

ORIGINAL RESEARCH

Severe Periprocedural Complications After Ablation for Atrial Fibrillation

An International Collaborative Individual Patient Data Registry

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ABSTRACT

BACKGROUND Catheter ablation for atrial fibrillation (AF) including pulmonary vein isolation and possibly further substrate ablation is the most common electrophysiological procedure. Severe complications are uncommon, but their detailed assessment in a large worldwide cohort is lacking.

OBJECTIVES The aim of this study was to determine the incidence of periprocedural severe complications and to provide a detailed characterization of the diagnostic evaluation and management of these complications in patients undergoing AF ablation.

METHODS Individual patient data were collected from 23 centers worldwide. Limited data were collected for all patients who underwent catheter ablation, and an expanded series of data points were collected for patients who experienced severe complications during periprocedural follow-up. Incidence, predictors, patient characteristics, management details, and overall outcomes of patients who experienced ablation-related complications were investigated.

RESULTS Data were collected from 23 participating centers at which 33,879 procedures were performed (median age 63 years, 30% women, 71% radiofrequency ablations). The incidence of severe complications ($n = 271$) was low (tamponade 6.8‰, stroke 0.97‰, cardiac arrest 0.41‰, esophageal fistula 0.21‰, and death 0.21‰). Age, female sex, a dilated left atrium, procedure duration, and the use of radiofrequency energy were independently associated with the composite endpoint of all severe complications. Among patients experiencing tamponade, 13% required cardiac surgery. Ninety-three percent of patients with complications were discharged directly home after a median length of stay of 5 days (Q1-Q3: 3-7 days).

CONCLUSIONS This large worldwide collaborative study highlighted that tamponade, stroke, cardiac arrest, esophageal fistula, and death are rare after AF ablation. Older age, female sex, procedure duration, a dilated left atrium, and the use of radiofrequency energy were associated with severe complications in this multinational cohort. One in 8 patients with tamponade required cardiac surgery. (J Am Coll Cardiol EP 2024;■:■-■) © 2024 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

**ABBREVIATIONS
AND ACRONYMS****AF** = atrial fibrillation**CPR** = cardiopulmonary resuscitation**EF** = esophageal fistula**ICE** = intracardiac echocardiography**LA** = left atrial/atrium**PV** = pulmonary vein**PVI** = pulmonary vein isolation**VF** = ventricular fibrillation

Atrial fibrillation (AF) is a growing public health problem and is currently leading to an increasing burden of morbidity, mortality, and hospitalizations worldwide.^{1,2} Catheter ablation has gained considerable popularity in the management of AF, and the indications for this procedure have widened in recent years, thereby increasing the number of patients undergoing pulmonary vein isolation (PVI) worldwide.¹⁻³

Periprocedural severe complications are rare, with tamponade and stroke being the 2 most common. The incidence of hemodynamically relevant pericardial complications and stroke has been estimated at 0.8% to 1.5% and 0.3% to 1%, respectively, in prior analyses of large retrospective studies and recent randomized controlled trials or registries.⁴⁻¹⁸ A recent worldwide survey revealed an incidence of 0.25‰ for esophageal fistula (EF).¹⁹ Although rare, these severe complications may lead to severe morbidity or mortality and increase health care utilization.

Given the continuous technological improvements associated with new catheter generations, improved ablation techniques, and increasing center experience worldwide, the incidence of these complications as well as their pragmatic management may evolve. Although previous studies provided incidence rates for these complications, most were conducted in a single country,^{4,6,9,11,12,14-18} thereby limiting their generalizability, or were based on insurance claims data,^{4,6,12} thereby limiting data granularity regarding complication management and the population included (eg, a U.S.-insured population only,⁶ patients ≥ 65 years of age only).^{4,12}

The aim of this large collaborative international project was to determine the incidence of periprocedural severe complications (cardiac tamponade, stroke, cardiac arrest, EF, and procedure-related death) and to provide a detailed characterization of the diagnostic evaluation and management associated with these complications in patients undergoing AF ablation.

METHODS

The results of this collaborative project are reported according to the Strengthening the Reporting of Observational Studies in Epidemiology statement²⁰ (Supplemental Table 1).

CALL FOR DATA, INDIVIDUAL PATIENT DATA COLLECTION, AND DATA SET MERGING. We personally contacted investigators in September 2020 and asked for participation. A sample of 41 centers were contacted based primarily on a previously established “PVI collaborative network,”¹⁰ in which investigators had formerly shown their interest to share and provide high-quality data stemming from investigator-initiated studies. The contacted investigators were encouraged to refer further centers. We asked for data from patients >18 years of age presenting in a consecutive fashion to undergo catheter ablation (PVI with or without specific lesion sets) for AF. We did not restrict the type of study design (randomized controlled trials, prospective registries or observational studies, retrospective data sets) if the incidence, diagnosis, and management of severe complications were carefully recorded, with at least a periprocedural follow-up (at least in hospital, if available any readmission or ambulatory visit

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postdischarge in which a complication likely related to the initial procedure was observed). Ultimately, after data collection, investigators offered data ranging from 2010 to 2022. We did not accept participation from centers missing essential baseline characteristics or missing the collection of sufficient details on the severe complications. We also did not accept participation of centers willing to provide fewer than 100 cases, to avoid numerically small and highly selected patient cohorts.

Few data points were required for the overall group of patients undergoing PVI, and an exhaustive REDCap database was established to collect exact patient characteristics, preprocedural diagnostic evaluation, and procedural and complication details for each patient who experienced a severe complication. A survey was sent to every participating center to record center-specific data. Additional details on data collection, data quality control, and merging of the data sets are provided in the [Supplemental Appendix](#).

This collaborative project was approved by the Institutional Review Board of the University Hospital Basel. Collaborating investigators all confirmed the existence of Institutional Review Board approval for their respective projects, if necessary, as required by local regulations and study design. Data use agreements were obtained when required by local institutions.

AIMS AND OUTCOMES. The 2 main goals of this study were: 1) to report the incidence of severe complications associated with AF ablation in a large collective of investigator-initiated studies worldwide; and 2) to accurately describe these complications and their management. We decided to focus on the specific complications of cardiac tamponade, cardiac arrest, stroke, EF and death, as these complications are linked with substantial morbidity, may increase health care utilization, and can be directly attributed to the procedure.

The endpoint of tamponade was defined as the development of a significant pericardial effusion (resulting in hemodynamic compromise, requiring urgent treatment, and/or resulting in ≥ 1 -cm pericardial effusion on echocardiography; see the [Supplemental Appendix](#)) during the AF ablation procedure or the subsequent hospitalization. Cardiac tamponade was deemed delayed if it took place 1 hour or more after the procedure.²¹ Stroke was defined as the rapid onset of a focal or global neurologic deficit lasting at least 24 hours without therapeutic intervention, with confirmation of the diagnosis either by imaging or by a neurologist.⁸

Cardiac arrest was defined as ventricular fibrillation (VF) requiring defibrillation or cardiopulmonary resuscitation (CPR) or asystole requiring CPR. EF included atriopharyngeal fistula, esophagopericardial fistula, and EF. When available, the collaborators provided follow-up, including complications taking place after discharge which could be likely linked to the initial procedure.

Additional details regarding outcome definitions are provided in the [Supplemental Appendix](#). A combined endpoint of tamponade, stroke, cardiac arrest, EF, and death was used in regression analysis.

An investigation of the relationship between center size and the incidence of complications was prespecified.

STATISTICAL ANALYSIS. Continuous variables are presented as mean \pm SD or median (Q1-Q3). The Fisher exact test (count per cell < 5) or chi-square was applied for comparisons of categorical variables. All tests were 2-sided, and a *P* value < 0.05 was considered to indicate statistical significance.

Before regression analyses in the overall cohort, missing data were imputed, and a 1-stage analysis was conducted on the merged data set using a multilevel data multiple imputation algorithm. A mixed-effects logistic regression model using a unique center identifier and the year of study start as random effects was fit to evaluate the effect of patient and center characteristics on the composite outcome or severe complications and tamponade alone, summarizing the imputed data sets using Rubin's rule. Patient and center characteristics evaluated as fixed effects are presented in the results. No outcome values were imputed. The rate of missing data was $< 1\%$ for essential data points. Statistical details are available in the [Supplemental Appendix](#).

All statistical analyses were performed using the R (R Foundation for Statistical Computing; see the [Supplemental Appendix](#)).

RESULTS

PARTICIPATING CENTER CHARACTERISTICS. Of the 41 contacted electrophysiology centers, 23 centers from 13 different countries agreed to participate (56%) with their data sets, providing a total of 33,879 AF ablation procedures. Importantly, all collaborators provided data stemming from observational studies. None of the provided data had been collected for the purpose of a randomized controlled trial. Five centers were located in the United States, 13 in Europe, and 5 in Asia. All centers were relatively large, performing a median of 400 AF ablations per year (Q1-Q3: 300-525;

TABLE 1 Characteristics in the Overall Patient Cohort (N = 33,879)

Age, y	33,790	63.00 (55.00-69.39)
Sex	33,838	
Female		10,203/33,838 (30)
Male		23,635/33,838 (70)
LVEF, % ^a	25,160	60.00 (55.00-64.03)
LA size ^a	27,729	
Normal		10,928/27,729 (39)
Mildly abnormal		7,866/27,729 (28)
Moderately abnormal		5,458/27,729 (20)
Severely abnormal		3,477/27,729 (13)
Type of AF	33,186	
Paroxysmal		19,530/33,186 (59)
Persistent		12,843/33,186 (39)
Long-standing persistent		716/33,186 (2.2)
Permanent		97/33,186 (0.3)
Anticoagulation ^a	28,604	
None		2,526/28,604 (8.8)
Antiplatelet agents only		101/28,604 (0.4)
Vitamin K antagonist		6,752/28,604 (24)
DOAC		19,030/28,604 (67)
Low-molecular weight heparin		195/28,604 (0.7)
Energy source	33,539	
Radiofrequency		23,874/33,539 (71)
Cryoballoon		9,007/33,539 (27)
Combined/other		625/33,539 (1.9)
Procedure aborted before any energy application		33/33,539 (<0.1)
Procedure duration, min ^a	27,673	149.00 (108.00-198.00)
Medical history		
Stroke or thromboembolism	32,627	2,241/32,627 (6.9)
Hypertension	32,588	16,683/32,588 (51)
Diabetes mellitus	32,515	3,706/32,515 (11)
Congestive heart failure	33,322	3,793/33,322 (11)
Vascular disease	32,528	3,526/32,528 (11)
CHA ₂ DS ₂ -VASc score	32,049	
0		6,777/32,049 (21)
1		8,508/32,049 (27)
2		7,419/32,049 (23)
3		5,145/32,049 (16)
4		2,643/32,049 (8.2)
5		1,070/32,049 (3.3)
6		359/32,049 (1.1)
7		102/32,049 (0.3)
8		21/32,049 (<0.1)
9		5/32,049 (<0.1)
Severe complications		
Tamponade	33,879	232/33,879 (0.7)
Tamponade requiring surgery	33,879	
Tamponade not requiring surgery		201/33,879 (0.6)
Tamponade requiring surgery		31/33,879 (<0.1)
Stroke	33,879	33/33,879 (<0.1)
Cardiac arrest	33,879	14/33,879 (<0.1)
Esophageal fistula	33,879	7/33,879 (<0.1)
Death	33,879	
Yes, intraprocedurally or immediately postprocedure		1/33,879 (<0.1)
Yes, but at a later time point (up to 30 d postprocedure, if available)		6/33,879 (<0.1)

Values are n, median (Q1-Q3), or n/N (%). ^aFor LVEF, 8,720 data points (25.7%) were missing; for LA size, 6,304 data points (18.6%) were missing; for anticoagulation, 5,277 data points (15.6%) were missing; and for procedure duration, 6,217 data points (18.3%) were missing. All other variables had <5% missing values. For definition of LA size, see the [Supplemental Methods](#).

AF = atrial fibrillation; DOAC = direct oral anticoagulant agent; LA = left atrial; LVEF = left ventricular ejection fraction.

range: 50-1,200). The largest U.S. center provided about 20% of the total number of cases. The vast majority of centers (20 of 23 centers [87%], covering 96% of the patients) had cardiac surgery departments on site. Thirty percent of the centers (7 of 23) were routinely using intracardiac echocardiography (ICE) intraprocedurally ([Supplemental Table 2](#)).

OVERALL BASELINE PATIENT CHARACTERISTICS. The baseline patient characteristics for the 33,879 included procedures are presented in [Table 1](#). The median age of the cohort was 63 years (Q1-Q3: 55-69 years), and 70% of patients were men. The majority of ablations was performed using radiofrequency energy (71%), and 59% of ablations were performed for paroxysmal AF. Of note, 33 ablations (<0.1%) were interrupted before any energy delivery because of severe complications. The median procedure duration was 149 minutes (Q1-Q3: 108-198 minutes). Of the comorbidities relevant to the calculation of the CHA₂DS₂-VASc score, hypertension was the most common (51%) among patients.

INCIDENCE OF SEVERE COMPLICATIONS DURING PERIPROCEDURAL FOLLOW-UP. The incidence of any severe complication was 0.8% (271 of 33,879) ([Table 2](#)).

Tamponade was the most common severe complication, occurring in 232 of 33,879 (0.7%; 7 of 1,000 AF ablations) of patients. Of the 232 patients who experienced tamponade, 31 (13.3%; 0.09% of the overall cohort) required cardiac surgery. Stroke, cardiac arrest, and EF were much less common, with incidence rates of <0.1% (stroke 0.97‰, cardiac arrest 0.041‰, and EF 0.21‰). Of those who experienced cardiac arrest, 75% (9 of 12) had concomitant pericardial tamponade. In total, 7 patients died of a procedure-related event (1 intraprocedurally, 6 at later time points during the same or subsequent admissions) ([Central Illustration](#)). Of the 7 patients who died, 4 had experienced tamponade and 3 EF. One of the 4 patients who died of tamponade underwent ablation at a center without cardiac surgery backup. The temporal occurrence of severe complications is presented in [Supplemental Figure 1](#).

PREDICTORS OF SEVERE COMPLICATIONS. In univariable models, age, sex, diabetes, hypertension, vascular disease, a dilated left atrium (LA), procedure duration, and ablation using radiofrequency or combined or other energy sources (laser or hot balloon) significantly predicted the incidence of the combined endpoint of tamponade, stroke, cardiac arrest, EF and death ([Supplemental Table 3](#)). The center-based use of ICE was not significantly associated with these

complications. In the multivariable model predicting the composite endpoint of all severe complications (Figure 1, Supplemental Table 4), older age (OR per 10-year increase: 1.2; 95% CI: 1.1-1.4; $P = 0.005$), female sex (OR: 1.7; 95% CI: 1.3-2.2; $P < 0.001$), a dilated LA (OR: 2.2; 95% CI: 1.5-3.1; $P < 0.001$), the use of radiofrequency energy (OR: 2.1; 95% CI: 1.5-3.1; $P < 0.001$), and procedure duration (OR per 10-minute increase: 1.2; 95% CI: 1.1-1.3; $P < 0.001$) remained predictors. Of note, the absence of any energy source denoted ablations that were aborted before energy application because of the occurrence of severe complications.

Univariable models assessing the occurrence of stroke in the overall cohort highlighted a longer procedure duration, a history of stroke, and female sex as predictors (Supplemental Table 5).

IMPACT OF THE ENERGY SOURCE USED FOR ABLATION. Most ablations were conducted using radiofrequency (23,874 [71%]) or cryoballoons (9,007 [27%]). Laser, pulsed-field ablation, and hot balloons were used sporadically. The incidence of severe complications was twice as high with the use of radiofrequency than cryoballoons (8‰ vs 4‰), but a larger proportion of the tamponades following cryoballoon ablation required cardiac surgery (0.89‰ of cryoballoon ablations vs 0.63‰ of radiofrequency ablations) (Supplemental Table 6). Regarding the use of radiofrequency catheters, non-contact-force-sensing catheters accounted for 104 of 179 of tamponades (58%), while contact-force-sensing catheters accounted for 75 of 179 (42%).

The majority of the complicated procedures involved performing a supplementary lesion set (192 of 271 [71%]) (Supplemental Table 7).

DETAILS OF DIAGNOSIS AND MANAGEMENT OF SEVERE COMPLICATIONS. Baseline characteristics of patients presenting with severe complications are presented in Supplemental Table 8. Briefly, patients who experienced severe complications had a median age of 66 years (Q1-Q3: 59-71 years) and presented with paroxysmal AF in 58% of cases. Of note, although most patients were anticoagulated, only very few had experienced relevant bleeding complications in the past.

Tamponade complicated the procedures of 232 patients and occurred mostly during the isolation of the left pulmonary veins (PVs) (24%) (Supplemental Table 9). A total of 185 of 232 tamponades (80%) took place intraprocedurally or directly postprocedurally, and 47 of 232 (20%) presented with a delay. The large majority of the patients experiencing tamponade did not pause their anticoagulation prior

TABLE 2 Outcomes of the Overall Cohort (N = 33,879)

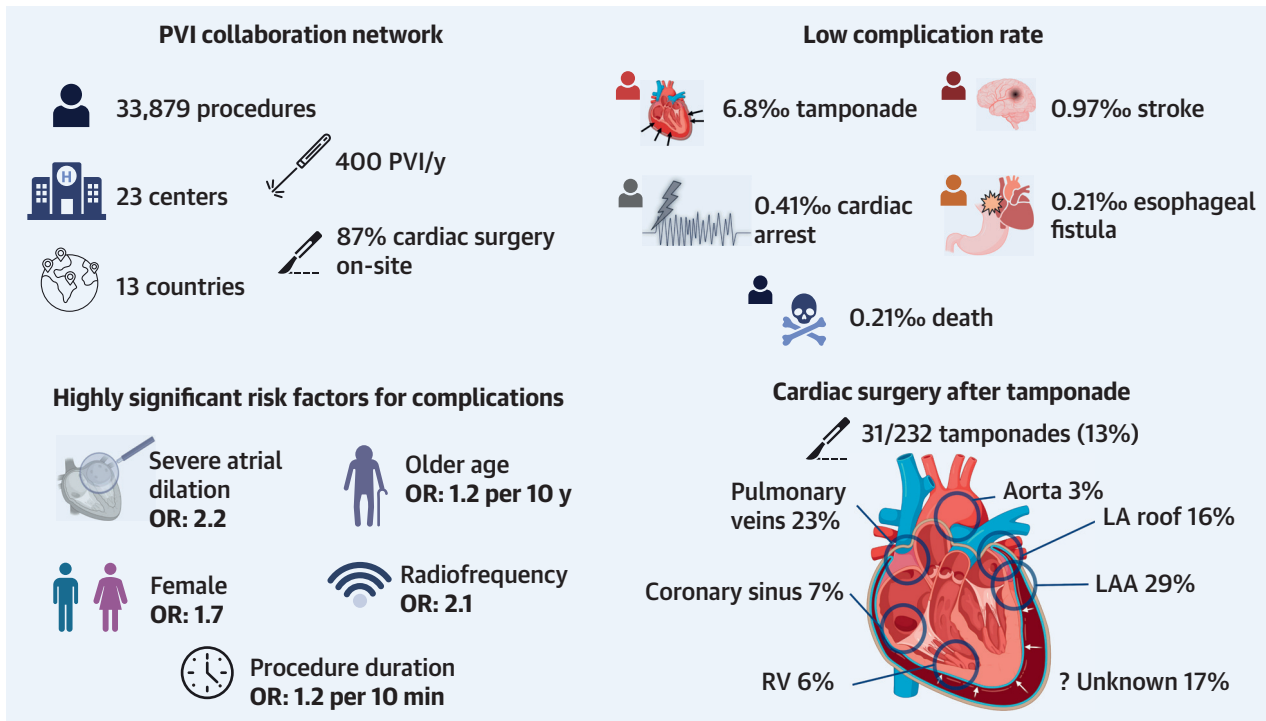
Outcome	n/N (%)	95% CI
Tamponade	232/33,879 (0.7)	0.60%-0.78%
Tamponade not requiring surgery	201/33,879 (0.6)	
Tamponade requiring surgery	31/33,879 (<0.1)	
Stroke	33/33,879 (<0.1)	0.07%-0.14%
Cardiac arrest	14/33,879 (<0.1)	0.02%-0.07%
Esophageal fistula ^a	7/33,879 (<0.1)	0.01%-0.04%
Death	7/33,879 (<0.1)	0.01%-0.04%
Yes, intraprocedurally or immediately postprocedure	1/33,879 (<0.1)	
Yes, but at a later time point (up to 30 d postprocedure ^a)	6/33,879 (<0.1)	

^aThirty-day follow-up was not systematically performed.

to the procedure (167 of 248 [67%]). Only 10% and 14% of patients required an autotransfusion of pericardial blood and allogenic packed red blood cells, respectively. The use of fresh-frozen plasma or thrombocyte concentrate was rare (19 of 232 [8.2%] and 14 of 232 [6%]). One-half of the procedures had to be aborted because of complications. The vast majority of patients (97%) required pericardiocentesis. In the remaining 3% of patients, the initially hemodynamically significant pericardial effusion was managed using a conservative approach. Among all patients with tamponade, 13% required cardiac surgery (4 of 31 [13%] as a primary approach and 27 of 31 [87%] as a subsequent treatment because of ongoing bleeding into the pericardial space and an unstable hemodynamic state). Three of 47 (6.4%) of delayed tamponades vs 28 of 185 of intra- or periprocedural tamponades (15.1%) required surgical management.

Presumed mechanisms were reported for 46% of the patients experiencing tamponade, with 34% occurring during energy delivery for AF ablation and 34% occurring immediately after trans-septal puncture. Of the 31 patients who underwent cardiac surgery for tamponade, perforations could be localized in 26 (84%), with the LA appendage (29%) and PVs (23%) being the most common locations (Central Illustration, Figure 2, Supplemental Table 10).

Of the 33 strokes that occurred, the majority (82%) were ischemic and noticed shortly postprocedure (36% just after the procedure). Three were recorded in patients presenting with EF during subsequent hospitalizations. Among patients with this complication, 8 of 33 had stopped their anticoagulation before the procedure and were bridged with heparin, 25 of 33 continued their oral anticoagulation throughout the procedure, and 29 of 33 had undergone transesophageal echocardiography, computed tomography, or magnetic resonance imaging before ablation

CENTRAL ILLUSTRATION The Present Atrial Fibrillation Ablation Complication Network Encompassed 23 Different Centers From 13 Countries That Provided a Total of 33,879 Procedures

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The median number of pulmonary vein isolation (PVI) procedures with or without other lesion sets conducted per center was 400 per year. Highly significant risk factors ($P < 0.005$) for complications were the presence of a severely dilated left atrium (LA), female, older age, procedure duration, and the use of radiofrequency energy for ablation. LAA = left atrial appendage; RV = right ventricle.

to exclude the presence of a LA appendage thrombus. The large majority (31 of 33 [94%]) of the patients who experienced stroke were managed conservatively (without thrombolysis), 1 patient received systemic as well as local thrombolysis, and 1 patient underwent neurosurgery. Sixty-one percent recovered completely (Supplemental Table 11).

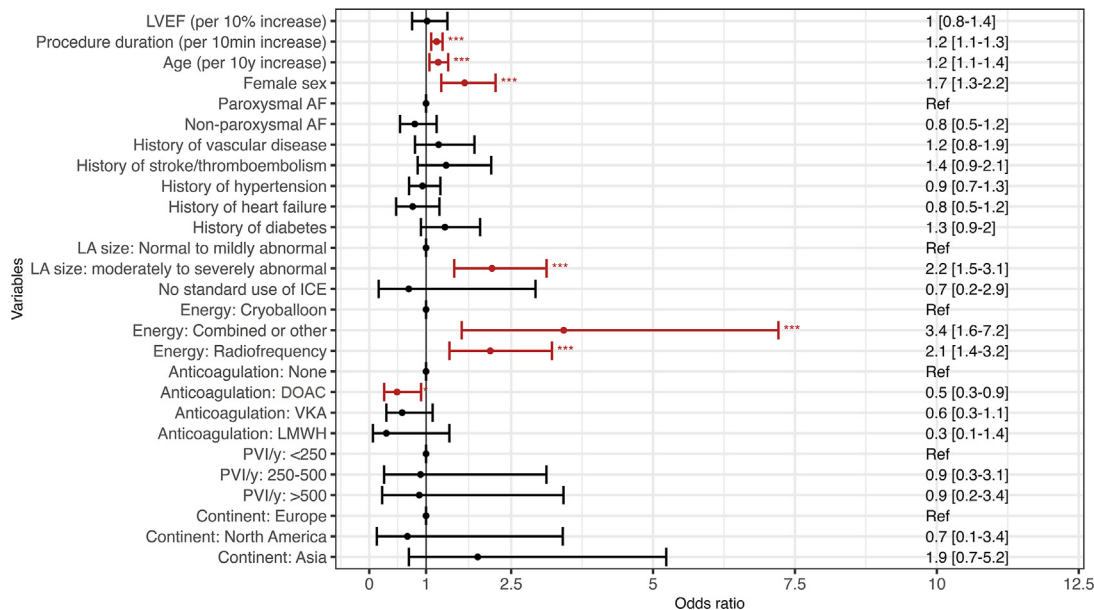
Twenty patients (39% of those who experienced stroke, 9.7% of patients with severe complications) were eventually discharged from the hospital with residual impairment.

Cardiac arrest complicated 14 of the ablations, 9 of which took place in the setting of tamponade and 2 in the setting of EF at a later time point and during a subsequent readmission. Of the 3 patients experiencing cardiac arrest without tamponade or EF, 1 developed VF requiring defibrillation after noticing ST-segment elevations in the inferior leads due to air embolism into the right coronary artery; another

developed VF of unknown cause prior to ablation, requiring CPR and defibrillation; and the third patient was reported to experience long-lasting sinus arrest requiring CPR in addition to atrial pacing. These 3 patients all survived and were discharged without impairment.

Overall, the occurrence of any complication increased the length of stay by 3 to 5 days.

Despite the occurrence of severe complications, 85% of patients (209 of 244; 27 missing data) fully recovered, and 93% (235 of 252; 19 missing data) could be discharged home. A total of 7 patients died, 1 intraprocedurally and 6 at later time points during the same hospitalization or after discharge and readmission. Of the 6 patients who died at later time points, 3 died of the complications of EF (after 26 and 29 days because of severe neurologic lesions and after 34 days because of a large myocardial infarction) and 3 of other, possibly procedure-related complications

FIGURE 1 Multivariable Model Assessing the Risk for All Severe Complications in the Overall Cohort

Estimates are provided on the left with their respective 95% CIs in parentheses. A significant interaction term between nonparoxysmal atrial fibrillation (AF) and moderately to severely abnormal left atrial (LA) size was accounted for. * $P < 0.05$ and *** $P < 0.001$. DOAC = direct oral coagulant; ICE = intracardiac echocardiography; LMWH = low-molecular weight heparin; LVEF = left ventricular ejection fraction; PVI = pulmonary vein isolation; Ref = reference; VKA = vitamin K antagonist.

(4 days after ablation because of anoxic brain damage, 18 days after ablation because of septic shock, and 34 days after ablation because of acute respiratory distress syndrome caused by tracheal perforation 2 days after the procedure).

IMPACT OF CENTER AND ELECTROPHYSIOLOGIST PROCEDURAL VOLUME ON THE OCCURRENCE OF SEVERE COMPLICATIONS AND TEMPORAL TRENDS. There was no significant relationship between the center procedural volume in AF ablations performed per year and the occurrence of the combined endpoint of all severe complications (decrease in incidence per 100 supplementary AF ablations per year: 0.99; 95% CI: 0.98-1.00; $P = 0.30$) (Supplemental Figure 2).

A model investigating the impact of the number of ablations conducted per specialized electrophysiologist per year on the incidence of overall severe complications revealed a nonsignificant trend toward a lower incidence with increasing procedural load per year (Supplemental Table 12).

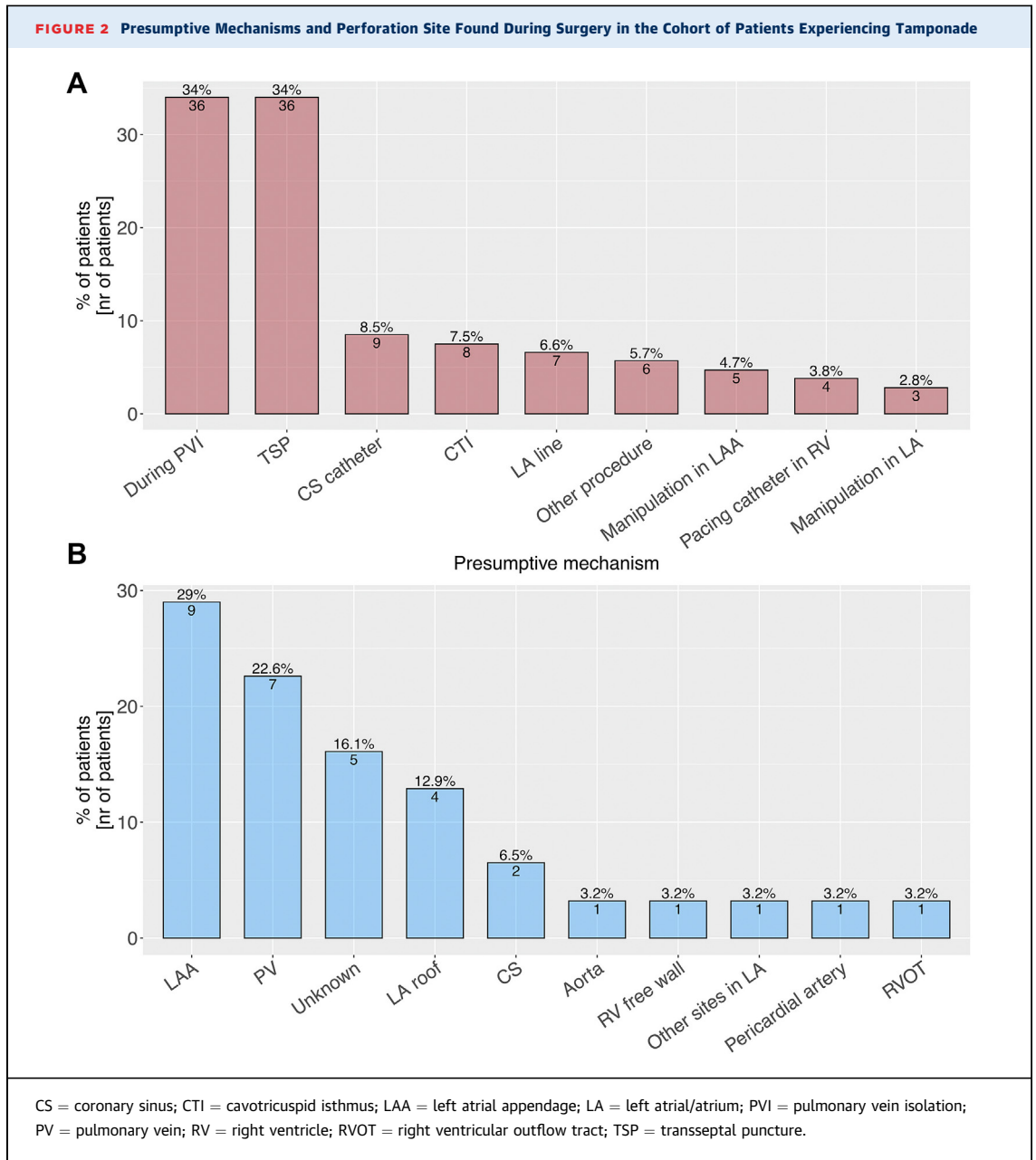
There was no significant temporal trend in the incidence of severe complications (Supplemental Figure 3).

DISCUSSION

We present one of the largest contemporary multinational, patient-level data analyses to evaluate the incidence, management, and outcomes of ablation-associated complications in patients with AF.

We report 4 major findings. First, the occurrence of severe complications associated with catheter ablation for AF was low, and death was extremely uncommon. Second, female sex, older age, procedure duration, a dilated LA, and the use of radiofrequency ablation catheters appeared to be predictors of severe complications, whereas other cardiovascular comorbidities were not. Third, surgical management was required in 13% of cases with tamponade, and perforations were found mainly in the LA appendage and PVs. Fourth, 85% of patients with severe complications fully recovered, and 93% could be discharged home.

INCIDENCE OF SEVERE COMPLICATIONS. The incidence of tamponade and stroke reported in the present study is consistent with previous studies, in which tamponade was observed in 0.5% to 1.5% of AF



ablations and stroke in 0.1% to 1%.^{4,6-13,15,17,18,22} The reported incidence of EF of 0.21‰ is consistent with the incidence reported in a recent worldwide survey.¹⁹ In the present study, death was extremely uncommon and less frequent compared with previously reported rates.^{4,6,7,15,18} Although under-reporting can never be definitively excluded, the reported incidence of complications is very similar to the ones recently reported in large multicenter studies and meta-analyses.^{15,23,24} The very low incidence of death in the present cohort could be due to

technological improvements reflected in this contemporary data set, the experience of the participating centers, the presence of cardiac surgery at most sites, and the inclusion of younger patients, not accounted for in prior reports of claims data.^{4,12}

The majority of the cardiac arrests reported in the present study were associated with tamponade (75%) or occurred later in the setting of a complicated intensive care unit stay, due mainly to cerebrovascular events. The present reported incidence of cardiac arrest appears to be lower than in previous

reports of administrative data,^{17,22} secondary analyses of randomized controlled trials,⁵ and a recent large U.S. registry.¹⁸

ROLE OF PATIENT CHARACTERISTICS, COMORBIDITIES, AND PROCEDURE DETAILS. The present report confirms the association of older age with higher complication rates.^{4,6,11,15} Compared with prior analyses of claims data, the present study reflects a younger cohort. Indeed, the differences in age between cohorts may account for a portion of the differences in complication rates observed.^{4,12} In addition, these results highlight the overall safety of AF ablation in younger patients.

Sex as an important factor associated with severe complications after AF ablations has been highlighted in a number of previous reports,^{6,9,10,12,13} but women have also been found to be at increased risk for vascular complications and cardiac tamponades after other procedures.²⁵⁻²⁸

When correcting for LA size, type of AF, procedure duration, and patient characteristics or comorbidities and accounting for aborted procedures (in which complications took place before energy delivery), radiofrequency was consistently associated with a higher risk for a severe complication, as has been the case in prior studies.^{9-11,16} However, given the observational nature of our analysis, this association needs to be interpreted with caution: in our study, the reasons for choosing radiofrequency ablation catheters as opposed to other ablation catheters because of known and unknown variables likely confound the association between the use of radiofrequency catheters and tamponade. For example, radiofrequency catheters were the technology of choice in patients requiring supplementary lesion sets in the LA or a flutter ablation (inherently exposing patients to more lesions, which was the case in the large majority of our complicated procedures) and also in patients undergoing redo procedures, whereas balloon-based ablations were conducted in patients with smaller LAs and usually involved a single trans-septal puncture. Although the regular use of ICE was available only on a per-center basis, its use did not seem to reduce the incidence of overall complications or tamponade. Interestingly, although one could have hoped for fewer perforations using contact-force technologies, these catheters contributed to 42% of the tamponades recorded in the present study, casting doubt on the better safety of real-time contact-force feedback.²⁹

The majority of the complications observed in the present data set took place during the procedure, so a longer procedure time is likely a consequence of complications and not a risk factor for their incidence.

NEED FOR CARDIAC SURGERY. The need for cardiac surgery because of tamponade after AF ablation varies widely in the literature, ranging from 1.6%^{15,16} to 33%,³⁰ with a multicenter study and a survey documenting incidence rates of 12%¹¹ and 16%.¹³ In the present study, 13% of patients experiencing tamponade required surgical management, a percentage that remains relatively high. Although fewer tamponades complicated cryoballoon than radiofrequency ablation, a greater proportion of tamponades after these cryoballoon-associated tamponades required cardiac surgery, suggesting larger lesions and a smaller likelihood of spontaneous resolution after conservative management.

Only a minority of delayed cardiac tamponades required cardiac surgery, suggesting that the delayed presentation was associated with smaller defects and a better chance for successful conservative management.

PROGNOSIS AFTER A SEVERE COMPLICATION. The overall prognosis of patients experiencing severe complications during AF ablation is poorly documented in the literature. In the present study, a large majority of patients experiencing severe complications both fully recovered or were discharged home, showing good recovery. Patients experiencing stroke were those most commonly discharged with residual impairment postprocedure, and patients presenting at a later time point with EF had a very poor prognosis.

STUDY LIMITATIONS. First, the centers were invited to participate on the basis of an established international PVI network. Therefore, only larger centers with well-established research infrastructure are represented in this study, and our findings may not be generalizable to smaller centers. Moreover, the data provided by collaborators were collected for research purposes and hence, despite representing consecutively recruited patients at each center over a given time frame, are not fully generalizable to an overall population of patients undergoing catheter ablation for AF.

Second, we decided to focus on a small number of life-threatening complications and did not collect any data regarding more common complications, such as vascular complications or phrenic nerve palsies.

Third, the data sets merged for the present analysis are observational, and no data and safety monitoring boards were appointed, as would have been the case in randomized controlled trials. Moreover, not all studies could provide long-term follow-up. Hence we cannot exclude that a few complications were missed, especially those presenting in a delayed manner, such as EF or delayed cardiac tamponade.

Fourth, we were not able to gather more detailed procedural data in the overall 33,879 patients undergoing AF ablation, thereby limiting the number of variables evaluated as risk factors for severe complications on a per-patient level. However, the present study includes a large number of centers internationally, and although some continents are missing in the present data set (South America, Australia/New Zealand, and Africa), we could gather data from countries where large administrative databases are not available and centers at which patients' electronic health records might not be as well established as in the United States or certain European countries. This largely bolsters the generalizability of our findings and avoids limitations typically included with claims or administrative data.

Fifth, we did not collect data on the underlying reasons for choosing the type of energy for ablation. However, we report a rather large rate of cryoballoon use (27%), higher than in previous large databases,^{11,15} thereby providing a large data set of patients in whom the safety of this energy could be assessed.

Sixth, tamponade represented the large majority of all severe complications and drove the composite endpoint. Finally, this study included very few patients undergoing ablation using a pulsed-field ablation system.

CONCLUSIONS

Our large international collaborative study showed that tamponade, stroke, cardiac arrest, EF, and death are rare after AF ablation. Female sex, age, and the use of radiofrequency catheters were associated with severe complications. Among the patients experiencing tamponade, 13% required cardiac surgery. The overall prognosis after a severe complication was good, with 93% of patients discharged home.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL

SKILLS: Worldwide, severe procedural complications of catheter ablation for AF are rare (tamponade 6.8‰, stroke 0.97‰, cardiac arrest 0.41‰, EF 0.21‰, and death 0.21‰). Among patients experiencing tamponade, 13% required cardiac surgery. Age, female sex, a dilated LA, procedure duration, and the use of radiofrequency energy appear to be linked to a higher risk for severe complications.

TRANSLATIONAL OUTLOOK, TRANSLATIONAL

OUTLOOK: Additional studies are required to understand the increased risk in women and possible increased risk for complications with different ablation energies.

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APPENDIX For an expanded Methods, supplemental tables, figures, and references, please see the online version of this paper.