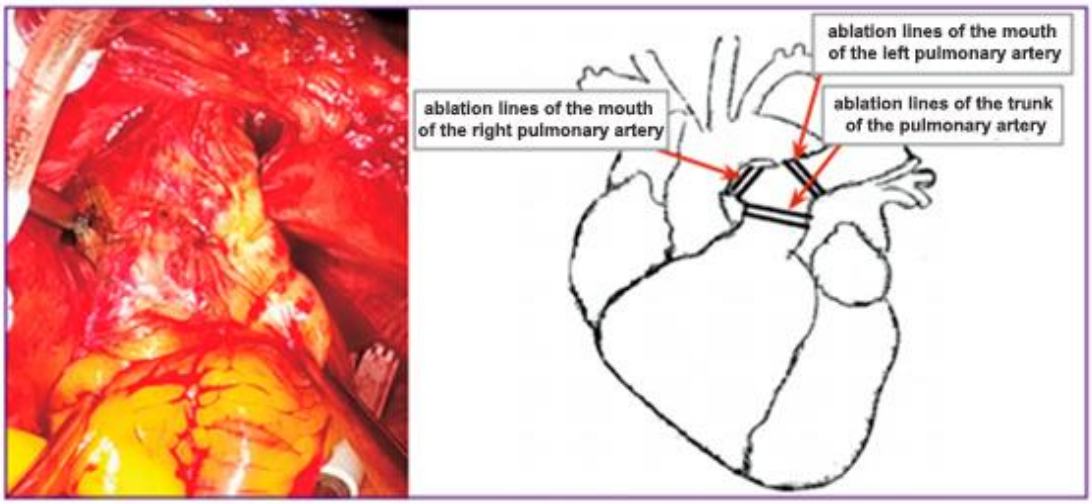

Fig. 1. Ablation lines of the trunk and orifices of the pulmonary arteries

The PADN procedure was performed circularly, using a bipolar radiofrequency clamp of the AtriCure ablator. Intraoperatively, after connecting the artificial circulation apparatus, the distal sections of the trunk of the pulmonary artery were isolated, two ablation lines, 3 applications each, were applied to the area of the pulmonary trunk. After that, the mouths of the PA were similarly isolated with the application of ablation lines with a radiofrequency destructor. In the final form, radiofrequency PADN was represented by 6 ablation lines, two at the mouths of the left and right PA and 2 at the level of the distal trunk of the pulmonary artery (Fig. 1).

The average time of radiofrequency PADN was 5.5 ± 1.5 minutes. The time of artificial blood circulation averaged 114.1 ± 33.4 minutes, the time of myocardial ischemia was 85.2 ± 26.6 minutes. The stay of patients with denervation in the intensive care unit was 2.4 ± 3.1 days and did not differ from patients in the control group (2.6 ± 2.8 days). The management of patients in the postoperative period was identical in both groups.

During the first day after the transfer to the ward from the intensive care unit, a wearable mobile cardioregistrator was installed in all the studied patients, providing continuous removal of an ECG of one thoracic lead V2. The device transmitted data in real time. The recording of one lead was carried out continuously from 24 to 48 hours, was automatically analyzed by machine analysis methods with the formation of a pre-medical conclusion and could be viewed by the attending physician on a smartphone or computer at any time. The cardioregistrator transmitted the native ECG signal of the postoperative patient, analyzed the average heart rate by the hour with the construction of tables of heart rate dynamics, automatically determined the types of rhythm: sinus, AF, atrial flutter, ventricular tachycardia, atrioventricular junction rhythm, etc., counted the number of atrial and ventricular extrasystoles by the hour, estimated the presence of heart rate pauses from 2.0 up to 3.0 seconds and more than 3.0 seconds, automatically detected urgent rhythm disturbances.

Statistical analysis of the results of the study was carried out on a personal computer using Exel and Statistica 10.0 programs. The data obtained as a result of the work are represented by arithmetic mean values and standard error (M ± m). The statistical significance of the parameters during the intergroup analysis was calculated using the Mann–Whitney criterion. The comparison of absolute values in the analysis of two groups was performed using the criterion $\chi 2$, in cases of analysis of observations less than five, the two-sided Fisher criterion was used. The assumed error was denoted as p and was considered statistically significant at $p < 0.05p$.

Results

There were no fatal outcomes in both groups. Complications associated with PADN were not observed in the study group.

The results of surgical treatment showed positive dynamics in both groups. Radiofrequency denervation of the sympathetic ganglia of the pulmonary trunk and PA contributed to the relaxation of smooth muscle cells in the wall of small arteries and arterioles, which led to vasodilation and, as a consequence, increased the total capacity of the small circulatory circle, which ultimately contributed to a decrease in PAH after surgery. The change in the mean values of PAH in both groups is presented in Figure 2.

The proposed method in the group of patients with severe PAH allowed to achieve a significant reduction in hypertension in the study group already 5 days after surgery.

The study group demonstrated the best indicators of recovery and preservation of the sinus rhythm in the early postoperative period due to additional surgical correction of high PAH by PADN, 92% of the patient had a sinus rhythm, while in the control group this indicator was at the level of 81% ($p = 0.05$) (Fig. 3).

In all 68 studies, a mechanism for remote transmission of single-channel ECG data in «real time» mode was implemented for evaluation by a cardiologist.

Automatic diagnosis of various classes of arrhythmias ranged from 91.2% to 98.5% ($p = 0.05$) in comparison with the medical analysis of studies (Table 2).

As a result of cardioregistration, the following cardiac arrhythmias were detected in the early postoperative period (Table 3).

In the control group, AF paroxysms were reported in six patients, atrial flutter in two patients, erratic ventricular tachycardia runs in 2 patients, frequent ventricular extrasystole and group supraventricular extrasystole were detected in 8 and 18 patients, respectively. Bradyarrhythmias in the early postoperative period were observed in a total of eleven patients of the control group and in two cases required the implantation of a permanent pacemaker.

In the study group, AF paroxysms were twice as rare in comparison with the control group - in three patients. Atrial flutter was also detected in two patients, paroxysms of ventricular tachycardia were recorded in two patients, frequent ventricular extrasystole and group supraventricular extrasystole were detected in 9 and 15 patients, respectively. Sinus bradycardia and atrioventricular conduction disorders were reported in 13 patients, three of them had a permanent pacemaker implanted.

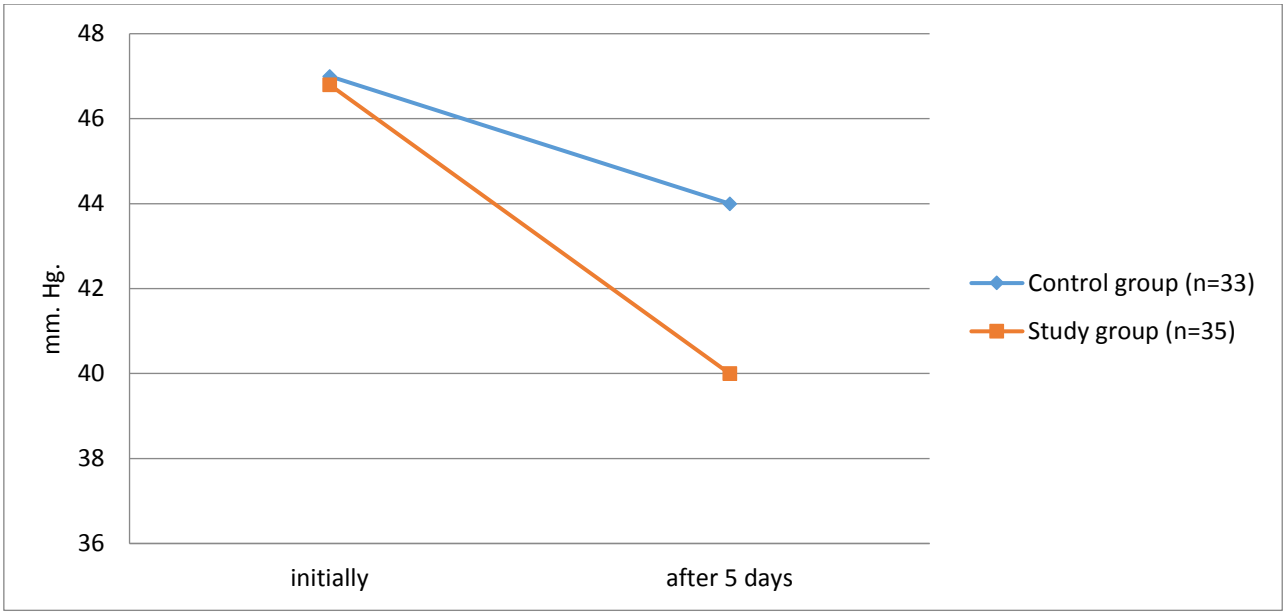

Fig. 2. Dynamics of pulmonary hypertension in the studied groups

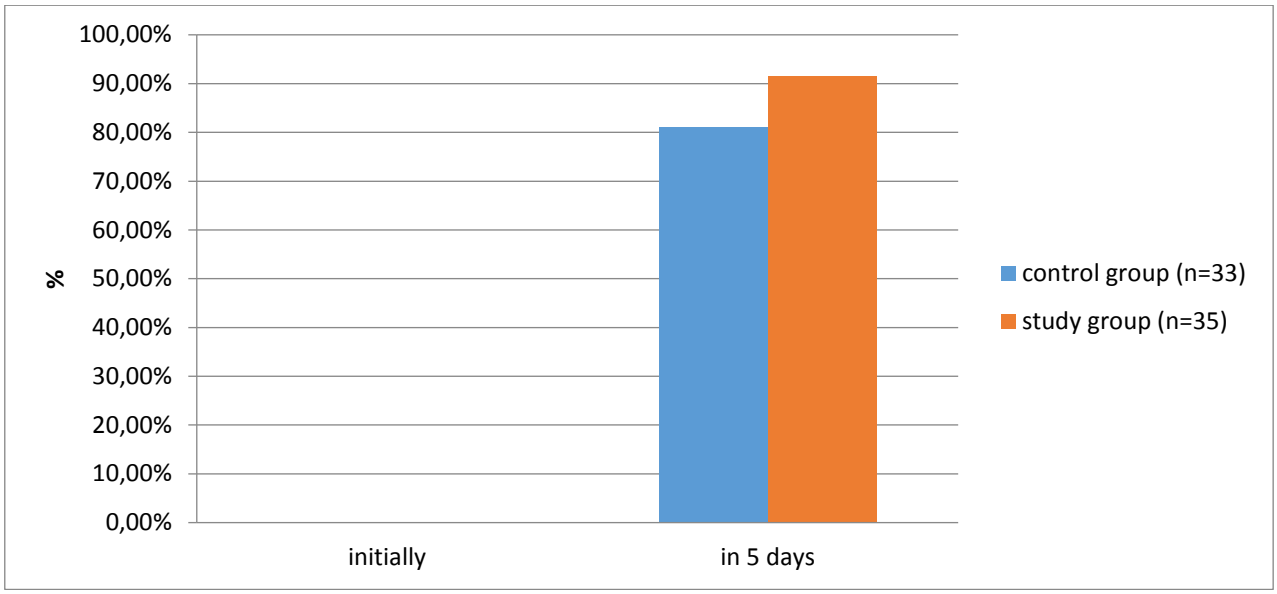

Fig. 3. Preservation of sinus rhythm in groups after surgical treatment

Table 2

Automatic diagnosis of various classes of arrhythmias

Class number	Class name	Number of ECGs from expert opinions	Number of true positives	Sensitivity	Number of true negatives	Specificity	Accuracy
		P	TP	TPR = = TP/P × 100%	TN	TNR = = TN / (n – – P) ×100%	A = (TP + + TN)/n
1	Sinus bradycardia	13	12	92.3%	55	100%	98.5%
2	Atrioventricular block	11	8	72.7%	54	94.7%	91.2%
3	Ventricular tachycardia	4	3	75.0%	62	96.8%	95.5%
4	Atrial fibrillation	9	8	88.9%	57	96.6%	95.6%
5	Atrial flutter	4	2	50.0%	62	96.8%	94.1%
6	Ventricular extrasystole	17	14	82.3%	49	96.0%	92.6%
7	Atrial extrasystole	33	30	91.0%	35	100%	95.6%

Table 3

Cardiac arrhythmias in the early postoperative period

Index	Control group (n-33)	Study group (n-35)
Sinus bradycardia	6 (18.1%)	7 (20%)
Atrioventricular block	5 (15.1%)	6 (17.1%)
Need for a pacemaker	2 (6%)	3 (8.5%)
Atrial fibrillation	6 (18.1%)	3 (8.5%)
Atrial flutter	2 (6%)	2 (5.7%)

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Index	Control group (n-33)	Study group (n-35)
Ventricular tachycardia, non-sustained	2 (6%)	2 (5.7%)
Frequent supraventricular e/systole	18 (54%)	15 (42.8%)
Frequent ventricular e/systole	8 (24.2%)	9 (25.7%)

Discussion

Thus, in the course of this work, the results of cardioregistration in the early postoperative period after surgical correction of PAH in patients with mitral valve defect, AF and high PAH using PADN were analyzed. Despite the insufficiently large sample of patients and the absence of long-term results, the data obtained suggest the safety of the PADN procedure, the absence of a statistically significant increase in the number of postoperative cardiac arrhythmias in the study group. It should be noted a decrease in the frequency of recurrence of AF in patients of the study group. The number of bradyarrhythmias and urgent ventricular arrhythmias did not differ statistically in the early postoperative period between the groups.

In the course of the work, the practical significance of the proposed method of treatment of secondary high PAH, its effectiveness and safety are demonstrated. In addition, the use of automatic cardioscreening is advisable to detect early cardiac arrhythmias in automatic mode with the possibility of timely personalized correction of antiarrhythmic therapy and treatment tactics in general.

Conclusion

– The algorithms of automatic ECG analysis have sensitivity and specificity for detecting various cardiac arrhythmias in the early postoperative period, allowing them to be used as routine ECG screening in all cardiac surgical patients.

– Analysis of cardiac arrhythmias in the early postoperative period did not reveal a significant increase in the number of arrhythmias in patients who underwent PADN.

– The best indicators of recovery and preservation of the sinus rhythm in the early postoperative period were demonstrated by patients who underwent additional surgical correction of high PAH by radiofrequency denervation of the trunk and mouths of the pulmonary arteries. The number of early recurrences of AF in the early postoperative period was higher according to cardioregistration data in the control group.

Thus, surgical radiofrequency PADN is a safe and effective method of correcting high pulmonary hypertension, contributes to the preservation of sinus rhythm after the concomitant Maze IV procedure ($p = 0.05$).

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