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CLINICAL RESEARCH

Epicardial and hybrid surgical ablation of atrial fibrillation: 1-year follow-up outcomes of the EORP EHAFA registry

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Aims

Stand-alone minimal invasive epicardial and hybrid atrial fibrillation ablation (EHAFA) has evolved to a recognized treatment option in challenging patients. The EHAFA registry was initiated to describe the applied diagnostic and therapeutic approaches used in routine practice for these procedures, as well as the outcomes in terms of rhythm, symptoms, and complications.

Methods and results

Between January 2016 and March 2018, patients who underwent an EHAFA procedure for all types of atrial fibrillation (AF) were consecutively enrolled in the international, prospective, observational EHAFA registry. Follow-up occurred after 1 year. A total of 468 patients were enrolled from 17 centres in 10 countries. Stand-alone ablation ($n = 464$) was performed epicardially in 47% ($n = 220$) or as epi-/endocardial hybrid in 53% ($n = 244$). The predominate type of AF was non-paroxysmal in 74% ($n = 342$), and 36% ($n = 166$) of patients had failed previous catheter ablation. The main lesion sets applied consisted of pulmonary vein isolation (99%, $n = 460$) and isolation of the left atrial (LA) posterior wall (82%, $n = 383$). In 82% ($n = 382$), the LA appendage was managed. The overall in-hospital major complication rate was 8.2% ($n = 38/464$). Freedom from atrial arrhythmias > 30 s with and without antiarrhythmic drug usage was 79% and 64% ($n = 279/353$, $n = 223/351$, respectively). The EHRA score at follow-up was clearly reduced compared to preoperatively (EHRA I: 72%, $n = 233/325$, vs. 3%, $n = 14/464$).

Conclusion

This international registry revealed good rhythm control efficacy for epicardial and hybrid AF ablation in patients with advanced AF, leading to improvement in AF-related symptoms. However, a certain associated complication rate needs to be considered.

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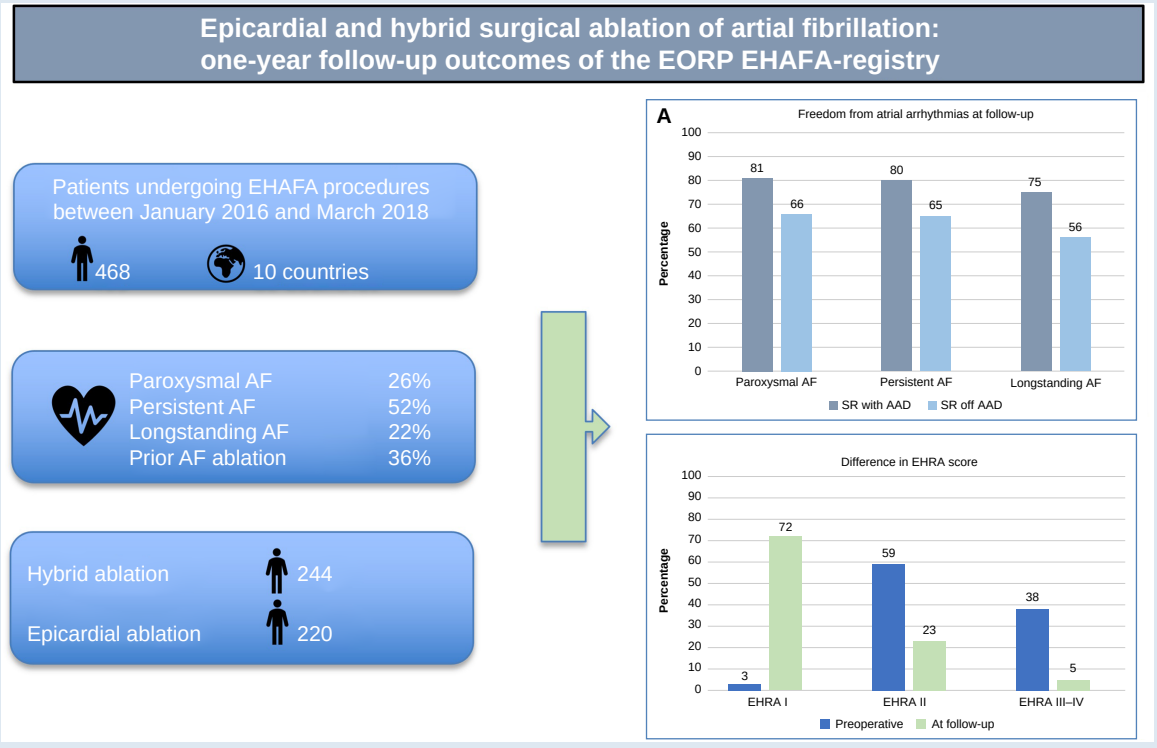
Graphical Abstract



AAD, antiarrhythmic drugs; AF, atrial fibrillation; EHAFA, stand-alone minimal invasive epicardial and hybrid atrial fibrillation ablation.

Keywords Atrial fibrillation • Surgical ablation • Epicardial ablation • Hybrid ablation • Registry

What's new?

- This is one of the largest international multicentre registries reporting on diagnostic and therapeutic approaches used in routine practice for stand-alone minimal invasive epicardial and hybrid atrial fibrillation ablation procedures, as well as the outcomes in terms of rhythm, symptoms, and complications.
- Although the majority of patients treated presented with non-paroxysmal atrial fibrillation and an enlarged left atrium, freedom from atrial arrhythmias > 30 s with and without antiarrhythmic drug usage was 79% and 64%, respectively.
- The overall in-hospital major complication rate was 8.2%. The addition of endocardial catheter ablation in the hybrid group did not affect the major complication rate.
- At follow-up, a clear improvement in EHRA score compared to pre-procedural could be confirmed, with 72% of the patients reporting not having any symptoms anymore vs. only 3% at baseline.

Introduction

Atrial fibrillation (AF) is associated with decreased quality of life and increased morbidity, hospitalizations, and risk for thromboembolic events, as well as the development of heart failure.[1,2] Antiarrhythmic drug (AAD) treatment is not always effective for long-term rhythm control and may even contribute to the observed higher mortality in the AF population.[3] The observation that rapidly firing foci in the pulmonary veins (PVs) initiates AF led to the development of various catheter ablation techniques for their electrical isolation. There is evidence that AF ablation provides an improvement in quality of life resulting from elimination of arrhythmia-related symptoms such as palpitations, fatigue, or effort intolerance, as well as reversal of left ventricular dysfunction, and a significant reduction in morbidity and mortality secondary to thromboembolism or heart failure.[4,5]

While results of catheter ablation in paroxysmal AF (PAF) are satisfactory, rhythm control becomes limited in patients with persistent (PersAF) and long-standing persistent AF (LSPersAF) and very often requires several interventional attempts.[6] The surgical Maze procedure, which in addition to PV isolation (PVI) also includes left and right atrial (LA, RA) linear lesions and management of the left atrial appendage (LAA), has remained the most effective technique to eliminate AF.[7] However, its complexity and the need for cardioplegic arrest kept it from general adaption and widespread use.

This has led to the development of minimal invasive stand-alone thoracoscopic AF ablation techniques, applying epicardial lesions on the beating heart that intend to mimic the original Maze for most parts. To further increase efficacy, the combination of minimally invasive surgical epicardial and catheter-based endocardial ablation by the means of a hybrid approach has become a considerable treatment strategy. Although these procedures are worldwide accepted and recognized by current guidelines due to well-documented freedom from AF, the used access, applied lesion set, and conducted follow-up differ substantially per country and centre.[8–11] Further, the impact on quality of life is not frequently reported.[12,13]

The primary objective of this registry was to describe the diagnostic and therapeutic approaches used in routine practice when performing stand-alone epicardial or hybrid AF ablation (EHAFA) procedures, as well as the outcomes in terms of rhythm, symptoms, and complications.

Table 1 Baseline characteristics

	Epicardial ($n = 220$) Percentage (number), median [IQR]		Hybrid ($n = 244$) Percentage (number), median [IQR]		Total ($n = 464$) Percentage (number), median [IQR]	
Patient characteristics						
Male	69	(152/220)	75	(183/244)	72	(335/464)
Age (years)	64 [56–69]		63 [56–68]		63 [56–69]	
BMI (kg/m^2)	28 [25–31]		29 [27–32]		28 [26–32]	
Chronic obstructive pulmonary disease	3.7	(8/219)	4.1	(10/244)	3.9	(18/463)
Stroke/TIA	12	(27/220)	7.4	(18/244)	9.7	(45/464)
Diabetes mellitus	10	(22/220)	12	(29/244)	11	(51/464)
Hypertension	54	(119/220)	51	(125/244)	53	(244/464)
OSAS	10	(20/202)	7.4	(18/243)	8.5	(38/445)
Kidney disease	6.4	(14/220)	0.8	(2/244)	3.4	(16/464)
Thyroid disorder	15	(30/207)	10	(25/244)	12	(55/451)
Prior MI	1.8	(4/219)	2.0	(5/244)	1.9	(9/463)
Previous chest surgery	0.9	(2/220)	0.8	(7/244)	1.9	(9/464)
CHA_2DS_2-Vasc score	2 [1–3]		2 [1–3]		2 [1–3]	
Echocardiography						
LAV (mL)	74 [58–92]	$n = 120$	85 [67–105]	$n = 143$	80 [63–99]	$n = 263$
RAV (mL)	46 [32–69]	$n = 55$	65 [41–87]	$n = 89$	58 [35–80]	$n = 144$
LVEF (%)	60 [55–63]	$n = 169$	56 [50–60]	$n = 235$	57 [50–61]	$n = 404$
Mitral regurgitation	11	(24/220)	9.1	(22/242)	10	(46/462)
AF characteristics						
Paroxysmal AF	34	(75/220)	19	(47/244)	26	(122/464)
Persistent AF	47	(103/220)	57	(138/244)	52	(241/464)
LS-persistent AF	19	(42/220)	24	(59/244)	22	(101/464)
AF and AFL or AT	18	(39/220)	21	(51/244)	19	(90/464)
Time-to-treatment (M)	50 [19–109]	$n = 219$	35 [12–73]	$n = 241$	41 [16–87]	$n = 460$
Current episode (W)	26 [13–66]	$n = 145$	36 [17–72]	$n = 194$	32 [14–68]	$n = 339$
EHRA score I	5.0	(11/220)	1.2	(3/244)	3.0	(14/464)
EHRA score II	53	(116/220)	64	(156/244)	59	(272/464)
EHRA score III–IV	42	(93/220)	35	(85/244)	38	(178/464)
Prior AF ablation	42	(93/220)	30	(73/244)	36	(166/464)
1–2 prior ablations	33	(72/219)	25	(62/244)	29	(134/463)
3–5 prior ablations	9.1	(20/219)	4.5	(11/244)	6.7	(31/463)
Prior AFL/AT ablation	10	(22/220)	11	(26/244)	10	(48/464)

AF, atrial fibrillation; AFL, atrial flutter; AT, atrial tachycardia; BMI, body mass index; LAV, left atrial volume; LS: long-standing; LVEF, left ventricular ejection fraction; M, months; MI, myocardial infarction; OSAS, obstructive sleep apnoea syndrome; RAV, right atrial volume; TIA: transient ischaemic attack; W: weeks.

Methods

Between January 2016 and March 2018, patients who underwent a stand-alone minimal invasive surgical ablation or a hybrid ablation for all types of AF were consecutively enrolled in the international, prospective, observational EHAFA registry. The study was approved by the ethics committee of Maastricht, the Netherlands (date of approval: 06/05/2015, reference number: METC 154086), and performed in accordance with the Declaration of Helsinki. The EURObservational Research Programme (EORP) department of the European Society of Cardiology (ESC) supervised the registry. No specific protocol, requirements, or recommendations for evaluation, management, diagnostic procedures, and/or treatment strategies were given for this study. The classification of AF in PAF, PersAF, or LSPersAF was adapted from the ESC guidelines.[8] Recurrence was defined as any documented occurrence of AF, atrial flutter (AFL), or atrial tachycardia (AT) lasting >30 s after the blanking period of 3 months. In hybrid ablation, the blanking period started after the endocardial ablation. Stand-alone minimal invasive surgical ablation involves epicardial ablation performed via either bilateral or unilateral thoracoscopy or minithoracotomy, under general anaesthesia. After opening of the pericardium, the surgical ablation is performed. The used lesions and energy sources were left to the centre's clinical practice. Hybrid ablation combines epicardial thoracoscopic ablation with conventional catheter ablation via a transfemoral and transvenous access. This can be performed either as one-stage procedure (both ablations in a single session) or as a two-stage procedure, where catheter ablation is performed within 6 months after the epicardial ablation. The selection of lesions and energy sources again were left to the centre's clinical practice.

Table 2 Procedural data

	Percentage (number), median [IQR]	
Type of procedure		
Epicardial ablation	47	(220/464)
Thoracotomy	0.9	(4/464)
Thoracoscopy	46	(216/464)
Hybrid one-stage ablation	35	(162/464)
Endocardial part not performed	2.5	(4/162)
Hybrid two-stage ablation	18	(82/464)
Endocardial part not performed	6.1	(5/82)
Procedure duration (min)		
Epicardial ablation	177 [136–220]	$n = 215$
Hybrid one-stage ablation	302 [241–344]	$n = 136$
Hybrid two-stage ablation	350 [300–401]	$n = 73$
Epicardial part	158 [149–190]	$n = 78$
Endocardial part	185 [145–238]	$n = 73$

An electronic case report form in a secured web-based database system was used for data collection. Data were collected pre-, intra-, and post-operatively. Follow-up information, including quality of life, was collected 12 months after the last procedure. Informed consent to allow for a detailed recording of data for this registry was obtained from each patient before the procedure.

Data were prospectively entered into the database and analysed using SPSS 29.0 (SPSS Inc., Chicago, IL). The normality of distribution of continuous variables was tested using the Shapiro–Wilk test. Continuous variables with normal distribution were presented as mean ± standard deviation (SD) and non-normal variables as median and interquartile range (IR). The EHAFA registry is purely descriptive and not confirmative.

A change in study personnel in April 2019 resulted in a temporary suspension of data cleaning; this work was resumed in February 2024, and the database was locked in August 2024 after outstanding queries were resolved. Statistical analysis and manuscript preparation were completed by January 2025.

Results

A total of 468 patients were enrolled in the EHAFA register from one Canadian centre and 16 European centres in nine countries (Belgium, Switzerland, Czech Republic, Germany, France, Great Britain, Italy, Netherlands, and Poland). The majority of patients (76%, $n = 357/468$) were treated in centres with a well-established AF programme defined as >20 stand-alone surgical ablations per year. No formal annual-volume threshold was mandated for the electrophysiologists involved in the hybrid or staged endocardial phase; operator expertise was left to individual centres' credentialing policies.

Table 3 Ablation details

	Epicardial[a] ($n = 229$) Percentage (number)		Hybrid ($n = 235$) Percentage (number)		Total ($n = 464$) Percentage (number)	
Epicardial ablation						
Left and right PVI	96	(219/229)	92	(217/235)	94	(436/464)
Left or right PVI only	4.3	(10/229)	6.0	(14/235)	5.2	(24/464)
No PVI performed	0	(0/229)	1.7	(4/235)	0.9	(4/464)
PVI tested for bid. block	83	(191/229)	35	(80/231)	59	(271/460)
Block confirmed	97	(186/191)	84	(67/80)	93	(253/271)
Linear lesions performed	82	(188/229)	94	(220/235)	88	(408/464)
Box lesion	77	(176/229)	88	(206/235)	82	(382/464)
Other LA lesions	33	(75/229)	7.2	(17/235)	20	(92/464)
RA lesions	5.2	(12/229)	23	(53/235)	14	(65/464)
Linear lesions tested	78	(144/188)	44	(97/220)	59	(241/408)
Block confirmed	92	(133/144)	71	(68/96)	84	(201/240)
Marshall ablation	52	(120/229)	32	(74/235)	42	(194/464)
GP ablation	28	(63/229)	25	(58/235)	26	(121/464)
LAA management	90	(206/229)	75	(176/235)	82	(382/464)
Endocardial ablation						
PVI tested at start		–	97	(228/234)		–
PVI (touch-up)		–	30	(68/228)		–
LA lesions		–	55	(129/234)		–
RA lesions		–	57	(134/234)		–

AF, atrial fibrillation; Bid., bidirectional; GP, ganglionated plexi; LA, left atrial; LAA, left atrial appendage; PVI, pulmonary vein isolation; RA, right atrial.
[a]Including patients planned for hybrid ablation who did not undergo the endocardial part.

Table 4 In-hospital outcomes

	Epicardial[a] ($n = 229$) Percentage (number), mean ± SD		Hybrid ($n = 235$) Percentage (number), mean ± SD		Total ($n = 464$) Percentage (number), mean ± SD	
Major complications						
Mortality	0	(0/229)	0	(0/235)	0	(0/464)
Cardiac arrest	0.9	(2/229)	0	(0/235)	0.4	(2/464)
Stroke/TIA	0	(0/229)	0.4	(1/235)	0.2	(1/464)
Pacemaker	1.3	(3/229)	0.9	(2/235)	1.1	(5/464)
Conversion to sternotomy or minithoracotomy	3.9	(9/229)	0.4	(1/235)	2.2	(10/464)
Haematoma requiring transfusion or evacuation	0.4	(1/229)	1.3	(3/235)	0.9	(4/464)
Diaphragmatic haematoma requiring laparoscopy	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Diaphragmatic perforation	0	(0/229)	0.4	(1/235)	0.2	(1/464)
Phrenic nerve damage	1.3	(3/229)	1.3	(3/235)	1.3	(6/464)
Pulmonary vein stenosis	0	(0/229)	0.4	(1/235)	0.2	(1/464)
Surgical pleurodesis	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Respiratory insufficiency	0.4	(1/229)	0.9	(2/235)	0.6	(3/464)
Ileus	0.9	(2/229)	0	(0/235)	0.4	(2/464)
Sepsis	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Minor complications						
Hemothorax	0	(0/229)	1.7	(4/235)	0.9	(4/464)
Pleuradrainage	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Pulmonary embolism	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Pericarditis	1.3	(3/229)	2.1	(5/235)	1.7	(8/464)
Incomplete ablation due to bleeding	0.4	(1/229)	0	(0/235)	0.2	(1/464)
Total major events	10.5	(24/229)	6.0	(14/235)	8.2	(38/464)
Total events	13	(30/229)	10	(23/235)	11	(53/464)
Total patients with events	13	(29/229)	8.5	(20/235)	11	(49/464)
Discharge						
SR at discharge	87	(189/217)	78	(182/232)	83	(371/449)
SR at discharge stage 2	–		92	(67/73)	–	
AAD at discharge	63	(144/229)	72	(169/234)	68	(313/463)
AAD at discharge stage 2	–		59	(45/76)	–	
Hospital stay (days)	6.0 ± 3.5	$n = 228$	6.6 ± 3.4	$n = 228$	6.3 ± 3.5	$n = 456$
Hospital stay stage 2 (days)	–		2.4 ± 3.1	$n = 77$	–	

AAD, antiarrhythmic drugs class I or III; SR, sinus rhythm; TIA, transient ischaemic attack.
[a]Including patients planned for hybrid ablation who did not undergo the endocardial part.

The predominate type of AF was non-paroxysmal in 74% ($n = 342/464$), with a higher prevalence in patients treated by hybrid ablation (81%, $n = 197/244$). Nineteen per cent also suffered from AFL or AT ($n = 90/464$). A previous AF ablation, with the dominant lesions being PVI (99%, $n = 164/166$) and LA linear lesions (7.9%, $n = 13/164$), had been performed in 36% ($n = 166/464$) and was seen more often in epicardial ablation (42%, $n = 93/220$). Other techniques used during previous catheter ablation were CFAE ablation and RA lesions, both in 4.2% ($n = 7$). Rotor ablation was not performed.

Reason for treatment was reduction of symptoms in the majority of patients (92%, $n = 430/464$), while previous stroke, drug intolerance, patient preference, or contraindication for oral anticoagulation with the need for LAA closure was the leading indication in the remaining 8% ($n = 38/468$). The predominant symptom was palpitations (57%, $n = 266/464$), leading to an EHRA score of ≥2 in 97% of patients ($n = 450/464$). The mean duration of AF was 41 months [16–87] ($n = 460$). The median LA volume (LAV) was 80 mL [63–99] ($n = 263$). More baseline characteristics are summarized in *Table 1*.

Adhesions ($n = 3/468$) and anatomical difficulties ($n = 1/468$) impeded completion of the ablation procedure in 0.9%. Ablation in the remaining 464 patients was either performed as stand-alone epicardial (47%, $n = 220/464$) or as a hybrid ablation (53%, $n = 244/464$). In the hybrid group, three patients were included in which the procedure was performed using a pericardioscopic approach (1.2%, $n = 3/244$). The remaining patients received a thoracoscopic approach (99%, 241/244). In the epicardial group, the predominant access also was a thoracoscopic approach with 98% ($n = 216/220$), while 2% received a minithoracotomy ($n = 4/220$). In all procedures, radiofrequency ablation devices were used. Further characteristics of the intraoperative course are given in *Table 2*. In the hybrid group, the endocardial ablation was abandoned

Table 5 Follow-up

	Epicardial[a] ($n = 188$) Percentage (number), median [IQR]		Hybrid ($n = 167$) Percentage (number), median [IQR]		Total ($n = 355$) Percentage (number), median [IQR]	
Follow-up completed	82	(188/229)	71	(167/235)	77	(355/464)
Time to follow-up (D)	367 [332–406], $n = 187$		381 [352–423], $n = 164$		373 [340–416], $n = 351$	
After hybrid stage 2(D)	–		282 [208–378], $n = 26$		–	
Method of follow-up						
Clinical visit	66	(123/186)	98	(163/166)	81	(286/352)
Telephone	34	(63/186)	1.8	(3/166)	19	(66/352)
ECG only	15	(27/186)	17	(28/167)	16	(55/353)
Holter	62	(109/177)	77	(128/167)	69	(237/344)
7-day Holter	5.1	(9/177)	17	(28/167)	11	(37/344)
Event recorder	12	(22/178)	1.2	(2/166)	7.0	(24/344)
Pacemaker/ICD	11	(21/186)	6.0	(10/166)	8.8	(31/352)
Rhythm						
Freedom from AF/AT/AFL	77	(143/186)	81	(136/167)	79	(279/353)
Freedom from AF/AT/AFL off AAD	60	(111/185)	67	(112/166)	64	(223/351)
AF recurrence	70	(30/43)	68	(21/31)	69	(51/74)
AFL/AT recurrence	56	(24/43)	52	(16/31)	54	(40/74)
Cardioversion	40	(17/43)	42	(13/31)	41	(30/74)
Repeated ablation	19	(8/43)	26	(8/31)	22	(16/74)
Oral anticoagulation	64	(116/182)	66	(106/161)	65	(222/343)
EHRA I	71	(130/182)	72	(103/143)	72	(233/325)
EHRA II	22	(40/182)	25	(36/143)	23	(76/325)
EHRA III–IV	6.6	(12/182)	2.8	(4/143)	4.9	(16/325)

AAD, antiarrhythmic drugs class I or III; AF, atrial fibrillation; AFL, atrial flutter; AT, atrial tachycardia; D, days; ICD, internal cardioverter defibrillator.
[a]Including patients planned for hybrid ablation who did not undergo the endocardial part.

in nine patients (3.7%, $n = 9/244$) due to intraoperative bleeding complications (1.6%, $n = 4/244$, one-stage), withdrawn consent (0.8%, 2/244, two-stage), or atrioesophageal fistula (0.4%, $n = 1/244$, two-stage), and in two patients, the endocardial ablation was not yet planned at the time of closure of the registry (0.8%, 2/244, two-stage). The median time between the epicardial and endocardial ablation in the hybrid two-stage group was 13 days [10–19] ($n = 75$). Ninety per cent ($n = 69/77$) of the patients underwent the second ablation within 6 months after the epicardial index procedure; in the remaining 10% ($n = 8/77$), the time frame for hybrid ablation was exceeded.

The main lesion sets applied consisted of PVI (99%, $n = 460/464$) and isolation of the LA posterior wall (82%, $n = 383/464$) (*Table 3*). In 82% ($n = 382/464$), the LA appendage (LAA) was managed. In the hybrid setting, there was fewer testing of lesions for bidirectional block during the epicardial procedure compared to epicardial only ablation (35% vs. 83% for PVI and 44% vs. 78% for the linear lesions). During the endocardial part of the hybrid ablation, a touch-up PVI was performed in 30% ($n = 68/228$).

The overall in-hospital major complication rate was 8.2% ($n = 38/464$) with conversion to minithoracotomy/sternotomy due to perforation/bleeding (2.2%, $n = 10/464$) and phrenic nerve injury (1.3%, $n = 6/464$) being the main causes (*Table 4*). A pacemaker was implanted in 1.1% ($n = 5/464$). Intraprocedural cardiac arrest occurred in one patient due to a thrombus in the left coronary; the cause in the other patient is unknown. The addition of endocardial catheter ablation in the hybrid group did not affect the major complication rate (10.5%, $n = 24/229$ epicardial vs. 6.0%, $n = 14/235$ hybrid). The median hospital stay was 6.3 ± 3.5 days ($n = 456$). Patients receiving a two-stage ablation stayed 2.4 ± 3.1 days ($n = 77$) more in the hospital for the catheter ablation.

Follow-up was completed in 77% ($n = 353/464$) of the patients with a median follow-up of 373 days [340–416] ($n = 351$). In 83% of the patients ($n = 292/352$), a Holter monitoring was performed or rhythm was verified via an implanted event recorder, pacemaker, or ICD. The remaining patients received an ECG only. Follow-up data are presented in *Table 5*. Freedom from AF, AFL, and AT with use of AAD class I or III was achieved in 79% of patients ($n = 279/353$), with a trend of hybrid ablation revealing better rhythm outcome than epicardial only ablation (*Figure 1A* and *B*). The EHRA score at follow-up was clearly reduced by the ablation compared to preoperatively (EHRA I: 72%, $n = 233/325$, vs. 3%, n = 14/464) (*Figure 2*).

During follow-up, two patients died: one 6 weeks after the procedure due to atrioesophageal fistula and one 15 months post-procedural due to unknown reason. Furthermore, four pacemakers for bradycardia were implanted (1.1%, $n = 4/355$). One patient was diagnosed with PV stenosis (0.3%, $n = 1/355$). Other complications which occurred during follow-up are listed in *Table 6*.

Discussion

The international EHAFA registry is one of the largest of its kind capturing current treatment strategies and outcomes of surgical epicardial as well as epi-/endocardial hybrid ablation in lone AF. As an

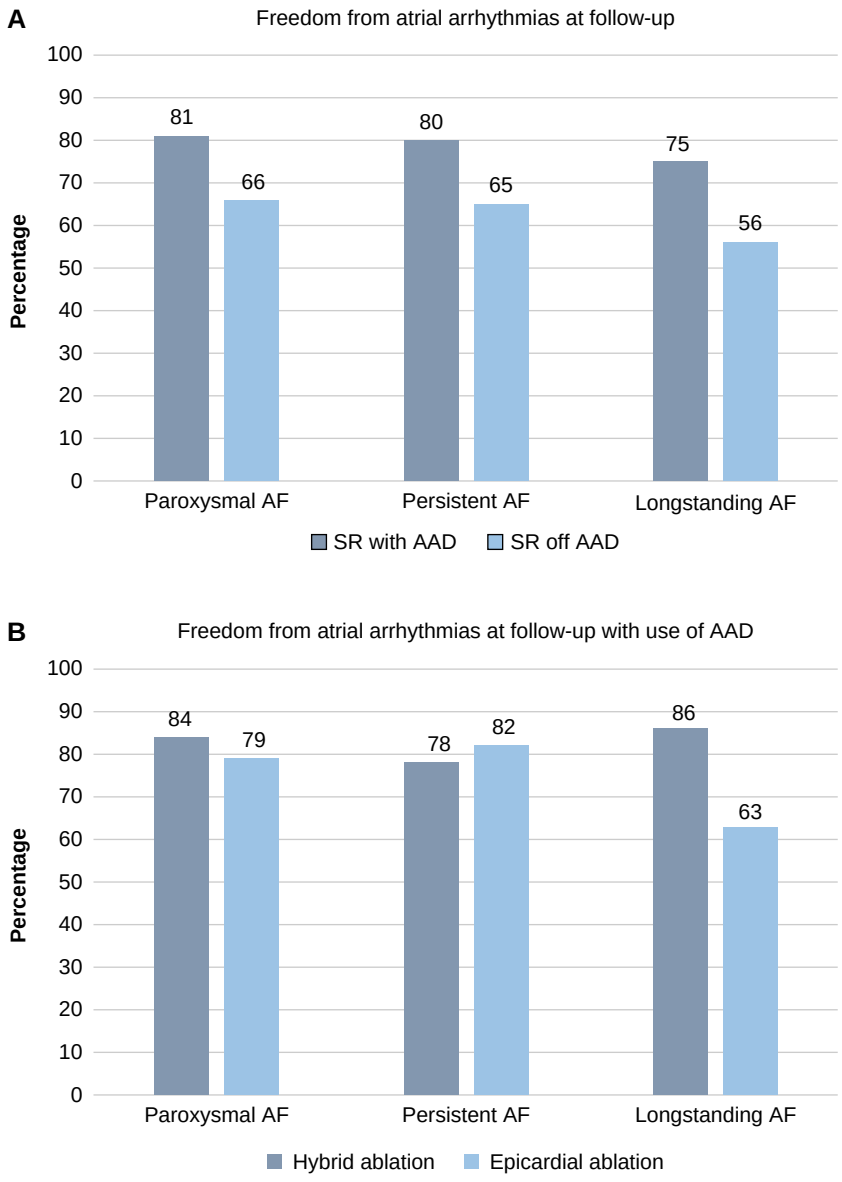


Figure 1 AAD, antiarrhythmic drugs class I or III; AF, atrial fibrillation; SR, sinus rhythm.

observational registry without in- and exclusion criteria or specific requirements on the applied treatment strategy or technique, it is believed that reported data of 464 patients reflect a real-world assessment.

The majority of patients treated with above modalities presented with non-PAF (74%) and an enlarged LA (80 mL [63–99]). In 36%, previous catheter ablation had failed. That is in line with rather unsatisfactory success rates which can be expected for catheter ablation only in this difficult to treat patient sub-group and confirms characteristics reported in other observational studies for these ablation techniques.[14,15] In terms of treatment strategy, the EHAFA registry could reveal an equal distribution of epicardial ($n = 220$) and hybrid ablation ($n = 244$). The pericardioscopic Convergent procedure, which reflects a mandatory hybrid approach, was only performed in three patients. While this approach evolved to one of the predominant hybrid ablation strategies, meanwhile, this technique was not widely adopted yet at the time the registry started.[16]

While literature on endocardial ablation could not conclusively show improved rhythm outcome for ablation strategies beyond PVI, a box lesion isolating the PVs and the posterior atrial wall has been the predominant lesion set for epicardial ablation in this registry, confirming the preferred lesion set reported for surgical ablation in previously published literature.[15,17] The used devices for epicardial ablation might overcome limitations of endocardial catheter technology in creating transmural lesions at the LA posterior wall to a certain extend and therefore might be better suited to target this area as a critical substrate in patients with non-PAF. In addition, a general high amount of ganglionated plexi ablation and division of the ligament of Marshall were observed. Data on the effect of ganglionated plexi ablation are not conclusive, and the only randomized trial showed no benefit but a higher rate of procedural complications.[18] Similarly, data on the beneficial effect of ablating the ligament of Marshall are arising but still not conclusive enough for guidelines to recommend it. Still, both structures are easily accessible during an epicardial approach which might lead to a low threshold for targeting those.

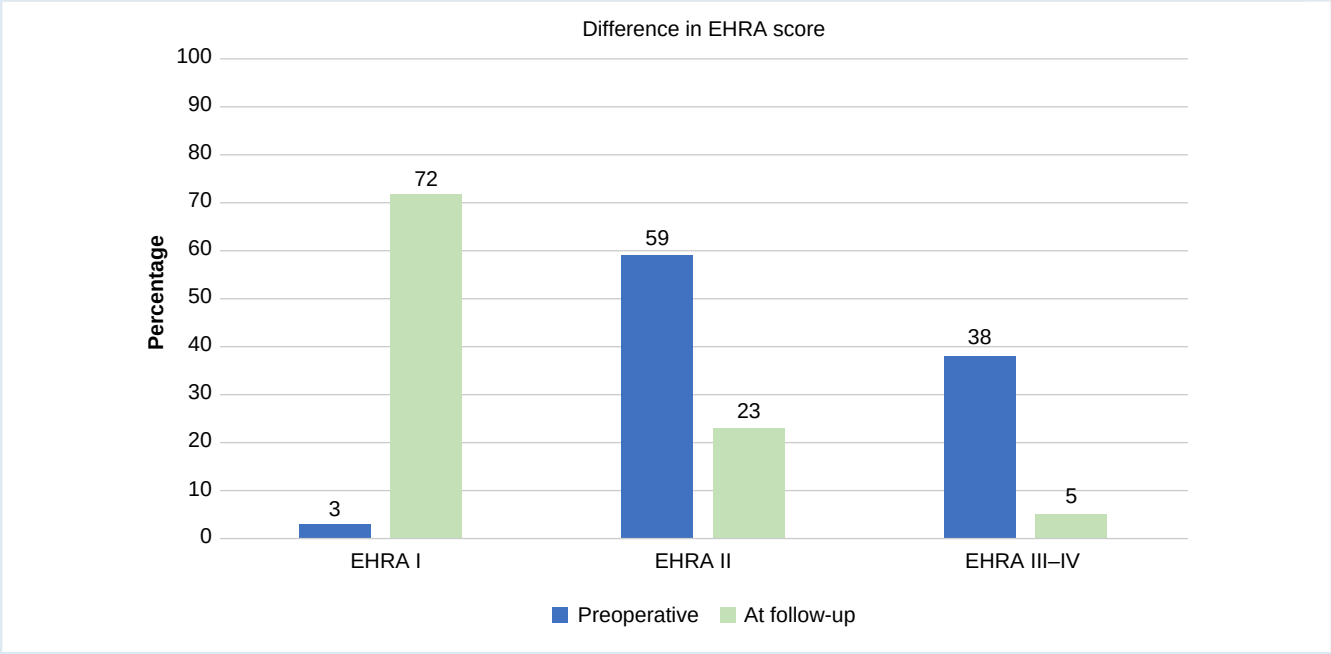


Figure 2 EHRA Score, European Heart Rhythm Association score of atrial fibrillation.

The LAA is known to be a major source for thromboembolic events in AF patients. The LAAOS III trial revealed nearly 33% stroke reduction with LAA management, which was additive to oral anticoagulation.[19] Furthermore, the LAA might also represent a trigger source and its electrical isolation might contribute to SR restoration.[20] In the current registry, the LAA was managed in 90% of the patients receiving epicardial ablation and in 75% of the patients receiving hybrid ablation. An overall stroke rate of 1.4% was seen through follow-up ($n = 5/353$). This reflects differences in how centres either implement LAA management as a general treatment strategy or as an action which is taken according to the patients CHA_2DS_2-VASc score. In general, epicardial ablation allows for easy access to the LAA with effective devices available to exclude and electrically isolate the LAA with almost no anatomical restrictions. Therefore, adoption is higher in this registry than in studies reporting on endocardial ablation only.

The total in-hospital complication rate in this registry was considerably high with 11%. While the majority of complications had no life-impacting character, we still need to balance a considerable risk against a certain treatment benefit expected with the studied treatment modalities. In general, a certain learning curve for a thoracoscopic procedure is evident and about 25% of the centres participating in this registry were expected to not having had high expertise in the procedure yet at the time of enrolment. Therefore, new technologies as well as experience seem to be indicators for a reduction in complication rates reported in meta-analyses and randomized controlled trials.[21,22] On the other hand, the minimal invasive character of the procedure did not increase non-resolvable complications compared to open surgical ablation using extracorporeal circulation.[7] One patient in the current registry receiving an epicardial ablation developed a lethal atrioesophageal fistula, one of the most feared complications of endocardial AF ablation. Oesophageal lesions on routine endoscopy after endocardial AF ablation can be found in 10–15% and ulcerations in circa 5% of patients.[23] Atrioesophageal fistulae occur in about 0.025%.[24] It is hypothesized that it results from transmural ablation lesion extending through the atrial wall to the oesophagus followed by subsequent ulcer erosion from gastroesophageal reflux.[25] However, in surgical epicardial ablation, the energy is directed and driven away from the oesophagus. This is why this complication would be actually not expected if the device is kept under vision and is not misused with regard of positioning. Still, heat transfer of the ablated tissue after ablation might be underestimated and could cause thermal damage to the oesophagus without direct device-energy interference.[26]

This registry showed an overall freedom from AF, AT, and AFL with and without the use of AADs of 79% and 64%, respectively. These results are solid considering the patients included being rather difficult to treat and are comparable to the few other multicentre studies comprising larger patients groups.[21,22,27] The addition of endocardial ablation in the hybrid group improved rhythm outcome by 4–7% (with and without the use of AAD respectively), with the most distinct improvement in LSPersAF. While several randomized trials are published comparing surgical ablation with catheter ablation, there are no randomized trials comparing epicardial with hybrid ablation. However, experienced centres reported better rhythm outcome as seen in this registry with up to 90% SR restoration after hybrid ablation independently from type of AF.[28,29] Improved outcome by checking the epicardial lesions and performing touch-up ablation where indicated, as well as adding lesions that cannot be performed epicardially, is expectable and could be revealed to a certain extend in this registry. A notable finding in this registry was that touch-up PVI was performed in 30% of the patients who underwent hybrid ablation. Although this percentage may seem high, it is likely related to the nature of the hybrid approach, where less testing for bidirectional block of lesions was conducted during the epicardial procedure. In general, rhythm outcome as well as complications in this study did not substantially differ from a recently published large randomized controlled trial investigating hybrid ablation.[22]

The patients included in this registry were all symptomatic, with the majority of patients complaining of moderate-to-severe symptoms (EHRA II–III). Consequently, reason for treatment was reduction of symptoms in the majority of patients (92%). At follow-up, a clear improvement in EHRA score compared to pre-procedural could be confirmed, with 72% of the patients reporting not having any symptoms anymore. Since AF can significantly reduce quality of life, this should

Table 6 Complications during follow-up

	Epicardial[a] ($n = 188$) Percentage (number), median [IQR]		Hybrid ($n = 167$) Percentage (number), nedian [IQR]		Total ($n = 355$) Percentage (number), median [IQR]	
Major complications						
Mortality	1.1	(2/188)	0	(0/167)	0.6	(2/355)
Pacemaker	1.6	(3/188)	0.6	(1/167)	1.1	(4/355)
Stroke/TIA	1.6	(3/188)	1.2	(2/167)	1.4	(5/355)
Sternotomy for bleeding	0.5	(1/188)	0	(0/167)	0.3	(1/355)
Pseudoaneurysm	0	(0/188)	0.6	(1/167)	0.3	(1/355)
Phrenic nerve damage	1.1	(2/188)	0.6	(1/167)	0.8	(3/355)
Tamponade requiring puncture/drainage	1.1	(2/188)	0.6	(1/167)	0.8	(3/355)
Femoral bleeding	0	(0/188)	0.6	(1/167)	0.3	(1/355)
Pulmonary vein stenosis	0.5	(1/188)	0	(0/167)	0.3	(1/355)
Minor complications						
Pericarditis	3.2	(6/188)	1.8	(3/167)	2.5	(9/355)
Pleural puncture	1.6	(3/188)	0	(0/167)	0.8	(3/355)
Pulmonary embolism	0.5	(1/188)	0	(0/167)	0.3	(1/355)
Therapy for heavy pain	1.1	(2/188)	0	(0/167)	0.6	(2/355)
Total major events	7.4	(14/188)	4.2	(7/167)	5.9	(21/355)
Total events	14	(26/188)	6.0	(10/167)	10	(36/355)
Total patients with events	13	(25/188)	6.0	(10/167)	9.9	(35/355)

TIA, transient ischaemic attack.
[a]Including patients planned for hybrid ablation who did not undergo the endocardial part.

remain an important endpoint for AF ablation and should be taken into account when considering success of a specific treatment approach.

There are several limitations when evaluating registry data. As such, it is impossible to define which exact lesion might have contributed to success or failure. Since the ablation was performed according to each centres and surgeon's clinical practice, there was no standardized approach in either group for the different types of AF. While registry data usually are less standardized and also lacking specific inclusion and exclusion criteria, it represents a mixture of treatment strategies as well as experience levels which reflects not only in differences in outcome but also in differences in documented complications. Second, we did not pre-specify electrophysiologist experience criteria and did not record individual operator volumes, which may introduce unmeasured confounding related to operator skill.

Conclusion

The international EHAFA registry revealed good mid-term rhythm control in patients presenting with advanced AF. Isolation of the LA posterior wall including PVI is the predominant lesion set applied, and LAA management was performed in the vast majority of patients in EHAFA procedures, resulting in acceptable rhythm outcome, a low stroke rate, and a clear reduction in AF-related symptoms during a follow-up of 1 year. In comparison, hybrid ablation, combining epi with endocardial lesions, tends to perform better than epicardial-only ablation, especially in patients with advanced AF. Complication rates remain a matter of concern in surgical ablation. While non-resolvable and therefore life-impacting complications remain low, the overall complication rate is considerably high and requires a thoughtful assessment in analysing the given benefit-risk ratio and choosing the right treatment strategy.

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Data availability

Upon reasonable request, the data that support the findings of this study are available from the Registries team: registries@escardio.org.

Appendix

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