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Reseach article

Analysis of the endocardial stage of treatment of tachyarhythmias after open interventions for atrial fibrillation. Experience of one center

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Abstract

AIM: To study EFI parameters and features of recurrent atrial tachyarrhythmias in patients who underwent surgical correction of AF.

MATERIALS AND METHODS: from January 2013 to December 2021, 447 combined interventions were performed to eliminate AF using the labyrinth-3 and left atrial labyrinth techniques with correction of CHD (congenital heart disease) and/or coronary artery disease.

Rhythm disturbances were detected in 57 (12.7%) patients at various follow-up periods. Endovascular interventions were performed in 39 patients. The average follow-up period after the endocardial stage was 34.37 (standard deviation 24.32) months. The median age of patients was 64 (58–67) years, 21 (54%) were men. The patients were divided into 2 groups: group 1 — after the classic biatrial (BA) labyrinth-3 — 23 (59%) patients, group 2 — after the left-atrial variant (LA) labyrinth-3 — 16 (41%) patients.

At the endocardial stage, electrophysiological studies (EFI) were performed to clarify the mechanism of arrhythmia, and ablation eliminated tachyarrhythmia. EFI protocol: revision of the pulmonary veins, determination of the isolation of the posterior wall of the LA assessment of atrial arrhythmia, elimination of arrhythmia, control induction of arrhythmia after ablation. After repeated intervention, patients were observed in the operating clinic every 3 months.

RESULTS: After the endocardial stage, a regular rhythm was determined in 19 (82.6%) patients of the BA group, 13 (92.9%) patients of the LA group ($p = 0.914$). Relapses in the form of AF were noted in 5 patients (4 — group 1 and 1 — group 2) group ($p = 0.306$) All relapses of tachyarrhythmia with an irregular cycle (AF) were detected in patients with AF before the endovascular stage In both groups, there were cases of restoration of conduction in the pulmonary veins — 10 (43.5%) patients after BA ablation and 1 (5.3%) patient after LA ablation. There are no recurrences of atrial arrhythmia after ablation of atrial flutter (arrhythmia with a stable cycle).

CONCLUSION: The endocardial stage is highly effective and demonstrates subsequent freedom from atrial arrhythmia in patients who have tachycardia with a regular cycle after both methods of surgical ablation of AF. Recurrent tachyarrhythmia in the form of AF (irregular cycle) is associated with a low probability of maintaining a regular atrial rhythm after a repeated endocardial procedure, due to the presence of structural and electrophysiological changes in the atrial myocardium.

Keywords: atrial fibrillation; atrial flutter; arrhythmia recurrence; “Maze” procedure; catheter ablation; surgical ablation.

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Научная статья

Анализ эндокардиального этапа лечения тахиаритмий после открытых вмешательств по поводу фибрилляции предсердий. Опыт одного центра

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Аннотация

Цель — изучение параметров электрофизиологического исследования и особенностей рецидивов предсердных тахиаритмий пациентов, перенесших хирургическую коррекцию фибрилляции предсердий.

Материалы и методы. С января 2013 по декабрь 2021 года выполнено 447 сочетанных вмешательств устранения фибрилляции предсердий по методикам лабиринт-3 и левопредсердный лабиринт с коррекцией врожденного порока сердца и/или ишемической болезни сердца. У 57 (12,7 %) пациентов в различные сроки наблюдения определены рецидивы нарушения ритма. Выполнены эндоваскулярные вмешательства 39 (8,7 %) пациентам. Средний срок наблюдения после эндокардиального этапа — 34,37 (стандартное отклонение 24,32) мес. Медианный возраст пациентов составил 64 (58–67) года, мужчин 21 (54 %). Пациенты разделены на 2 группы: 1-я группа — после классического биатриального лабиринта-3 — 23 (59 %) пациента, 2-я группа — после левопредсердного варианта лабиринта-3 — 16 (41 %) пациентов. На эндокардиальном этапе выполнены электрофизиологические исследования для уточнения механизма аритмии, аблация, устраняющая тахиаритмию по протоколу: ревизия легочных вен, определение изоляции задней стенки левого предсердия, оценка предсердной аритмии, устранение аритмии, контрольная индукция аритмии после аблации. После повторного вмешательства пациенты каждые 3 мес. наблюдались в оперирующей клинике.

Результаты. После эндокардиального этапа регулярный ритм определяется у 19 (82,6 %) пациентов 1-й группы, 13 (92,9 %) пациентов 2-й группы (p = 0,914). Рецидивы в виде фибрилляции предсердий — у 5 (4 (17,4 %) в 1-й группе и 1 (7,1 %) во 2-й группе) пациентов (p = 0,306). Все рецидивы тахиаритмии с нерегулярным циклом фибрилляции предсердий выявлены у пациентов с ФП перед эндоваскулярным этапом. В обеих группах выявлены случаи восстановления проведения в легочных венах — у 10 (43,5 %) пациентов после биатриальной аблации и 1 (5,3 %) пациента после левопредсердной аблации. Рецидивы предсердной аритмии после аблации трепетания предсердий (аритмии со стабильным циклом) отсутствовали.

Заключение. У пациентов, имеющих после применения обоих методов хирургической аблации фибрилляции предсердий тахикардии с регулярным циклом, эндокардиальный этап высокоэффективен и демонстрирует последующую свободу от предсердной аритмии. Рецидив тахиаритмии в виде фибрилляции предсердий (нерегулярный цикл) ассоциирован с низкой вероятностью удержания регулярного предсердного ритма после повторной эндокардиальной процедуры, что можно объяснить наличием структурных и электрофизиологических изменений в миокарде предсердий.

Ключевые слова: фибрилляция предсердий; трепетание предсердий; рецидив аритмии; хирургическая процедура лабиринт; катетерная аблация; хирургическая аблация.

Как цитировать

Постол А.С., Антипов Г.Н., Иванченко А.В., Ляшенко В.В., Калинин Д.А., Котов С.Н., Выговский А.Б., Шнейдер Ю.А. Анализ эндокардиального этапа лечения тахиаритмий после открытых вмешательств по поводу фибрилляции предсердий. Опыт одного центра // Cardiac Arrhythmias. 2023. Т. 3, № 3. С. 5–18. DOI: https://doi.org/10.17816/cardar529671

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INTRODUCTION

Although atrial fibrillation (AF) is not a life-threatening arrhythmia, the negative components of this atrial arrhythmia, namely, embolic complications, structural heart pathologies, and high all-cause mortality, can hardly be overestimated [1]. Current meta-analyses indicate that biatrial ablation promotes long-term freedom from recurrent AF and may be indicated in patients with long-term persistent AF [2–4]. In addition to restoring and maintaining a regular atrial rhythm, surgical ablation demonstrates to improve the psychological and physical components of the quality of life of patients compared with other methods for AF ablation [5]. Despite the nearly radical elimination of the main mechanisms supporting AF through open surgery using the classical maze III procedure, some patients are diagnosed with clinically significant relapses of rhythm disorders that require additional catheter procedures [4, 6–12]. The concept of a "hybrid approach to AF treatment", which emerged in the last decade, implies the possibility of performing the next endocardial stage (or stages) following surgical interventions to eliminate AF or implant devices for rhythm control [13–16]. During the endocardial stage, arrhythmia can be verified, and the presence of scar fields in the atrial structure and parameters of low-amplitude segments can be determined [17]. These zones have significantly different myocardial structures, extent, and localization and contribute to the probability of maintaining a regular atrial rhythm, and restoring the systolic contribution of the atria to myocardial kinetics. Accordingly, this paper presents an analysis of long-term results based on the maintenance of regular atrial rhythm after two methods of the surgical correction of AF, and an assessment of the efficiency of the subsequent endocardial ablation stage.

This study aimed to analyze the incidence of relapses and results of the treatment of atrial arrhythmias in patients who underwent various types of surgical ablation of AF during combined cardiac interventions.

MATERIALS AND METHODS OF RESEARCH

The study enrolled patients who underwent surgery at the Federal Center for High Medical Technologies (FCHMT) in Kaliningrad between January 2013 and December 2021. A total of 447 combined interventions were performed to eliminate AF using maze III (217) and left atrial (LA) maze (230) methods and correct other cardiac pathologies, such as acquired heart disease (AHD) and/or ischemic heart disease (IHD).

The indications for surgical and endocardial intervention include the presence of AF or its relapse (if referred to the endocardial stage) > 3 months after surgery, concomitant cardiac pathology such as AHD or lesions of the coronary arteries in IHD, relapses of various atrial tachyarrhythmias, and ineffectiveness of antiarrhythmic therapy based on Heart Rhythm Society/European Heart Rhythm Association/ European Cardiac Arrhythmia Society guidelines [1].

Initially, when referred for surgical and subsequently endocardial correction of tachyarrhythmias, all patients had comparable demographic and clinical characteristics (Table 1).

This retrospective, uncontrolled study with an interrupted time series of two groups depending on the surgical treatment option for AF was assessed and approved by the members of the ethics committee of the FCHMT (Protocol No. 4 of 11/01/2021).

In 57 (12.7%) patients, tachyarrhythmias relapsed at various times after surgery. Only the following patients were enrolled for the endocardial ablation stage:

1) Patients with maintained regular atrial rhythm after the surgical correction of AF and subsequently diagnosed with relapse of atrial tachyarrhythmia at the outpatient follow-up.

2) Patients without persistent sinus rhythm after the surgical correction of AF despite therapy aimed at restoring and maintaining the rhythm (twice electrical cardioversion [ECV], correction of antiarrhythmic therapy, and electrolyte and metabolic disorders). Such patients were referred to the endocardial ablation stage > 3 months after the surgical correction of AF.

Of the 57 patients, 39 (68.4%) received repeated interventions, or 8.7% of the combined open interventions were performed. The average follow-up period after the endocardial stage of treatment was 34.37 (standard deviation, 24.32) months. The median age of the patients was 64 (58–67) years. The study enrolled 21 (54%) men and 17 (46%) women. The patients were distributed into two groups: group 1 underwent the classic biatrial (BA) maze III surgery (n = 23, 59%), and group 2 underwent the LA version of maze III (n = 16, 41%).

During the follow-up period, every 3 months after re-intervention, electrocardiographic (ECG) rhythm recording, Holter ECG monitoring, echocardiography (EchoCG), and programming of the pacemaker with analysis of atrial electrograms were performed. The presence of implanted pacemakers was considered a positive factor for detailed verification of the atrial rhythm. The study aimed to assess electrophysiological heart test (EPT) parameters and the characteristics of recurrent atrial tachyarrhythmias in patients who had a history of surgical correction of AF and who were heterogeneous according to the primary selection criteria. Relapses of atrial arrhythmias were differentiated by the presence of regular and irregular cycles, endocardial

Table 1. Clinical characteristics of patients who underwent surgery
Таблица 1. Клиническая характеристика пациентов, перенесших хирургическое вмешательство

Parameters	Group 1 (*n* = 23)	Group 2 (*n* = 16)	*p*
Age, years, *Me*	63 (45–70)	63 (43–73)	0.810
Sex, F/M	9/14 (39/61)	12/4 (75/25)	0.027
Duration of AF before surgery, months (*Me*)	60 (6–240)	48 (6–156)	0.746
AF type:			
Paroxysmal, *n* (%)	2 (8.7)	1 (6.2)	0.779
Persistent, *n* (%)	21 (91.3)	15 (93.8)	0.779
LA volume before the surgical stage, mm^3 (*Me*)	121.2 (80–180)	148.7 (100–350)	0.935
LA volume before the endovascular stage, mm^3 (*Me*)	118.1 (70–138)	111.5 (75–124)	0.140
CABG, *n* (%)	11 (47.8)	8 (50.0)	0.322
Mitral and tricuspid valve repair, *n* (%)	3 (13.0)	2 (12.5)	0.240
MV prosthesis, *n* (%)	5 (8.7)	3 (18.7)	0.064
Mitral valve repair, *n* (%)	9 (39.1)	8 (50.0)	0.401
AV prosthesis, *n* (%)	4 (17.4)	2 (12.5)	0.275
De-Vega repair of the TV, *n* (%)	10 (43.3)	9 (56.3)	0.799
LVEF% (%) before the surgical stage (initial)	47.1 (22.0–61.0)	48.2 (30.0–60.0)	0.143
LVEF% (%) before the endocardial stage,	51 (38.0–60.0)	53 (40–62)	0.411
CHD, *n* (%)	3 (13.0)	1 (16.0)	0.410
AHD, *n* (%)	13 (56.5)	8 (50.0)	0.420
Beta blocker therapy, *n* (%)	10 (50.0)	7 (43.7)	0.398
Diuretic therapy, *n* (%)	4 (17.4)	3 (18.7)	0.440
Anticoagulant therapy, *n* (%)	19 (82.7)	12 (75.0)	0.414

Note: AF — atrial fibrillation; AHD — acquired heart defect; AV — aortic valve; BA — biatrial maze; CABG — coronary artery bypass grafting; CHD — congenital heart defect; EF — ejection fraction; LA — left atrial maze; LA — left atrium; MV — mitral valve; TV — tricuspid valve.

Примечание: ФП — фибрилляция предсердий; ФВ — фракция выброса; ЛП — левое предсердие; АКШ — аортокоронарное шунтирование; МК — митральный клапан; ТК — трикуспидальный клапан; АК — аортальный клапан; БА — биатриальный лабиринт; ЛП — левопредсердный лабиринт; ВПС — врожденный порок сердца; ППС — приобретенный порок сердца.

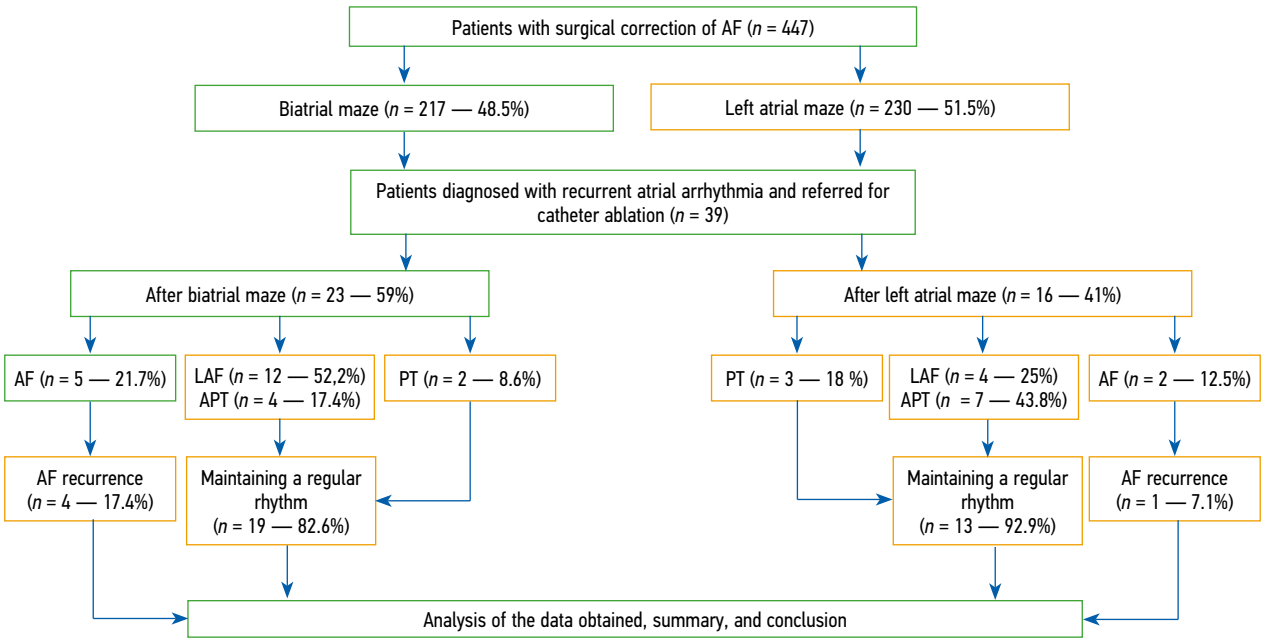

Fig. 1. Design diagram of the completed study
Рис. 1. Дизайн-схема выполненного исследования. ФП — фибрилляция предсердий; РЧА — радиочастотная аблация; ПТ — пароксизмальная тахикардия; ППТ — предсердная пароксизмальная тахикардия

correction of tachyarrhythmias was performed, and rhythm maintenance was assessed.

Statistical processing

The results were statistically analyzed using IBM Statistics for Windows version 21.0 (IBM Corp., Armonk, NY, USA). Normally distributed indicators are presented as the average value for the sample and its standard deviation ($\overline{X} \pm sd$), whereas non-normally distributed indicators are presented as medians and interquartile ranges, *Me* (min–max). When scores were normally distributed, paired Student's *t*-tests for related and unrelated samples were used to test the null hypothesis. When the distribution differs from the normal, the χ^2 (Chi-square) test was used to assess the statistically significant difference between nominative indicators. To assess the quantitative indicators of two unrelated samples, the Mann — Whitney *U*-test was used.

Subgroup characteristics for continuous measures are presented as mean ± standard deviation. For qualitative indicators, numerical data and percentages are given. Differences in indicators between groups were defined as statistically significant at $p < 0.05$.

Endovascular intervention

Catheter intervention was performed using the Carto (Biosense Webster, USA) and Ensite (Abbott, USA) navigation systems. The diagnostic electrodes used were the 10-pole electrode for coronary sinus catheterization (Biosense Webster) and the 10-pole Lasso electrode (Biosense Webster). For mapping and ablation, the ablation-mapping irrigated SmartTouch (Biosense Webster) and CoolFlex (Abbott) were used. The ablation parameters were 30–45 W and exposure duration of 30–60 s. The irrigation rates were 17–28 and 25–35 mL/min for CoolFlex and SmartTouch, respectively.

After the catheterization of the coronary sinus, to assess the type of atrial arrhythmia, regularity of the tachyarrhythmia cycle, its duration, and spread of the arrhythmia activation front were assessed. Then, the presence of conduction in the pulmonary veins (PVs), consistency of the isolation of the LA posterior wall, and the intensity and number of low-amplitude zones in the atria were assessed. An amplitude of the recorded signal of ⩽0.2 mV from the electrode along the coronary sinus was considered low. When an arrhythmia with a regular cycle of atrial flutter was detected, differential diagnostics of the flutter substrate cavity (right atrial or LA flutter) was performed. The type of flutter was clarified according to the criteria of analyzing the activation front and determining the involvement of the treatment electrode location relative to the arrhythmia cycle. If LA flutter was detected, subsequent EPT and ablation techniques were similar to that for AF. The interatrial septum was punctured twice using Preface Multipurpose introducers (Cordis, USA) under X-ray control. Then, three-dimensional endocardial reconstruction of the left or right atrium, amplitude mapping to identify scar areas in the left and right atria (Fig. 2), and activation mapping with a window of interest 10–20 ms shorter than the tachycardia cycle was performed. In the case of atrial flutter, ablation was performed along the identified critical conduction zones with the creation and mandatory monitoring of the presence of a bidirectional conduction block (at least 140 ms). The criteria for the formation of a conduction block during atrial flutter include an episode of the formation of "double" spikes and a sharp prolongation of signal transmission according to the endogram data on the treatment electrode.

In the presence of conduction breakthroughs in the PVs or posterior wall of the left atrium, radiofrequency (RF) re-isolation was performed to monitor the absence of conduction (monitoring during high-frequency [HF] influences and again at the end of the procedure for tachyarrhythmias and after ECV).

The ablation scheme for persistent tachyarrhythmia with an irregular cycle included a mandatory anteroseptal line from the mitral valve to the superior right PV, at the base of the ligated or resected LA appendage and along the coronary sinus, and the interatrial septum on the right and left. An intercaval line and isolation of the superior vena cava were performed if a right atrial role in maintaining rhythm disorders was assumed and right atrial arrhythmia with a regular cycle was excluded (with the analysis of the arrhythmia cycle, its duration, and propagation of the arrhythmia activation front). When the AF transitioned to atrial flutter or atrial extrasystole, ablation was performed according to the criteria of the newly recorded arrhythmia (cycle regularity and duration and analysis of the activation front based on recordings from the coronary sinus) and ablation of areas critical for tachycardia after the clarification of the specified parameters. For focal atrial tachycardias, mapping was performed according to the protocol for

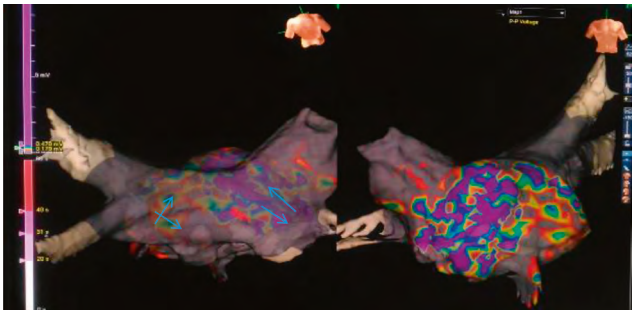

Fig. 2. Typical amplitude map of a patient after labyrinth-3 surgery. The arrows indicate zones of absence of electrical activity in all pulmonary veins and the posterior wall of the left atrium
Рис. 2. Типичная амплитудная карта пациента после операции лабиринт-3. Стрелками указаны зоны отсутствия электрической активности всех легочных вен и задней стенки левого предсердия

Table 2. Type of tachyarrhythmia according to electrophysiological studies
Таблица 2. Вид тахиаритмии по данным электрофизиологического исследования

Parameters	Group 1 (*n* = 23)	Group 2 (*n* = 16)	*p*
AF	5 (21.7)	2 (12.5)	0.460
Left atrial AFl	12 (52.2)	4 (25)	0.090
Right atrial AFl	4 (17.4)	7 (43.8)	0.072
AT	2 (8.6)	3 (18.7)	0.356

Note: AF — atrial fibrillation; AFl — atrial fluttering; AT — atrial tachycardia; BA — biatrial; LA — left atrial.

Примечание: БА — биатриальный; ЛП — левопредсердный; ФП — фибрилляция предсердий; ТП — трепетание предсердий; ПТ — предсердная тахикардия.

searching for the earliest activation area from the reference electrode. The criteria for atrial tachycardia included tachycardia incidence different from flutter, presence of an unstable cycle (warming up and cooling down of tachycardia), impossibility of constructing an activation map owing to the absence of a macro re-entry tachycardia mechanism, and eliminating tachycardia by determining the earliest activation zone from the treatment electrode. If AF persisted and/or the tachyarrhythmia cycle was not organized, ECV was performed after all interventions, with mandatory restoration of sinus rhythm in each patient. After eliminating atrial tachyarrhythmia, in each patient, the consistency of HF influences was also tested. The presence or absence of a conduction block was analyzed by recording signals from the treatment and Lasso electrodes. The absence of spike activity in the electrodes was regarded as the blockade of arrhythmic activity. The consistency of the lines was assessed by the achievement of a bidirectional conduction block (at least 140 ms).

After the analysis of the consistency of the effects through frequent stimulations using a therapeutic electrode and an electrode installed in the coronary sinus, arrhythmia was induced. The stimulation parameters were selected based on the tachyarrhythmia data of each patient, with atrial flutter and stimulation with a tachycardia cycle duration of 10–20–30 ms less than the initial arrhythmia cycle. Frequent and ultra-frequent stimulations (stimulation cycle duration sequentially 300–250–200 ms) were also performed to induce AF. The procedure was completed if, despite the "active" induction of arrhythmia, a regular atrial rhythm was maintained.

RESULTS

Tachyarrhythmia recurrence parameters after two methods of surgical treatment of AF

To determine the recurrence parameters of atrial arrhythmias, the indicators of significant differences in clinical and demographic criteria between groups were analyzed. In the two groups, 9 (39%) and 12 (75%) female patients with recurrent atrial arrhythmias underwent surgery. No sex differences were found among patients who underwent various types of surgical ablation of AF during combined cardiac interventions.

According to the endogram recordings from the coronary sinus, no significant differences in the type of atrial tachyarrhythmias were detected between the two groups. LA flutter was diagnosed in 12 (52.2%) and 4 (25%) patients, right atrial fluttering in 4 (17.5%) and 7 (43.8%) patients, AF in 5 (21.7%) and 2 (12.5%) patients, and atrial tachycardias in 2 (8.6%) and 3 (18.7%) patients, in groups 1 and 2 respectively (Table 2).

The lack of isolation of the LA posterior wall was detected in 6 (26%) patients of group 1 and 4 (25%) of group 2 (p = 0.875). The shortcoming in both groups was the roof at the confluence of the superior left PV; basically, the re-isolation of the posterior wall of the PVs was achieved there. PV re-isolation was also often achieved by performing additional ablations along the posterior wall of the right PVs (Figs. 3 and 4).

Recanalization of conduction in the PVs was identified in 10 (43.5%) patients in group 1 and 1 (5.3%) patient in group 2. In all cases, only segmental ablation was required to eliminate conduction breakthroughs in the PVs. An anterior septal line was made in 8 (34.8%) patients in group 1 and 4 (25%) patients in group 2 (ablation was performed until a bidirectional conduction block of at least 140 ms was achieved; p = 0.400), as well as in the mitral isthmus in 4 (17.4%) patients in group 1 and 4 patients (25.0%) in group 2 (p = 0.563). During resection and successful ligation of the LA appendage in patients with AF, anteroseptal and mitral lines were performed in some cases, excluding the base of the appendage stump, because pronounced rhythmic activity was recorded there. However, after linear influences, no arrhythmia or restoration of sinus rhythm was organized. In these patients, extrapulmonary foci played the leading role in maintaining arrhythmia against progressive cardiosclerosis in both atria and interatrial septum. In the cavotricuspid

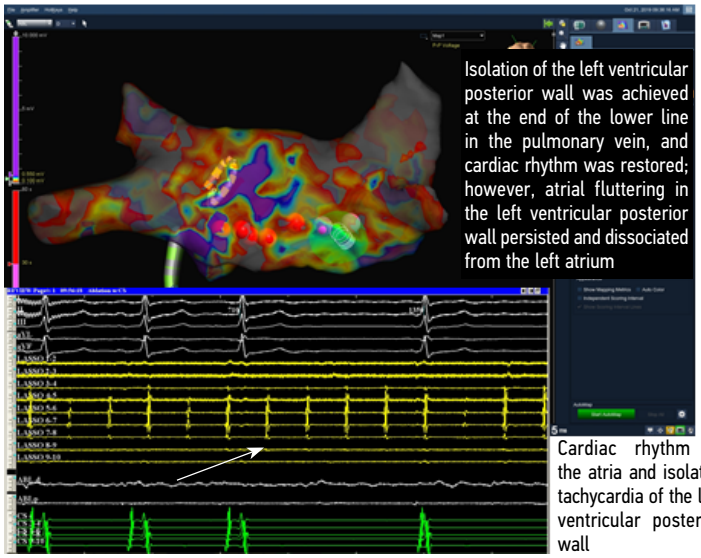

Fig. 3. Amplitude map and recording of the electrocardiogram and endograms of the patient after the labyrinth-3 operation. *Top–down*: amplitude map of the patient, standard electrocardiogram leads, and signals from the multipole circular electrode (yellow) on the posterior wall of the left atrium, where the arrows indicate the activity from the anastomosis on the left, signals from the ablation electrode (white), and signals from the multipole electrode in the coronary sinus (green). Isolation of the posterior wall was achieved, the dissociation of arrhythmic activity corresponded to data from the Lasso catheter, and flutter persists, and sinus rhythm exists along the electrode from the coronary sinus (also the arrowhead is the lower horizontal arrow on the recording from the coronary sinus). The EPT system "Claris" (Abbott, USA) was used. The recording speed was 200 mm/s

Рис. 3. Амплитудная карта и запись электрокардиограммы и эндограмм пациента после операции лабиринт-3. *Сверху вниз*: амплитудная карта пациента, стандартные отведения ЭКГ, сигналы с многополюсного циркулярного электрода (желтые) на задней стенке левого предсердия — стрелками указана активность с соустья слева, сигналы с аблационного электрода (белые), сигналы с многополюсного электрода в коронарном синусе (зеленые). Изоляция задней стенки достигнута, диссоциация аритмической активности — по данным с катетера «Lasso», сохраняется трепетание, при этом по электроду из коронарного синуса — синусовый ритм (также стрелка-указатель — нижняя горизонтальная стрелка на записи с коронарного синуса). ЭФИ-система «Claris» (Abbot, США). Скорость записи 200 мм/с

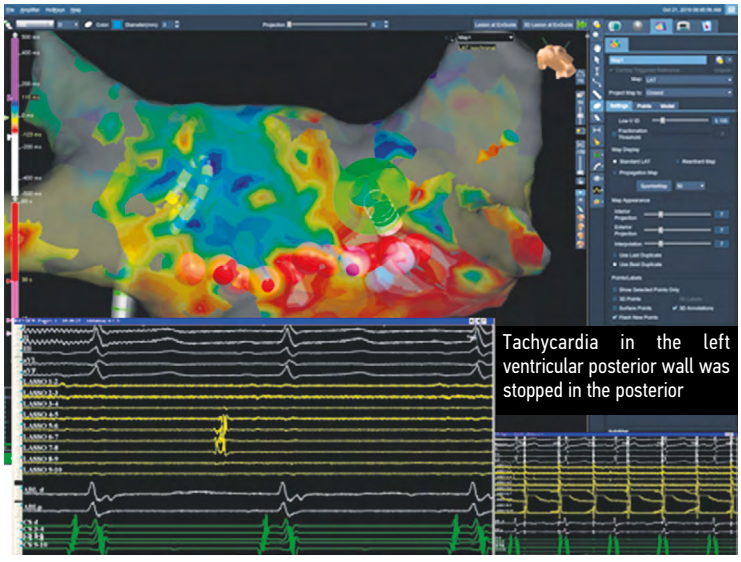

Fig. 4. Relief of tachycardia in the posterior anastomosis on the right. *Top–down*: amplitude map of the patient, standard leads of the electrocardiogram, and signals from the multipole circular electrode (yellow) on the posterior wall of the left atrium. The arrows indicate the absence of activity from the anastomosis on the right, where the treatment electrode is located. White, signals from the ablation electrode; green, signals from the multipole electrode in the coronary sinus. The Claris EPT system (Abbott, USA) was used. The recording speed was 200 mm/s

Рис. 4. Купирование тахикардии в заднем соустье справа. *Сверху вниз*: амплитудная карта пациента, стандартные отведения электрокардиограммы, сигналы с многополюсного циркулярного электрода (желтые) на задней стенке левого предсердия стрелками указано отсутствие активности с соустья справа, там, где располагается лечебный электрод, сигналы с аблационного электрода (белые), сигналы с многополюсного электрода в коронарном синусе (зеленые). ЭФИ-система Claris (Abbot, США). Скорость записи 200 мм/с

region, ablation was needed in 4 patients (17.4%) in group 1 and 7 patients (43.8%) in group 2 (p = 0.091). The intercaval line was made in 2 patients (9.1%) only in the maze III group in cases of "silent" left atrium. Against cicatricial changes when relieving the main rhythm disorder during the ablation procedure, the tachycardia cycle often transformed. This happened in 8 patients (36.4%) and 3 patients (18.8%) of both groups, respectively (p = 0.203). Atrial extrasystoles often occurred after relief, requiring additional interventions. The restoration of sinus rhythm upon the closure of the ablation line was recorded in 15 patients (71.4%) of group 1 and 14 patients (87.5%) of group 2 (p = 0.117; Fig. 5).

Table 3 presents the interventions performed and the arrhythmia parameters. In all patients, after the arrest

Table 3. Performed interventions and arrhythmia parameters
Таблица 3. Выполненные воздействия и параметры аритмий

Parameter	BA group (n = 23)	LA group (n = 16)	p
LA posterior wall isolation, n (%)	6 (26)	4 (25)	0.940
LA roof, n (%)	2 (8.7)	2 (12.5)	0.701
MI, n (%)	4 (17.4)	4 (25)	0.563
CTI, n (%)	4 (17.4)	7 (43.8)	0.091
Breakthrough in the PV, n (%)	10 (43.5)	1 (5.3)	0.02
Anteroseptal line, n (%)	8 (34.8)	4 (25)	0.515
Isolation of the superior vena cava, n (%)	1 (4.3)	1 (6.25)	0.792
ECV relief, n (%)	4 (30.8)	3 (21.4)	0.914
RFA relief, n (%)	15 (71.4)	14 (87.5)	0.117
Low-amplitude EG, n (%)	12 (52.2)	9 (56.3)	0.802
Cycle switching, n (%)	8 (36.4)	3 (18.8)	0.274
Low-signal amplitude based on the recording from the coronary sinus, n (%)	13 (59)	9 (56)	0.228

Note: CTI — cavatricuspid isthmus; ECV — electrical cardioversion; EG — electrogram; LA — left atrium; MI — mitral isthmus; PV — pulmonary veins; RFA — radiofrequency ablation.

Примечание: ЛП — левое предсердие; МИ — митральный истмус; КТИ — каватрикуспидальный истмус; ЛВ — легочные вены; ЭИТ — электроимпульсная терапия; РЧА — радиочастотная аблация; ЭГ — электрограмма.

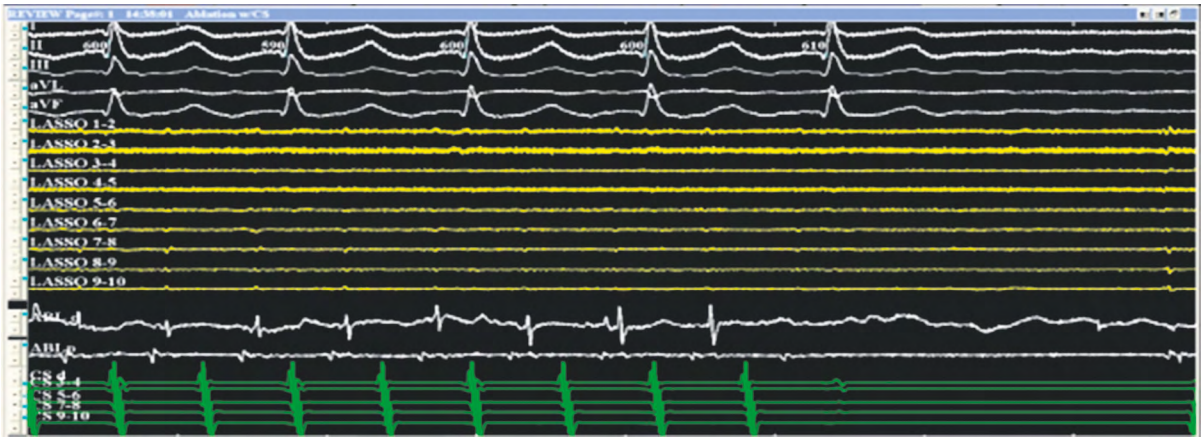

Fig. 5. Fragment of the operation of radiofrequency ablation of septal atrial flutter after the labyrinth-3 operation, arrest of arrhythmia and restoration of sinus rhythm during ablation. *Top–down:* standard electrocardiogram leads, signals from a multipole circular electrode (yellow) on the left atrial posterior wall, signals from an ablation electrode (white), and signals from a multipole electrode in the coronary sinus (green). The EPT system "Claris" (Abbott, USA) was used. The recording speed was 200 mm/s

Рис. 5. Фрагмент операции радиочастотной аблации септального трепетания предсердий после операции лабиринт-3, купирование аритмии и восстановление синусового ритма во время аблации. *Сверху вниз*: стандартные отведения ЭКГ, сигналы с многополюсного циркулярного электрода (желтые) на задней стенке левого предсердия, сигналы с аблационного электрода (белые), сигналы с многополюсного электрода в коронарном синусе (зеленые). ЭФИ система «Claris» (Abbot, США). Скорость записи 200 мм/с

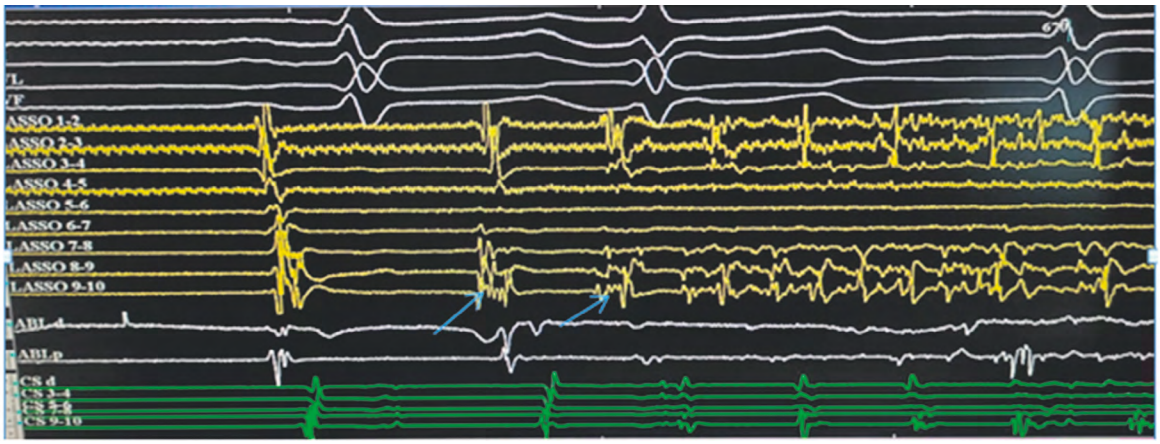

Fig. 6. Re-induction of atrial fibrillation after cardioversion. The arrows indicate the onset of atrial fibrillation through several sinus complexes immediately after cardioversion. *Top–down:* standard electrocardiogram leads, signals from a multipole circular catheter "Lasso" located in the superior vena cava (yellow endograms) which starts from a single ectopy (the earliest signal during the start of an arrhythmia) and transforms into arrhythmic fibrillatory activity (also indicated by an arrow), signals from the ablation electrode (white), and signals from the multipole electrode in the coronary sinus (green). The EPT system "Claris" (Abbott) was used. The recording speed was 200 mm/s

Рис. 6. Повторная индукция фибрилляции предсердий после кардиоверсии. Стрелками указан старт фибрилляции предсердий через несколько синусовых комплексов сразу после проведения кардиоверсии. *Сверху вниз*: стандартные отведения электрокардиограммы, сигналы с многополюсного циркулярного катетера «Lasso» расположенном в верхней полой вене (желтые эндограммы) — запуск с одиночной эктопии (самый ранний сигнал во время запуска аритмии) и трансформация в неритмичную фибрилляторную активность (также указание стрелкой), сигналы с аблационного электрода (белые), сигналы с многополюсного электрода в коронарном синусе (зеленые). ЭФИ-система «Claris» (Abbot). Скорость записи 200 мм/с

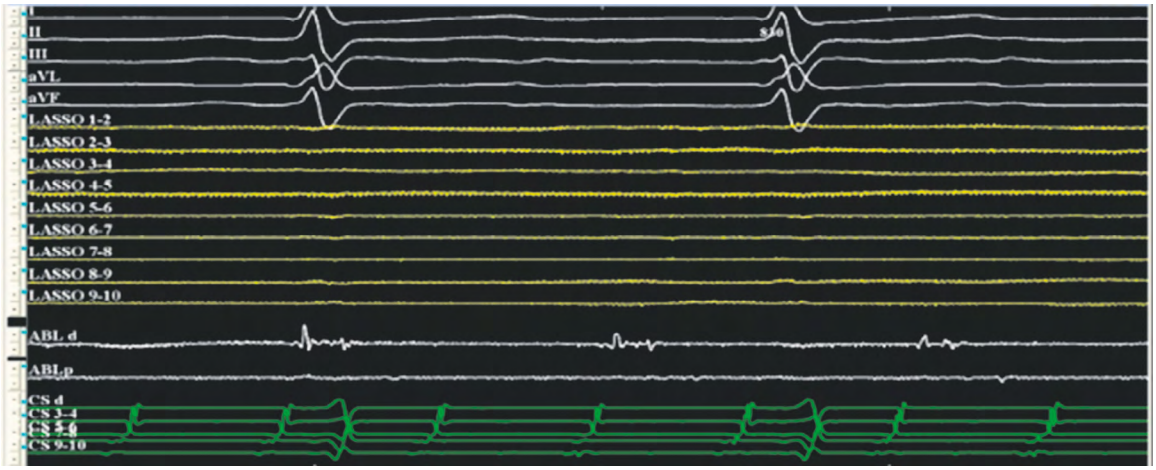

Fig. 7. Atrial flutter in a patient after labyrinth-3 surgery. *Top–down*: standard electrocardiogram leads, signals from a multipole circular electrode on the left atrial posterior wall (yellow), signals from the ablation electrode (white), ablation electrode located on a partially isolated site of the atrial myocardium, and signals from the multipole electrode in the coronary sinus (green). The EPT system "Claris" (Abbott, USA) was used. The recording speed was 200 mm/s

Рис. 7. Трепетание предсердий у пациента после операции лабиринт-3. Стрелками указаны низкоамплитудные фрагментированные сигналы. *Сверху вниз*: стандартные отведения электрокардиограммы, сигналы с многополюсного циркулярного электрода на задней стенке левого предсердия (желтые), сигналы с аблационного электрода (белые). Аблационный электрод расположен на частично изолированном участке миокарда предсердий, сигналы с многополюсного электрода в коронарном синусе (зеленые). ЭФИ-система «Claris» (Abbot, США). Скорость записи 200 мм/с

of arrhythmias during the ablation procedure, repeated inductions did not provoke the appearance of arrhythmias with previously diagnosed parameters in all cases (100%). The consistency of the lines must be monitored on stimulation from the treatment electrode. If not divided into groups, 3 (1–8) linear influences were performed on average on each patient. AF persisted despite all the effects, and ECV was required in 4 (30.8%) patients in group 1 and 3 (21.4%) in group 2 (p = 0.914). Repeated ECVs were performed in three patients because of AF onset (Fig. 6). The amplitude of the signal from the electrode along the coronary sinus was low, i.e., < 0.2 mV, and was detected in 13 patients (59%) in group 1 and 9 (56%) in group 2 (Fig. 7). Such signal amplitude parameters

were attributed to atrial cardiosclerosis and structural remodeling. During this study, the low-amplitude zones in each case were not determined; perhaps this will be conducted in subsequent studies.

Electrophysiological aspects during the electrophysiological study after two options for the surgical treatment of AF

Owing to the presence of massive cicatricial changes in the atria, interventions resulting in the occurrence of cicatricial changes along the coronary sinus, and the absence of the LA appendage, difficulties are noteworthy in choosing a stable reference channel for activation mapping. After constructing an activation map, the simultaneous presence of several "early-late" fields is often diagnosed due to the presence of consistent lines (surgical cut-and-sew correction of arrhythmia). Owing to massive scar changes in the atria and the interventions performed, stimulation was difficult even at 20 mA with a pulse duration of 4 ms. The EPT aspects presented the need for additional control of the treatment electrode location relative to the arrhythmia cycle, and the procedure duration was increased. Ablation after maze III is characterized by the presence of extensive fibrous fields with slow electrophysiological activity up to LA asystole in comparison with the preserved fibrillatory activity in the right atrium and interatrial septum. The classic maze III procedure prevents right atrial arrhythmias in the postoperative period. Such a pattern was not found when we performed ablation after an isolated LA maze.

Patient follow-up after the endocardial stage

The average follow-up period after the endocardial stage of treatment was 34.37 (standard deviation, 24.32) months. A regular atrial rhythm was maintained in 19 (82.6%) and 13 (92.9%) patients in groups 1 and 2, respectively (p = 0.914). AF relapses occurred in 4 (17.4%) patients in group 1 and 1 (7.1%) in group 2.

All cases of AF relapse were recorded in patients with arrhythmias previously diagnosed at the endocardial stage in the form of AF and atrial tachycardia. After RF ablation of atrial flutter, no relapses of atrial arrhythmia were recorded during follow-up.

In this study, determining the clinical indicators that predict recurrent AF after two-staged correction of AF was impossible. This may be related to the following:

1) Absence of difference in the technique of the surgical correction of AF. Both groups underwent surgery using the LA cut-and-sew technique, and the BA group also underwent right atrial correction. The technique of the LA procedure was not different between the groups.

2) Small sample size. We hope that future studies will provide additional information on this issue.

However, the AF duration before stage 1 of AF correction (p = 0.074) and the method of the surgical correction of AF (p = 0.054) had comparable significance values (p = 0.074). Thus, increasing the sample size in subsequent studies may have positively affected changes in the indicators of the significance criterion.

DISCUSSION

Currently, the maze III procedure is considered a highly effective method of treating AF during combined cardiac interventions [6, 12, 13]. Despite the high efficiency of the BA procedure, no clear opinion is presented in the literature about the need for the fragmentation of the right atrium. Evidence shows that the simplified LA scheme of the maze III procedure is associated with postoperative tachyarrhythmias such as atrial fluttering in 8%–10% of cases [3]. In this study, a highly effective endocardial termination of macro re-entry tachycardias such as atrial fluttering was performed when the ablation line was closed in all cases. No recurrences of arrhythmias were recorded after the ablation of atrial flutter intraoperatively during arrhythmia induction and after 34.37 (standard deviation 24.32) months of follow-up.

Despite the use of the highly effective maze III technique, which virtually eliminates the risk of recurrent arrhythmias, in this study, both groups showed signs of recurrent AF and reconnection of conduction in the PVs. Among the published studies, some studies have confirmed the restoration of conduction in the veins after performing various modifications of maze III procedure [18–20]. In our opinion, the finding of the reconnection in the veins can be due to the following:

1. The actual use of the maze III technique with additional lines toward the fibrous ring of the tricuspid valve and mitral valve using the AtriCure cryoICE cryoablator (AtriCure, USA), which may cause the local recanalization of the conduction.

2. Many years of surgical skills gained in the surgical treatment of AF. When analyzing the timing of surgeries, patients who underwent the two-atrial "classical" maze technique with recurrences of conduction in the PVs had undergone surgery at the beginning of the FCHMT activities, which was at the stage of mastering the technique. Moreover, the LA maze modification was attributed to the implementation of experience and continuation of work for many years. We assumed that the transmurality of all effects (cut-and-sew and cryoablation lines) turned out to be more achievable with surgeons' acquisition of practical skills. Moreover, the endocardial re-isolation was segmental and easily achievable in all cases.

The study showed no differences in subsequent tachyarrhythmias depending on the method used for the surgical correction of AF during combined cardiac interventions. We believe that the high effectiveness of endocardial ablation of recurrent atrial arrhythmias demonstrated in this study (82.6% and 92.9% in groups 1 and 2, respectively) was associated with the presence of tachyarrhythmias with a regular tachycardia cycle, atrial fluttering, and atrial tachycardia in patients referred for ablation (32 of 39).

Thus, the lack of differences in the outcomes of surgical treatment between the groups may be due to the following factors:

1. Relatively small sample size. Our preliminary results should be confirmed by studies with larger sample sizes to describe better the negative effect of long persistent arrhythmia on rhythm maintenance after two-stage AF correction.

2. Important criteria for differences in groups were not considered, such as the degree of deformity and three-dimensional changes in atrial contractility based on the progressive speckle-tracking method of the ultrasound visualization of cardiac cavities. Although this new technique was introduced exclusively for the analysis of left ventricular function, several studies have recently expanded its application to other cardiac chambers, such as the left atrium [22]. Our subsequent work on assessing the maintenance of a regular atrial rhythm after two-stage AF correction will focus on the study of these parameters.

Based on the results of the analysis of factors that influence atrial rhythm after maze surgeries, the severity of structural and electrophysiological pathologies of the atria is the main cause of the recurrence of tachyarrhythmias despite the two-staged correction of long-term AF. In our opinion, the presence of AF after the maze procedure indicates significant electrophysiological changes in the structure of the atria, and is the main criterion for the impossibility of maintaining a regular atrial rhythm.

CONCLUSION

The results of a study conducted at the FCHMT demonstrate the high effectiveness of the hybrid approach in the treatment of AF. Stage 1 involved the surgical correction of AF and other cardiac interventions. Stage 2 included endocardial ablation of recurrent tachyarrhythmias. Options for surgical correction of AF were BA maze or only LA correction, which did not demonstrate significant differences in the incidence and type of recurrence of atrial tachyarrhythmias. The occurrence of AF after both types of maze surgery reduces the probability of the restoration and maintenance of sinus rhythm with repeated catheter procedures. Tachyarrhythmias with a regular arrhythmia cycle, namely, atrial flutter and atrial tachycardia, are prognostically favorable atrial arrhythmias for the restoration and long-term maintenance of a regular atrial rhythm.

ADDITIONAL INFORMATION

Authors' contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study. The contribution of each author: A.S. Postol — research concept and design, data collection and processing, text writing and editing, integration of all article parts; G.N. Antipov, V.V. Lyashenko — data collection, discussion of data obtained, text editing, statistical data analysis; A.V. Ivanchenko — data collection, concept of research parameters, data analysis; D.A. Kalinin — data collection, text and tables editing; S.N. Kotov, A.B. Vygovsky — statistical data analysis; Yu.A. Shneider — editing, approval of the final version of the article.

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Competing interests. The authors declare that they have no competing interests.

Consent for publication. Written consent was obtained from the patient's parents for publication of relevant medical information and all of accompanying images within the manuscript.

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Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

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