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LONG-TERM OUTCOMES OF THORACOSCOPIC ABLATION FOR ATRIAL FIBRILLATION

E.D.Strebkova[1,2], A.Sh.Revishvili[1,2], E.S.Malishenko[2], E.A.Artyukhina[1,2], V.A.Popov[1,2], M.A.Novikov[2], E.V.Yalova[2], K.E.Bondurko[2], G.G.Karmazanovsky[2], M.Kadirova[2]

[1]Federal State Budgetary Educational Institution of Further Professional Education "Russian Medical Academy of Continuous Professional Education" of the Ministry of Healthcare of the Russian Federation, Moscow, 2/1 Barrikadnaya str, build. 1; [2]Federal State Budgetary Educational Institution "A.V. Vishnevskiy National Medical Research Center of Surgery" of the Ministry of Healthcare of the Russian Federation, Moscow, 27 Bolshaya Serpukhovskaya str.

The **aim** of this work is to analyze the effectiveness of thoracoscopic ablation (TSA) of atrial fibrillation (AF) and to define the risk factors for the return of atrial tachyarrhythmias after TSA in the long-term follow-up period.

Methods. From January 2019 to December 2021, 150 patients with symptomatic atrial fibrillation (persistent 29.3% (n=44), long-standing 32% (n=48) and paroxysmal 38.7% (n=58) after unsuccessful catheter ablations underwent TSA and amputation of the left atria appendage. All patients underwent Holter monitoring at the control points of the study, the results of which evaluated the effectiveness of the procedure.

Results. The overall efficiency of TSA in the long-term follow-up period was 72.5%. After off-antiarrhythmic drugs, freedom from any atrial tachyarrhythmias was 79.2%, 70.5% and 68.9% after 6, 12 and 24 months, respectively. Additional catheter ablations after 3 months increase the effectiveness of the procedure to 82.9%. Important risk factors for the return of arrhythmia after TSA should be considered the patient's age, duration of AF, previous catheter ablations and the left atria diameter of more 40 mm.

Conclusion. The hybrid approach significantly improves the effectiveness of TSA for patients with non-paroxysmal forms of AF. The results obtained require further study of this problem in order to improve the quality of TSA and determine the optimal set of ablation lines, considering the risk factors for the return of arrhythmia.

Key words: atrial fibrillation; toracoscopic ablaton; risk factors; catheter ablation; atrial fibrillation recurrence

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Corresponding author: Strebkova Elizabeth, E-mail: elizabeth.strebkova@yandex.ru

E.D.Strebkova - ORCID ID 0000-0001-5837-7255, A.Sh.Revishvili - ORCID ID 0000-0003-1791-9163, E.S.Malishenko - ORCID ID 0000-0002-1572-3178, E.A.Artyukhina - ORCID ID 0000-0001-7065-0250, V.A.Popov - ORCID ID 0000-0003-1395-2951, M.A.Novikov - ORCID ID 0000-0001-9160-6531, E.V.Yalova - ORCID ID 0000-0002-9409-5164, K.E.Bondurko - ORCID ID 0000-0003-3495-6898, G.G.Karmazanovsky - ORCID ID 0000-0002-9357-0998, M.Kadirova - ORCID ID 0000-0001-8231-6866

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The prevalence of atrial fibrillation (AF) in the adult population is 2-4% [1]. Due to rapid demographic aging over the next thirty years, the number of patients with AF may double [2, 3]. The main risks associated with AF are due to thromboembolic complications, and in some cases are accompanied by arrhythmogenic collapse [4, 5].

For a long time, surgical treatment was the only highly effective method of AF treatment [6, 7]. In modern arrhythmology, Cox-Maze IV surgery and its modifications are considered exclusively as a simultaneous procedure.

Minimally invasive catheter ablation (CA) has replaced highly traumatic surgeries [4], the main stage of which is the pulmonary vein isolation (PVi), but it is not always effective, in persistent forms of AF [8-10]. Electroanatomical mapping data in patients with nonparoxysmal forms of AF usually demonstrate areas of marked low-amplitude activity in the left atrium, indicating the development of fibrosis in these areas [11]. In such cases, the long-term success rate of catheter ablations is 20-60%, decreasing with each subsequent procedure [11-14]. The cause of cicatricial changes in patients with paroxysmal AF is most often caused by multiple previous CAs, which significantly worsens the effectiveness of the latter [15]. R.S.Oakes et al. (2009) based on magnetic resonance imaging data reported a correlation between recurrence of AF after radiofrequency ablation (RFA) of PVI and the degree of fibrosis of PVI and left atrium (LA) [16].

Thoracoscopic treatment (TT) of AF is an alternative surgical method for the treatment of isolated forms of AF on the working heart, which has been actively developed during the last decade [4, 17]. Given the factors supporting macroresponsiveness of the posterior wall of the LA, the

Table 1.

Main characteristics of patients and data of of investigation before surgery

Indicator	Value
Gender (male), n (%)	97 (64.7)
Age, years (Me (IQR))	59 (51-64)
Body mass index, kg/m^2 (mean±SD)	29.5±3.4
Atrial fibrillation duration, years (Me (IQR))	5 (2-8)
Paroxysmal atrial fibrillation, n (%)	58 (38.7)
Persistent atrial fibrillation, n (%)	44 (29.3)
Long-standing atrial fibrillation, n (%)	48 (32)
EHRA IIa-IIb, n (%)	26 (17.3)
EHRA III-IV, n (%)	124 (82.7)
Hypertension, n (%)	121 (80.7)
Diabetes mellitus, n (%)	19 (12.7)
Chronic heart failure NYHA functional class II, n (%)	108 (72)
Chronic heart failure NYHA functional class III, n (%)	22 (14.7)
Cerebrovascular events, n (%)	13 (8.7)
Previous catheter ablations, n (%)	58 (38.7)
Previous radiofrequency and cryoinflation of pulmonary vein orifices, n (%)	47 (31.3)
Preceding cryoinflations of pulmonary vein orifices, n (%)	11 (7.4)
Antiarrhythmic drugs, n (%)	146 (97.3)
Vaughan-Williams Class IC antiarrhythmic drugs, n (%)	12 (8)
Vaughan-Williams Class II antiarrhythmic drugs, n (%)	67 (44.7)
Vaughan-Williams Class III antiarrhythmic drugs, n (%)	58 (38.7)
Vaughan-Williams Class IV antiarrhythmic drugs, n (%)	9 (6)
Anticoagulant therapy, n (%)	130 (86.7)
Apixaban	47 (31.3)
Rivaroxaban	48 (32)
Dabigatran	16 (10.7)
Warfarin	19 (12.7)
CHA_2DS_2-VASc scores (Me (IQR) [min-max])	2 (1-3) [0-6]
HAS-BLED scores (Me [min-max])	1 [0-4]
Left ventricular ejection fraction, % (mean±SD)	62.6±6.4
Left atrial volume index, ml/m^2 (Me (IQR) [min-max])	35 (30-45) [16-81]
Left atrial diameter, mm (Me (IQR))	41 (39-44)
Mitral regurgitation, n (%)	61 (40.7)
Minor mitral regurgitation, n (%)	52 (34.7)
Moderate mitral regurgitation, n (%)	5 (3.3)
Severe mitral regurgitation, n (%)	4 (2.7)
Multislice computed tomography with contrast of the left atrium and pulmonary veins	
Left atrial appendage volume, ml (Me (IQR))	10.0 (6.4-13.1)
Typical pulmonary vein infiltration on the right side, n (%)	108 (72.0)
Convergent right pulmonary vein infiltration, n (%)	28 (18.7)
Infiltration of pulmonary veins on the right by a single/common trunk, n (%)	10 (6.7)
Right accessory pulmonary vein, n (%)	4 (2.7)
Typical left pulmonary vein occlusion, n (%)	35 (23.3)
Conjoined pulmonary vein occlusion on the left side, n (%)	43 (28.7)
Left pulmonary vein infiltration by a single/common trunk, n (%)	72 (48)
Left accessory pulmonary vein, n (%)	0 (0)

method of "Box lesion" - isolation of the posterior wall of the LA was introduced into wide clinical application. In this regard, the main principles of TT AF should be considered: isolation of the PVI, fragmentation of the posterior wall of the LA and amputation of the appendage of the LA [18-21]. The number of studies on the efficacy of TT AF is increasing significantly, but their data vary considerably from 38 to 83% due to the heterogeneity of patients, surgical technique, and follow-up period [22-25].

The purpose of the present study is to present the data on the effectiveness of thoracoscopic ablation of atrial fibrillation and to determine the risk factors of atrial tachyarrhythmia return in the long-term follow-up period.

METHODS

From January 2019 to December 2021 at the Vishnev Research Institute of Surgery, 150 patients with symptomatic isolated AF registered by electrocardiogram (ECG) or daily ECG monitoring refractory to antiarrhythmic therapy (AAT) or with a history of failed catheter ablation, underwent TT AF and LA appendage amputation [4, 17, 18].

All patients underwent a comprehensive examination 24 hours prior to surgery, including ECG in 12 leads, daily ECG, transthoracic echocardiography using "speckle tracking imaging" technology, transesophageal echocardiography to exclude thrombus, multislice computed tomography with contrasting of LA and PVI, coronary angiography when indicated.

The median age of the patients was 59 (61-64) years, 64.7% (n=97) males prevailed. The study included 29.3% (n=44) of patients with persistent AF, 32% (n=48) with long-period persistent, and 38.7% (n=58) with paroxysmal atrial fibrillation, after failed CA. Full clinical characteristics of patients and data of instrumental methods of investigation are presented in Table 1. Antiarrhythmic therapy (AAT) correction prior to surgery was not performed. The preoperative Vaughan-Williams distribution of antiarrhythmic drugs is shown in Table 1. Before surgery, all patients were switched from direct oral anticoagulants or warfarin to low-molecular-weight heparin at least 5 days before surgery. Before surgery, all patients were discussed at a consilium with a cardiologist, arrhythmologist, and cardiac surgeon. Participants gave informed consent to perform TT AF. The study was approved by a local ethics committee.

Evaluating the effectiveness of the procedure

The efficacy of TT AF was evaluated after 3, 6, 12 months and then annually by 24-hour ECG. The procedure was considered successful in the absence of any atrial tachyarrhythmia (AF, AFl, or supraventricular tachycardia) lasting more than 30 seconds, according to the consensus statement of the Heart Rhythm Society [4, 17, 18, 26]. ECG recording was recommended for any symptomatic rapid nonrhythmic heartbeat. The study excluded the "blind" period during the first 3 months after surgery.

Adverse cardiovascular events and 30-day postoperative complications were recorded. All patients (n=150) underwent a telephone interview and recording of daily ECG data at the control points of the study. Anticoagulant therapy with warfarin (target INR 2-3) or direct oral anticoagulants was started the day after surgery.

AAT with amiodarone was continued after surgery in the absence of contraindications. It was definitely recommended to continue taking all medications for up to 3 months. Antiarrhythmic therapy was discontinued after 3-6 months, with complete absence of any supraventricular tachyarrhythmia on ECG. In the absence of arrhythmia after 6-9 months, the issue of complete withdrawal of anticoagulant therapy in CHA2DS2-VASc less than 2 points, complete occlusion of the left LA appendage, absence of thrombus according to transesophageal echocardiography and contrast multispiral computed tomography was decided.

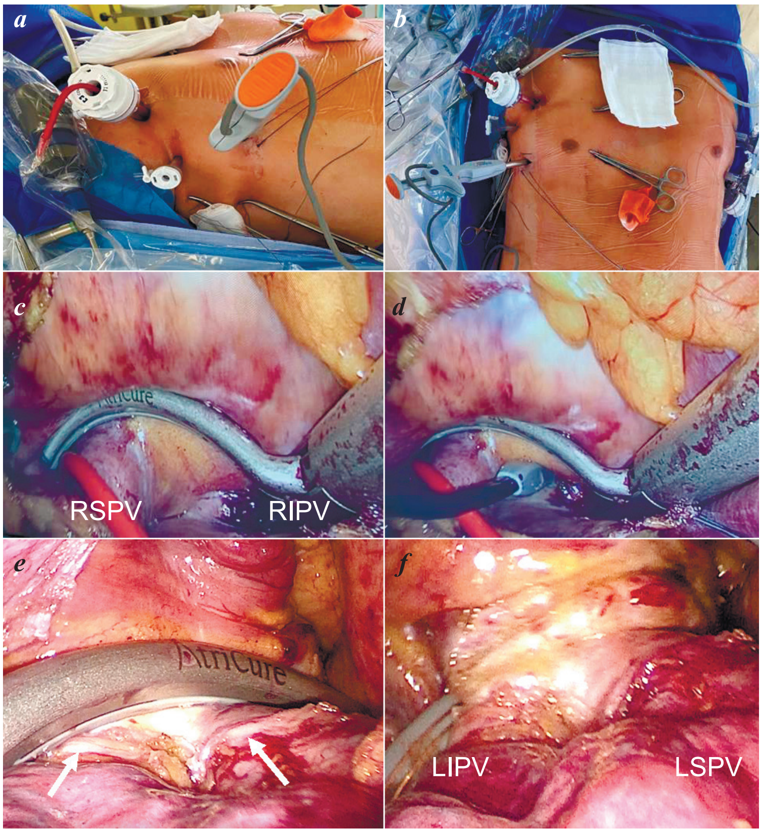


Fig. 1. Intraoperative photographs: single-stage bilateral thoracoscopic access (a-b); radiofrequency ablation of the right pulmonary veins (c); signal check from the right pulmonary veins after their ablation, electrode jaws open (d); marked fibrosis of the left pulmonary veins due to previous catheter ablation (arrows - e); radiofrequency ablation of left pulmonary veins (f). Note: RSPV - right superior pulmonary vein; RIPV - right inferior pulmonary vein; LIPV - left inferior pulmonary vein; LSPV - left superior pulmonary vein.

Operation technique

All surgeries were performed in the cardiac surgical operating room by one surgical team under general anesthesia with selective ventilation. The procedure was performed from a single-stage bilateral access through standard positioning of the thoracoscopic ports (Fig. 1a, b). The procedure was performed according to the "Box lesion set" technique. PVI was isolated with a bipolar electrode (Fig. 1c, e). Achievement of transmurality was monitored by impedance changes according to the algorithm of the RF oscillator. After reaching the transmural lesion, the clamp was unclamped and after a slight change of position, radiofrequency ablations were performed again, up to 10 applications on each side.

After removing the electrode, the ablation line block was checked (Fig. 1d). When recording sinus rhythm with a multifunctional electrode, we performed sequential stimulation of the upper and lower right pulmonary veins with heart rate 30-50% higher than own rhythm and current strength 15-25 mA. The absence of increase in heart rate at the moment of stimulation was considered as achievement of pulmonary vein isolation. In case a patient had AF, atrial signal reading was performed on isolated pulmonary veins using a monopolar electrode. The absence of signal was considered as achievement of pulmonary vein isolation. Then we proceeded to the formation of the upper and lower "Box" lines using a linear bipolar electrode.

LA appendage amputation was performed through one of the ports of the left-side access using an endostapler (Fig. 2a). To exclude the presence of thrombus in the atria, transesophageal echocardiography was performed intraoperatively in all patients before and after LA appendage amputation.

Transmurality was assessed and a bidirectional conduction block through the ablation lines (exit and entrance block) was achieved. The entrance block was confirmed using a bipolar mapping electrode in the absence of potentials at the site of exposure. The exit block was confirmed by stimulation during sinus rhythm. Additional ablations were performed if necessary.

High-frequency stimulation was used to provoke the initiation of AF, its spontaneous cessation within 30 seconds was considered normal. In case of registration of stable AF at the moment of procedure termination, electro-pulse therapy was carried out. Detailed schemes and stages of the operation are presented in previously published works [27, 28].

Statistical analysis

Statistical analysis and visualization of the data were performed using the R 4.2.1 statistical computing environment (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics are presented as the observed number of observations (relative frequency) for qualitative variables and the mean (standard deviation) and median (1st and 3rd quartiles), depending on the normality of the distribution, for quantitative variables. The Shapiro-Wilk test was used to test the conformity of the sample distribution to the normal law. The Kaplan-Meier method, log-rank test, single and multifactorial Cox proportional hazards models were used for survival analysis. A stepwise selection with exclusion based on the Akaike information criterion was used to select variables for the multivariate Cox proportional risk model. Model quality was assessed using Harrell's C-index and Nigelkerke's pseudo-R2. Fisher's exact test was used to analyze the association between categorical variables.

RESULTS

A general description of the procedure is presented in Table 2. Two patients (1.33%) did not undergo the right-sided stage of surgery due to a pronounced adhesion process and high risk of bleeding. On intraoperative electrophysiological examination, the right and left pulmonary veins after catheter ablation were isolated only in 34.04% (16/47). The recovery of sinus rhythm at the time of ablation was in 12% in the group of patients with persistent and long-term persistent AF. It should be noted that the recovery of sinus rhythm was predominantly at the time of completion of the procedure in the left-sided stage, after amputation of the LA appendage. Amputation of the LA appendage was not performed in 6.7% (n=10) patients due to its small size and high risk of bleeding. After LA appendage amputation, sinus rhythm recovery was registered

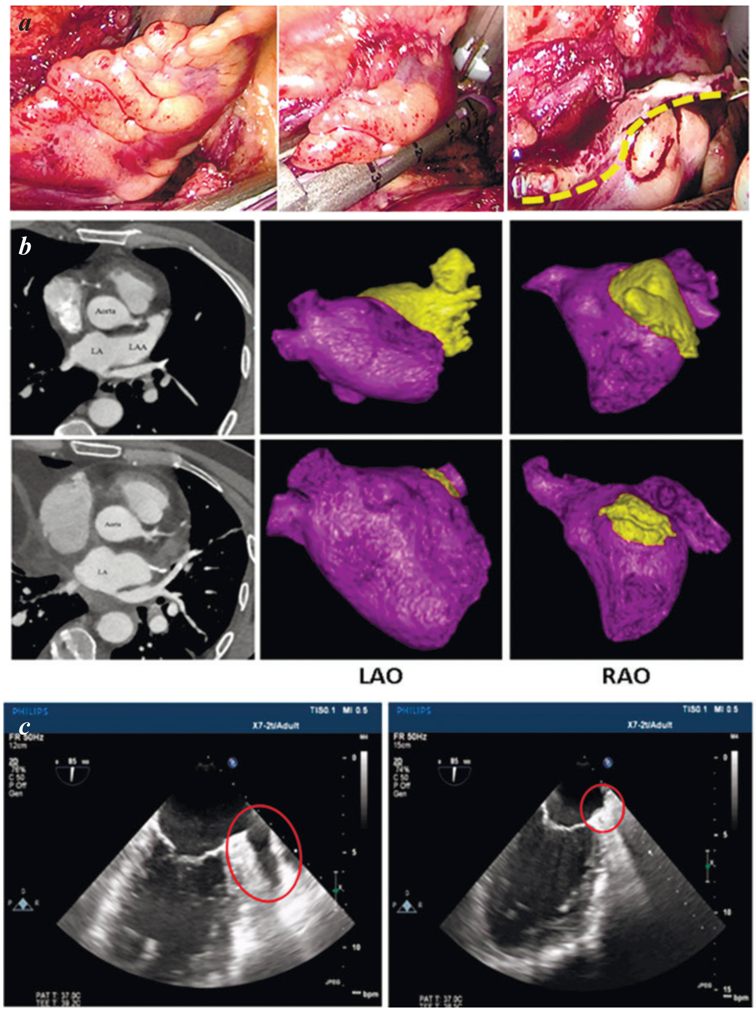


Fig. 2. Left atrial appendage amputation (a), the yellow dotted line marks the resection line of the LA appendage (intraoperative photos). MSCT (b) with contrast of the left atrium and left atrial appendage with 3D reconstruction before (top) and after (bottom) surgery in right and left oblique projections (RAO and LAO). The residual part after amputation of the left atrial appendage is marked in yellow. Intraoperative transesophageal echocardiography (c) before and after LA LA appendage amputation.

in 4/92 (4.34%) patients with long-peristive form of AF.

Total operation time was 220 (188.5-260) minutes, ablation time was 68 (59-84) minutes, and artificial lung ventilation (ALV) time was 9.4 (7.5-12) hours. Sustained AF at the end of the operation was registered in 81 (54%) patients with nonparoxysmal AF, which required electropulse therapy. Persistent sinus rhythm at the end of the procedure was registered in 94.7% of patients. Two patients (1.3%) were transferred to the intensive care unit with atypical atrial flutter.

Complications

Major complications were represented exclusively by pacemaker implantation due to sinus node weakness syndrome - 0.7%. The incidence of minor complications was 10.1% (Table 3). Hemothorax and hydrothorax predominated, requiring drainage of pleural cavities in the early postoperative period. Two patients (1.3%) required prolonged ventilation with additional drainage of pleural cavities due to tension pneumothorax, unstable hemodynamics and increasing respiratory failure. Temporary paralysis of the diaphragmatic nerve was recorded in 4 (2.7%) patients, which resolved within 12 months. Adverse cardiovascular events, thromboembolic complications, including pulmonary embolism, were not reported in any patient.

Long-term results

The efficacy of TT AF in our center after 3, 6, and 12 months was 81.7%, 80.9%, and 77.3%, respectively. At 3 years, freedom from AF according to the Kaplan-Meier method was 72.5%. The efficacy of TT AF for the persistent form was 91.7% and 79.3%, long-period persistent 76.5% and 66.8%, and paroxysmal 77.8% and 73.3% after 6 and 12 months, respectively (p=0.3961) (Figure 3a). If patients with paroxysmal AF had prior catheter ablations, the long-term efficacy of THF AF was significantly reduced 75%, 66.7%, and 61.5% after 6, 12, and 24 months, respectively (p=0.404) (Fig. 3b). Catheter ablations after TT AF at 3 months were required in 14.7% (n=22) and in 4.7% (n=7) at 12 months. Cavotricuspid isthmus RFA was performed in 4 (2.7%) patients with typical atrial flutter (AFl) with restoration of sinus rhythm at the time of ablation. The efficacy of the hybrid treatment was 100% in the early period and 82.9% after 2 years.

Table 2.

Characteristics of the procedure

Indicator	Value
Left atrial appendage amputation	140 (93.3)
Total procedure time, min (Me (IQR))	220 (188.5-260)
Ablation time, min (Me (IQR)	68 (59-84)
Restoring of SR at the moment of ablation, n (%)*	11/92 (12)
Cardioversion at the end of surgery, n (%)	81 (54)
TD at the end of surgery, n (%)	142 (94.7)
Postoperative period	
Sequestrate by pleural drains, ml (Me (IQR))	200 (127.5-300)
Ventilation time, hours (Me (IQR) [min-max])	9.4 (7.5-12) [2.9-48]
Hospital day after surgery (Me (IQR)	6 (5-7)

Note: * - considered only for patients with nonparoxysmal forms of AF; SR - sinus rhythm; ALV - artificial lung ventilation.

When a stable sinus rhythm was recorded on daily ECG after 3-6 months, antiarrhythmic drugs were discontinued. The efficacy of TT AF after AAT withdrawal was 79.2%, 70.5%, and 68.9% after 6, 12, and 24 months, respectively; the decrease in results can be explained by the need to return AAT after 24 months in 29 patients. Fig. 4 shows in detail the efficacy of TT AF depending on antiarrhythmic therapy after 12-36 months, obtaining a statistically significant difference between the groups, p<0.05

Risk factors

A single-factor Cox proportional hazards analysis (Table 4) showed that a 1-year increase in age was statistically significantly associated with a 1.953 increased risk of arrhythmia return [hazard ratio (HR) 1.953, 95% confidence interval (CI) 1.916; 3.993, p=0.0209]. The presence of prior CA and an LA diameter greater than 40 mm increased the risk of recurrence by 1.936 [OR 1.936, 95% CI 1.931; 4.026, p=0.0370] and 1.123 [OR 1.123, 95% CI 1.039; 1.215, p=0.0036], respectively. A 1-year increase in duration of AF and an increase in duration of surgery per minute were statistically significantly associated with a 1.088 [95% CI 1.029; 1.149, p=0.0028] and 1.006 [95% CI 1.001; 1.012, p=0.0265] increase in risk of recurrence, respectively. Whereas EHRA grade I-II reduced the risk of arrhythmia return by a factor of 3.389 [OR 0.295, 95% CI 0.137; 0.635, p=0.0018] relative to EHRA III-IV.

Multivariate analysis was performed exclusively for variables with p<0.15 in the single-factor analysis. The resulting Cox proportional hazards multivariate analysis model was characterized by Najelkerke's pseudo-R2 of 0.329 and Harrell's C-index of 0.81 (SE=0.05). It was found that the duration of AF, prior CA and LA diameter >40 mm are independent risk factors for the return of supraventricular tachyarrhythmias in the postoperative period.

DISCUSSION

The main challenge for patients with isolated AF is to find minimally invasive treatment methods. Due to the work of M.Haïssaguerre et al. (1998) [10] it was established that pulmonary veins should be considered as the main target of CA in AF, but the effectiveness of RFA PVI in persistent and long-term persistent AF turned out to be extremely low [9]. Therefore, alternative methods of surgical treatment, close in effectiveness to the Cox-Maze procedure, but with a lower rate of complications, began to be developed.

This method was first proposed in 2005 by R.K.Wolf and colleagues, who reported the use of bilateral video-assisted thoracoscopic surgery for the treatment of AF. After 4 years, freedom from arrhythmia in paroxysmal AF was 92%, in persistent and long-period AF - 85% and 75%, respectively [20]. The FAST and FAST II randomized clinical trials demonstrated a high efficacy of TT AF of 65.6% versus CA of 36.5% (p=0.002), but with a higher rate of complications [29, 30].

Freedom from AF in TT AF according to a multicenter study for patients with paroxysmal form was 72.7% (174/241), persistent 68.9% (111/161), and 54.2% (32/59) for long-onset AF and overall effectiveness of the procedure with AAT was 68.8% (317/461) and without AAT was 63.3% [31]. The TT AF efficacy of our center for persistent AF was 91.7% and 79.3%, long-period persistent 76.5% and 66.8%, and paroxysmal 77.8% and 73.3% after 6 and 12 months, respectively (p=0.3961) (Figure 3a). The results are like those of a multicenter study [31].

The decreased efficacy of TT AF for long-standing AF is due to more pronounced fibrosis and remodeling of the left and right atria. It has not been fully investigated whether additional ablation lines outside the "Box lesion" regimen improve the efficacy of TT [32]. [32].

The efficacy of TT AF in a recent meta-analysis without AAT administration was 77% after 2 years [22]; our rates after 36 months without AAT were 68.9% (Fig. 4). This may be related to the limited control of heart rate in the meta-analysis [22].

In R.S.Oakes et al. (2009) it is said about recurrence of AF after RFA of PVI due to a pronounced degree of PV and LA ostium fibrosis on the basis of magnetic resonance imaging data [16]. Another study reported the presence of multiple cicatricial changes of the LA after extensive CA [15]. This factor may also influence the low efficacy of TT AF, compared with patients without prior CA.

Within the study we presented, we also analyzed the efficacy of TT AF for patients with prior CA. In patients with failed CAs, the efficacy of TT AF in the long-term follow-up period decreased to 61.5% in contrast to the group without CAs, p=0.404 (Fig. 3b). According to S.K.Lim et al (2020), the efficacy of TT AF after 5 years in the group with prior CA 55.3%±11.0% and without CA 55.7%±5.1% was also comparable (p=0.690) [33].

A single-factor Cox proportional hazards analysis showed that the presence of failed prior CA increases the risk of arrhythmia return by a factor of 1.936. A pronounced adhesions and fibrosis in the PV ostium (Fig. 1d) prevailed in patients with previous CA, which significantly increased the risks of bleeding and the time of surgery. Therefore, in several cases, TT AF can be recommended as the first stage in order to reduce the risks of intraoperative complications. A single-factor Cox analysis showed that a LA diameter greater than 40 mm increased the risk of rhythm failure by 1,123. Previously, it was reported that at LA volume index>34 mL/m2 the efficacy of TT AF was 77.8%, and at LA volume index <34 mL/m2 it was 88.9% [27].

The results of our study are consistent with those of C. Yu et al. (2021). Multivariate Cox regression analysis in a study by C.Yu et al (2021) showed that LA diameter >40 mm [OR 2.837, 95% CI 1.408; 5.716; p=0.004] and age >50 years [OR 2.927, 95% CI 1.359; 6.305; p=0.006] were associated with recurrent atrial tachyarrhythmias [34]. The risk factors presented in the study of C.van Laar et al. (2019): female gender, postoperative AF in the hospital period, a long history of AF, mitral regurgitation were independent predictors of AF recurrence, which has been previously reflected in other studies for catheter ablation and Cox-Maze procedure [31].

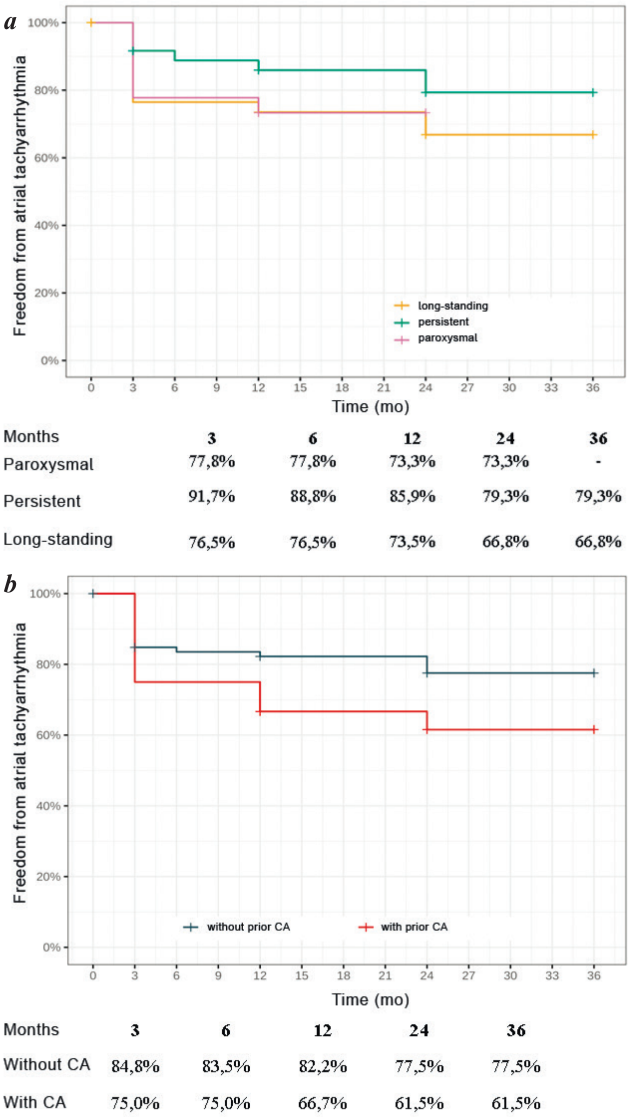
Catheter ablations after TT AF at 3 months were required in 14.7% (n=22) and 4.7% (n=7) at 12 months, respectively. Predominantly, the patients underwent ablation in the area of the posterior wall of the LA, in particular, the formation of the upper and lower line along the posterior wall of the LA was completed. At high-density mapping of pulmonary veins, the latter were isolated in all patients, which once again confirms almost 100% effect of achieving transmurality using bipolar RF electrode. At the beginning of CA, typical AFl

Table 3.

Structure of minor complications (n=150)

Small complications	Value
Pneumonia, n (%)	1 (0.7)
Pneumothorax, n (%)	2 (1.3)
Hemothorax, n (%)	4 (2.7)
Hydrothorax, n (%)	4 (2.7)
Temporary DN paresis, n (%)	4 (2.7)
Total, n (%)	13 (10.1)

Note: DN - diaphragmatic nerve



Months	3	6	12	24	36
Paroxysmal	77,8%	77,8%	73,3%	73,3%	-
Persistent	91,7%	88,8%	85,9%	79,3%	79,3%
Long-standing	76,5%	76,5%	73,5%	66,8%	66,8%

Months	3	6	12	24	36
Without CA	84,8%	83,5%	82,2%	77,5%	77,5%
With CA	75,0%	75,0%	66,7%	61,5%	61,5%

Fig. 3. Kaplan-Meier curves of freedom from atrial tachyarrhythmias depending of the atrial fibrillation type (a) p=0.3961 and of prior catheter ablations (b) p=0.404.

was registered in 4 patients, therefore, cavotricuspidal isthmus RFA was performed, with restoration of sinus rhythm in all patients now of ablation. In the early period of observation, the efficacy of staged treatment of AF reached 100%, but by the second year tended to decrease to 82.9%.

In our study, the overall incidence of major complications was 0.7% and that of minor complications was 10.1%, which is also comparable with data from previously published works. E.Beyer et al. [35], first noted in their study 13% complication rate (pacemaker implantation, diaphragmatic nerve injury, postoperative hemothorax and transient ischemic attack), 30-day complication rate in the meta-analysis was 7.6% [31]. In L.M.Vos et al. (2018), the rate of major complications was 3.2% and minor complications was 8.1% [36].

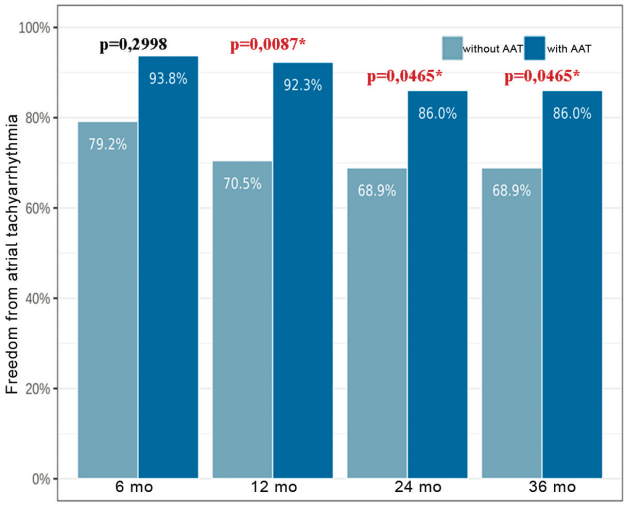


Fig. 4. Freedom from atrial tachyarrhythmias depending on antiarrhythmic therapy (AAT). Note: * - statistically significant difference between groups at p<0.05.

An important advantage of TT AF is the possibility of LA appendage amputation. Today, there is no consensus on the optimal prevention of thromboembolic events in patients with AF. However, it is proved that up to 90-95% of all thrombi in patients with non-valvular AF form in the LA appendage [37-39]. Therefore, isolation or removal of the LA appendage as an alternative option of anticoagulation therapy is of great clinical importance.

Currently, the following surgical methods of removing/excluding the LA appendage from the bloodstream are distinguished: (1) incision and stapling technique; (2) clipping; (3) occlusion; (4) stapler stitching and excision [40, 41]. Early studies stated that removal of the LA appendage using endoscopic incision stapling increases the risk of intraoperative bleeding due to the rupture of the LA tissues under the staple line [42]. The efficiency and safety of modern devices became significantly higher due to changes in the staple line and the availability of mechanized cutting and stapling support [43].

In our center, we prefer the endoscopic incision stapler, which has proven to be a good choice for performing TT AF. LA appendage amputation was performed in 93.3% (n=140). All anastomoses in the LA appendage stump were valid. After LA appendage amputation, sinus rhythm recovery was registered in 4/92 (4.34%) patients with long-peristive AF. L.Di Biase et al. (2016) showed that LA appendage isolation improved freedom from AF/AFl in patients with long-peristive form of AF [44]. However, A. Romanov et al. (2016) did not observe a decrease in the rate of recurrent AF after LA appendage amputation in TT AF [45].

Thus, the overall efficacy of TT AF in the long-term follow-up period was 72.5%, which is comparable with the worldwide data. After AAT withdrawal, freedom from any atrial tachyarrhythmias was 79.2%, 70.5%, and 68.9% after 6, 12, and 24 months, respectively. The patient's age, the duration of AF, previous catheter ablations, and an LA

Table 4.

Cox's single-factor and multi-factor proportional risk analysis

Predictor	Single-factor analysis			Multivariate analysis		
	HR	95% CI	p	HR	95% CI	p
Male gender	1.159	0.527; 2.549	0.7130			
Age	1.953	1.916; 3.993	0.0209	0.957	0.912; 1.004	0.07
Age > 50 years	1.458	1.213; 2.985	0.0458			
Body mass index ≥ 28 kg/m^2	1.459	0.678; 3.137	0.3341			
Persistent form of AF	0.570	0.214; 1.520	0.2617			
Long-standing AF	1.125	0.494; 2.561	0.7795			
Duration of AF, years	1.088	1.029; 1.149	0.0028	1.062	1.001; 1.128	0.0477
EHRA I-II	0.295	0.137; 0.635	0.0018	0.405	0.166; 0.992	0.0481
CHA_2DS_2-VASc	0.860	0.636; 1.162	0.3261			
HAS-BLED	0.601	0.345; 1.048	0.0726			
Previous catheter ablations	1.936	0.931; 4.026	0.0370	1.917	0.897; 4.098	0.043
Left ventricular ejection fraction	0.994	0.938; 1.053	0.8410			
Left atrial diameter >40 mm	1.123	1.039; 1.215	0.0036	1.123	1.032; 1.222	0.007
Procedure time	1.006	1.001; 1.012	0.0265			

Note: HR - hazard ratio; CI - confidence interval; AF - atrial fibrillation.

diameter greater than 40 mm should be considered as important risk factors for arrhythmia recurrence after TT AF.

CONCLUSION

Thoracoscopic treatment of AF should be considered a promising method of arrhythmia elimination both for patients with paroxysmal AF after unsuccessful catheter ablations, and for patients with persistent and long-term persistent AF. The two-stage approach significantly improves the efficacy of TT AF, particularly in patients with nonparoxysmal forms of AF.

Important risk factors for arrhythmia recurrence after TT AF should be considered patient's age, duration of AF, previous catheter ablation and left atrial diameter greater than 40 mm. The results obtained require further study of this problem in order to improve the quality of TT AF and determine the optimal set of lines, taking into account the predictors of arrhythmia return. Large randomized trials are also needed to study the prevention of thromboembolic events and the antiarrhythmic effect of left atrial appendage removal.

REFERENCES

1. Benjamin EJ, Muntner P, Alonso A, et al. Heart disease and stroke Statistics-2019 update: A report from the American Heart Association. *Circulation*. 2019;139: 56-528. https://doi.org/10.1161/CIR.0000000000000659.
2. Krijthe BP, Kunst A, Benjamin EJ, et al. Projections on the number of individuals with atrial fibrillation in the European Union, from 2000 to 2060. *Eur Heart J*. 2013;34: 2746-51. https://doi.org/10.1093/eurheartj/eht280.
3. Staerk L, Sherer JA, Ko D, et al. Atrial fibrillation: epidemiology, pathophysiology, and clinical outcomes. *Circ Res*. 2017;120: 1501-17. https://doi.org/10.1161/CIRCRESAHA.117.309732.
4. Hindricks G, Potpara T, Dagres N, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association of Cardio-Thoracic Surgery (EACTS). *Eur Heart J.* 2021;42: 373-498. https://doi.org/10.1093/eurheartj/ehaa945.
5. Kawabata M, Goya M, Maeda S, et al. A survey of direct oral anticoagulant cessation in general surgery and outcomes in patients with nonvalvular atrial fibrillation. *Int Heart J*. 2020;61: 905-12. https://doi.org/10.1536/ihj.19-625.
6. Prasad SM, Maniar HS, Camillo CJ, et al. The Cox maze III procedure for atrial fibrillation: long-term efficacy in patients undergoing lone versus concomitant procedures. *J. Thorac. Cardiovasc. Surg.* 2003;126: 1822-1828. https://doi.org/10.1016/s0022-5223(03)01287-x.
7. Cox JL. The longstanding, persistent confusion surrounding surgery for atrial fibrillation. *J Thorac Cardiovasc Surg*. 2010;139: 1374-86. https://doi.org/10.1016/j.jtcvs.2010.02.027.
8. Verma A, Jiang CY, Betts TR, et al., for the STAR AF II Investigators. Approaches to catheter ablation for persistent atrial fibrillation. *N Engl J Med*. 2015;7(372): 1812-22. https://doi.org/10.1016/j.ahj.2012.04.002.
9. Tilz RR, Rillig A, Thum AM, et al. Catheter ablation of long-standing persistent atrial fibrillation: 5-year outcomes of the Hamburg Sequential Ablation Strategy. *J Am Coll Cardiol*. 2012:60; 1921-1929. https://doi.org/10.1016/j.jacc.2012.04.060.
10. Haïssaguerre M, Jaïs P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med*. 1998: 339; 659-666. https://doi.org/10.1056/NEJM199809033391003.
11. DeWith RR, Marcos EG, Van Gelder IC, et al. Atrial fibrillation progression and outcome in patients with young-onset atrial fibrillation. *Europace*. 2018;20: 1750-7. https://doi.org/10.1093/europace/euy028.
12. Artyukhina EA, Dedukh EV, Yashkov MV. Stage surgical and catheter approach to the treatment of long-persistent atrial fibrillation. Russian Journal of Cardiology. 2019;(7): 96-98. (In Russ.). https://doi.org/10.15829/1560-4071-2019-7-96-98.
13. Berger WR, Meulendijks ER, Limpens J, et al. Persistent atrial fibrillation: a systematic review and meta-analysis of invasive strategies. *Int J Cardiol*. 2019;278: 137-43. https://doi.org/10.1016/j.ijcard.2018.11.127.
14. Demarchi A, Neumann L, Rordorf R, et al. Long-term outcome of catheter ablation for atrial fibrillation in patients with severe left atrial enlargement and reduced left ventricular ejection fraction. *Europace*. 2021;17: 213. https://doi.org/10.1093/europace/euab213.
15. Nuhrich JM, Geisler AC, Steven D, et al. Active atrial function and atrial scar burden after multiple catheter ablations of persistent atrial fibrillation. *Pacing Clin Electrophysiol.* 2017;40: 175-82. https://doi.org/10.1111/pace.13004.
16. Oakes RS, Badger TJ, Kholmovski EG, et al. Detection and quantification of left atrial structural remodeling with delayed-enhancement magnetic resonance imaging in patients with atrial fibrillation. *Circulation*. 2009;119: 1758-67. https://doi.org/10.1161/CIRCULATIONAHA.108.811877.
17. Hindricks G, Potpara T, Dagres N, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association of Cardio-Thoracic Surgery (EACTS). *Eur Heart J.* 2021; 42: 373-498. (In Russ.). https://doi.org/10.1093/eurheartj/ehaa945.
18. Badhwar V, Rankin JS, Damiano RJ, et al. The Society of Thoracic Surgeons 2017 clinical practice guidelines for the surgical treatment of atrial fibrillation. *Ann Thorac Surg*. 2017;103: 329-41. https://doi.org/10.1016/j.athoracsur.2016.10.076.
19. Cox JL, Malaisrie SC, Kislitsina ON, et al. The Electrophysiologic basis for lesions of the contemporary Maze operation. *J Thorac Cardiovasc Surg*. 2019;157: 584-90. https://doi.org/10.1016/j.jtcvs.2018.08.007.
20. Wolf RK, Schneeberger EW, Osterday R, et al. Video-assisted bilateral pulmonary vein isolation and left atrial appendage exclusion for atrial fibrillation. *J Thorac Cardiovasc Surg*. 2005;130: 797-802. https://doi.org/10.1016/j.jtcvs.2005.03.041.
21. Guo H, Qing H, Zhang Y, et al. Stand-alone surgical ablation for atrial fibrillation: a novel bilateral double-port approach. *J Thorac Dis.* 2019;11: 1989-95. https://doi.org/10.21037/jtd.2019.04.98.

22. van Laar C, Kelder J, van Putte BP. The totally thoracoscopic maze procedure for the treatment of atrial fibrillation. *Interact Cardiovasc Thorac Surg*. 2017;24: 102-111. https://doi.org/10.1093/icvts/ivw311.
23. Hu QM, Li Y, Xu CL, et al. Analysis of risk factors for recurrence after video-assisted pulmonary vein isolation of lone atrial fibrillation-results of 5 years of follow-up. *J. Thorac Cardiovasc Sur*. 2014;148: 2174-80. https://doi.org/10.1016/j.jtcvs.2013.10.054.
24. Saini A, Hu Y, Kasirajan V, et al. Long-term outcomes of minimally invasive surgical ablation for atrial fibrillation: A single-center experience. *Heart Rhythm*. 2017;14: 1281-1288. https://doi.org/10.1016/j.hrthm.2017.04.029.
25. Nardaia SG, Rzaev FG, Mustapaeva ZV, et al. Electrophysiological predictors of effectiveness of RFA of persistent atrial fibrillation. *The Siberian Journal of Clinical and Experimental Medicine*. 2015;30(1):44-49. (In Russ.). https://doi.org/10.29001/2073-8552-2015-30-1-44-49.
26. Calkins H, Hindricks G, Cappato R, et al. HRS/EHRA/ECAS/APHRS/ SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation. *Heart Rhythm*. 2017;14(10): 275-444. https://doi.org/10.1016/j.hrthm.2017.05.012.
27. Revishvili ASh, Kadirova M, Popov VA, et al. Influence of Left Atrium Volume Index on effectiveness of Thoracoscopic Ablation in the Treatment of Atrial Fibrillation. *Medical Visualization*. 2022;26(3): 22-33. (In Russ.). https://doi.org/10.24835/1607-0763-1162.
28. Revishvili ASh, Taimasova IA, Artyukhina EA, et al. Mid-term outcomes of thoracoscopic and hybrid therapy of atrial fibrillation. *Journal of Arrhythmology*. 2021;28(3): 5-12. (In Russ.). https://doi.org/10.35336/VA-2021-3-5-12.
29. Boersma LV, Castella M, van Boven W, et al. Atrial fibrillation catheter ablation versus surgical ablation treatment (FAST): a 2-center randomized clinical trial. *Circulation*. 2012;125: 23-30. https://doi.org/10.1161/CIRCULATIONAHA.111.074047.
30. Sindby JE, Vadmann H, Lundbye-Christensen S, et al. Percutaneous versus thoracoscopic ablation of symptomatic paroxysmal atrial fibrillation: a randomised controlled trial-the FAST II study. *J Cardiothorac Surg*. 2018;13: 101. https://doi.org/10.1186/s13019-018-0792-8.
31. van Laar C, Bentala M, Weimar T, et al. Thoracoscopic ablation for the treatment of atrial fibrillation: a systematic outcome analysis of a multicentre cohort. *Europace*. 2019: 1;21(6): 893-899. https://doi.org/10.1093/europace/euy323.
32. Wesselink R, Neefs J, van den Berg NWE, et al. Does left atrial epicardial conduction time reflect atrial fibrosis and the risk of atrial fibrillation recurrence after thoracoscopic ablation? Post hoc analysis of the AFACT trial. *BMJ Open*. 2022;12(3): 829. https://doi.org/10.1136/bmjopen-2021-056829.
33. Lim SK, Kim JY, On YK, et al. Mid-Term Results of Totally Thoracoscopic Ablation in Patients with Recurrent Atrial Fibrillation after Catheter Ablation. *Korean J Thorac Cardiovasc Surg*. 2020;53(5): 270-276. https://doi.org/10.5090/kjtcs.19.059.
34. Yu C, Li H, Zhang H, et al. Midterm results of stand-alone thoracoscopic epicardial ablation with box lesion for atrial fibrillation. *Interact Cardiovasc Thorac Surg*. 2021:18;33(3): 354-361. https://doi.org/10.1093/icvts/ivab148.
35. Beyer E, Lee R, Lam BK. Point: Minimally invasive bipolar radiofrequency ablation of lone atrial fibrillation: early multicenter results. *Journal of Thoracic and Cardiovascular Surgery*. 2009:137(3); 521-526. https://doi.org/10.1016/j.jtcvs.2008.11.031.
36. Vos LM, Kotecha D, Geuzebroek GSC, et al. Totally thoracoscopic ablation for atrial fibrillation: a systematic safety analysis. *Europace*. 2018:1;20(11): 1790-1797. https://doi.org/10.1093/europace/eux385.
37. Pidanov OYu, Bogachev-Prokophiev AV, Elesin DA, et al. Thoracoscopic ablation for treatment of patients with lone atrial fibrillation in Russia. *Circulation Pathology and Cardiac Surgery*. 2018;22(2): 14-21. (In Russ.). http://doi.org/10.21688/1681-3472-2018-2-14-21.
38. Prosper A, Shinbane J, Maliglig A, et al. Left Atrial Appendage Mechanical Exclusion: Procedural Planning Using Cardiovascular Computed Tomographic Angiography. *J Thorac Imaging*. 2020; 35(4): 107-118. https://doi.org/10.1097/RTI.0000000000000504.
39. Cresti A, García-Fernández MA, Sievert H, et al. Prevalence of extra-appendage thrombosis in non-valvular atrial fibrillation and atrial flutter in patients undergoing cardioversion: a large transoesophageal echo study. *EuroIntervention*. 2019;15: 225-30 https://doi.org/10.4244/EIJ-D-19-00128.
40. Hildick-Smith D, Landmesser U, Camm AJ, et al. Left atrial appendage occlusion with the Amplatzer™ Amulet™ device: full results of the prospective global observational study. *Eur Heart J*. 2020; 41: 2894-901. https://doi.org/10.1093/eurheartj/ehaa169.
41. Lee R, Vassallo P, Kruse J, et al. A randomized, prospective pilot comparison of 3 atrial appendage elimination techniques: internal ligation, stapled excision, and surgical excision. *J Thorac Cardiovasc Surg*. 2016;152: 1075-80. https://doi.org/10.1016/j.jtcvs.2016.06.009.
42. Gillinov AM, Pettersson G, Cosgrove DM. Stapled excision of the left atrial appendage. *J Thorac Cardiovasc Surg*. 2005;129: 679-80. https://doi.org/10.1016/j.jtcvs.2004.07.039.
43. Yan T, Zhu S, Zhu M, et al. Clinical Performance of a Powered Surgical Stapler for Left Atrial Appendage Resection in a Video-Assisted Thoracoscopic Ablation for Patients with Nonvalvular Atrial Fibrillation. *Int Heart J*. 2021:30;62(4): 764-770. https://doi.org/10.1536/ihj.20-765.
44. Di Biase L, Burkhardt JD, Mohanty P, et al. Left atrial appendage isolation in patients with longstanding persistent AF undergoing catheter ablation: BELIEF trial. *J Am Coll Cardiol*. 2016;68: 1929-40. https://doi.org/10.1016/j.jacc.2016.07.770.
45. Romanov A, Pokushalov E, Elesin D, et al. Effect of left atrial appendage excision on procedure outcome in patients with persistent atrial fibrillation undergoing surgical ablation. *Heart Rhythm*. 2016;13: 1803-9. https://doi.org/10.1016/j.hrthm.2016.05.012.