JACC: CLINICAL ELECTROPHYSIOLOGY
VOL. 3, NO. 11, 2017

ISSN 2405-500X/$36.00
PUBLISHED BY ELSEVIER
http://dx.doi.org/10.1016/j.jacep.2017.05.005

Catheter Ablation for Cardiac Arrhythmias

Utilization and In-Hospital Complications, 2000 to 2013

Seyed Mohammadreza Hosseini, MD,[a,b] Guy Rozen, MD, MHA,[a] Ahmed Saleh, MD,[a,b] Jeena Vaid, MD, MPH,[a,b] Yitschak Biton, MD,[a] Kasra Moazzami, MD,[a,b] E. Kevin Heist, MD, PhD,[a,b] Moussa C. Mansour, MD,[a,b] M. Ihsan Kaadan, MD, MS,[a,b] Mark Vangel, PhD,[c] Jeremy N. Ruskin, MD[a,b]

ABSTRACT

OBJECTIVES This study sought to investigate the utilization of and in-hospital complications in patients undergoing catheter ablation in the United States from 2000 to 2013 by using the National Inpatient Sample and Nationwide Inpatient Sample.

BACKGROUND Catheter ablation has become a mainstay in the treatment of a wide range of cardiac arrhythmias.

METHODS This study identified patients 18 years of age and older who underwent inpatient catheter ablation from 2000 to 2013 and had 1 primary diagnosis of any of the following arrhythmias: atrial fibrillation, atrial flutter, supraventricular tachycardia, or ventricular tachycardia.

RESULTS An estimated total of 519,951 (95% confidence interval: 475,702 to 564,200) inpatient ablations were performed in the United States between 2000 and 2013. The median age was 62 years (interquartile range: 51 to 72 years), and 59.3% of the patients were male. The following parameters showed increasing trends during the study period: annual volume of ablations, number of hospitals performing ablations, mean age and comorbidity index of patients, rate of ≥1 complication, and length of stay ($p < 0.001$ for each). Substantial proportions (27.5%) of inpatient ablation procedures were performed in low-volume hospitals and were associated with an increased risk for complications (odds ratio: 1.26; 95% confidence interval: 1.12 to 1.42; $p < 0.001$). Older age, greater numbers of comorbidities, and complex ablations for atrial fibrillation and ventricular tachycardia were independent predictors of in-hospital complications and in-hospital mortality. In addition, female sex and lower hospital volumes were independent predictors of complications.

CONCLUSIONS From 2000 to 2013, there was a substantial increase in the annual number of in-hospital catheter ablation procedures, as well as the rate of periprocedural complications nationwide. Low-volume centers had a significantly higher rate of complications. (J Am Coll Cardiol EP 2017;3:1240–8) © 2017 by the American College of Cardiology Foundation.

From the [a]Cardiac Arrhythmia Service, Massachusetts General Hospital, Boston, Massachusetts; [b]Department of Medicine, Harvard Medical School, Boston, Massachusetts; and the [c]Department of Biostatistics, Massachusetts General Hospital, Boston, Massachusetts. This study was supported in part by the Al Sagri Research Fund and the Deane Institute for Integrative Research in Atrial Fibrillation and Stroke at Massachusetts General Hospital. This work was conducted with support from Harvard Catalyst/ The Harvard Clinical and Translational Science Center (National Center for Research Resources and the National Center for Advancing Translational Sciences, National Institutes of Health Award UL1 TR001102) and financial contributions from Harvard University and its affiliated academic health care centers. The content is solely the responsibility of the authors and does not necessarily represent the official views of Harvard Catalyst, Harvard University and its affiliated academic health care centers, or the National Institutes of Health. Dr. Ruskin is a consultant for Advanced Medical Education, Cardiome, Daiichi-Sankyo, InCarda Therapeutics, and Portola Pharmaceuticals; is on the data monitoring committees of Gilead Sciences and Laguna Medical; is on the scientific advisory boards of InfoBionic and Medtronic; is on the steering committee of Pfizer; and holds equity in Portola Pharmaceuticals and InfoBionic. Dr. Heist is a consultant for Abbott, Biotronik, Biosense Webster, Boston Scientific, Janssen, Medtronic, Pfizer, and St. Jude Medical; and has received research grants from Biotronik and St. Jude Medical. Dr. Mansour is a consultant for Abbott, Biosense Webster, St. Jude Medical, Boston Scientific, and Medtronic; and has received research grants from Abbott, Biosense Webster, Boehringer Ingelheim, Boston Scientific, Medtronic, Pfizer, and St. Jude Medical. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose. Drs. Hosseini, Rozen, and Saleh contributed equally to this work.

Over the last 3 decades, catheter ablation has become a mainstay in the treatment of a wide range of cardiac arrhythmias and has become the treatment of first choice for many patients with symptomatic arrhythmias (1-6). Catheter ablation techniques have evolved, and their use has extended from supraventricular tachycardias (SVTs) to include complex arrhythmias such as atrial fibrillation (AF) (2) and many forms of ventricular tachycardia (VT) (7). The dramatic rise in the number of catheter ablation procedures performed annually has been driven over the past decade primarily by the increasing utilization of the technique to treat AF (8,9).

SEE PAGE 1249

Given the rapid growth in both the technology and utilization of catheter ablation techniques, we sought to assess trends in utilization, as well as changes in patient groups and associated complications in a real-world setting. The importance of real-world outcomes derives from the finding that most of the available data on the safety of radiofrequency ablation and cryoablation come from selected, high-volume academic centers. The main focus of previous studies was on trends and complications associated with AF ablation (9,10). The purpose of this study was 2-fold: 1) to analyze trends in the utilization of the full spectrum of the inpatient catheter ablation procedures; and 2) to analyze trends in and predictors of in-hospital complications associated with various types of ablation procedures in the United States between 2000 and 2013.

METHODS

DATA SOURCE. The data were drawn from the National Inpatient Sample and the Nationwide Inpatient Sample (NIS), the Healthcare Cost and Utilization Project (HCUP), and the Agency for Healthcare Research and Quality (AHRQ) (11,12). The NIS is the largest collection of all-payer data on inpatient hospitalizations in the United States. The dataset represents an approximate 20% stratified sample of all inpatient discharges from U.S. hospitals. The database provides de-identified information for each hospital stay. This information includes patient-level and hospital-level factors: patients' demographic characteristics; primary and secondary diagnoses and procedures; AHRQ comorbidities; length of stay (LOS); hospital region; hospital teaching status; hospital bed size; and cost of hospitalization. National estimates can be calculated using the patient-level and hospital-level sampling weights that are provided by the NIS. For the purpose of this study, we obtained data for the years 2000 to 2013.

STUDY PATIENTS AND VARIABLES. The International Classification of Diseases-9th Revision-Clinical Modification (ICD-9-M) is used for reporting diagnoses and procedures in the NIS database. For each index hospitalization, the database provides a principal discharge diagnosis and a maximum of 14 or 24 additional diagnoses (depending on the year), in addition to a maximum of 15 procedures. We identified patients 18 years of age or older who underwent catheter ablation (ICD-9-CM code 37.34) during 2000 to 2013. From this cohort of patients, we selected only those discharges that had 1 of the following arrhythmias as its principal diagnosis: 1) AF (ICD-9-CM code 427.31); 2) AFL (ICD-9-CM code 427.32); 3) SVT (ICD-9-CM codes 427.0, 427.89, 426.7, and 426.89); 4) VT (ICD-9-CM code 427.1). These are all well-known indications for ablation. Furthermore, we excluded patients with any of the following cardiac procedures during the index hospitalization, to avoid attributing their complications to the ablation procedure: 1) pacemaker implantation (ICD-9-CM 00.50, 00.52, 00.53, 37.71-37.79); 2) implantable cardioverter-defibrillator insertion (ICD-9-CM 37.94-37.98, 00.51, 00.54); and 3) open surgical ablation (ICD-9-CM 37.33). Detailed information on exclusion criteria are provided in the Online Appendix.

STUDY OUTCOMES. We identified the common in-hospital complications of catheter ablation by using the ICD-9-CM diagnosis and procedures codes. These complications include the following: 1) cardiac complications (i.e., post-operative cardiac block, myocardial infarction); 2) pericardial complications (tamponade, hemopericardium, pericarditis, and pericardiocentesis); 3) vascular complications (arteriovenous fistula, blood vessel injury, accidental puncture, injury to the retroperitoneum, vascular complications requiring surgery, and other iatrogenic vascular complications); 4) post-operative

ABBREVIATIONS AND ACRONYMS

AF = atrial fibrillation

AFL = atrial flutter

AHRQ = Agency for Healthcare Research and Quality

CI = confidence interval

Deyo-CCI = Deyo modification of the Charlson comorbidity index

HCUP = Healthcare Cost and Utilization Project

ICD-9-CM = International Classification of Diseases-9th Revision-Clinical Modification

NIS = Nationwide Inpatient Sample and National Inpatient Sample

OR = odds ratio

SVT = supraventricular tachycardia

TIA = transient ischemic attack

VT = ventricular tachycardia

All authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the *JACC: Clinical Electrophysiology* author instructions page.

Manuscript received April 12, 2017; accepted May 4, 2017.

hemorrhage or hematoma (including post-operative hemorrhage requiring blood transfusion); 5) post-operative stroke or TIA (transient ischemic attack); 6) pneumothorax or hemothorax; 7) diaphragm paralysis; 8) infections (fever, septicemia, and post-procedural aspiration pneumonia); and 9) in-hospital deaths. All codes used in identifying complications are shown in Online Table 1.

The following patient-related demographic features were collected from the database: age, sex, and race. The hospital identification number (HOSPID) was used to calculate hospital volumes. We defined high-volume hospitals as those with 100 or more annual catheter ablation procedures, medium-volume hospitals as those with 50 to 100 annual procedures, and low-volume hospital as those having fewer than 50 annual procedures. Associated comorbidities were identified by measures from the AHRQ. For the purpose of calculating the Deyo-Charlson comorbidity index (Deyo-CCI), an additional list of comorbidities was identified from the database by using ICD-9-CM codes (Online Table 2). Deyo-CCI is a modification of the Charlson comorbidity index. It contains 17 comorbid conditions (13). Higher Deyo-CCI indicates more severe comorbid conditions, and is an indicator of patient mortality 1 year after admission.

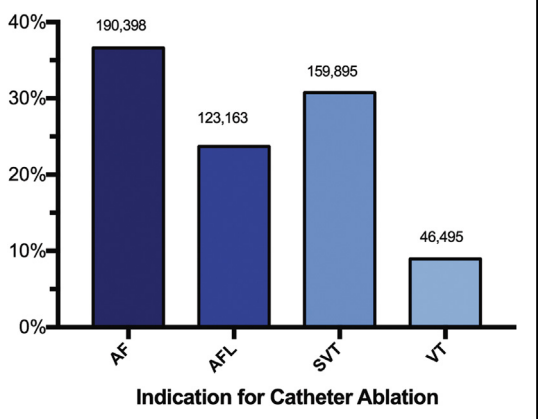
STATISTICAL ANALYSIS. Trend weight files (TRENDWT) provided by the AHRQ were used to reflect national estimates. Detailed information on the implementation of sampling weights is provided in the Online Appendix. The chi-square test and the Wilcoxon rank sum test were used to compare categorical variables and continuous variables, respectively. Trends for continuous variables were tested using the nonparametric test for trend by Cuzick (14).

To account for hospital-level clustering of discharges, we generated a 2-level mixed-effects logistic regression model to identify independent predictors of complications. Congruent with the Healthcare Cost and Utilization Project NIS design, the hospital identification number was used as a random effect with patient-level factors clustered within hospital-level factors. Candidate variables included patient-level characteristics, Deyo-CCI, hospital-level factors, and hospital volume. For all analyses, we used survey estimation in Stata/SE software version 14.1 (StataCorp LP, College Station, Texas) to account for the complex survey design of the NIS database. A p value <0.05 was considered significant.

RESULTS

After exclusion criteria were applied, a total of 108,273 unweighted observations were included in the final analysis. This represents an estimated 519,951 (95% confidence interval [CI]: 475,702 to 564,200) patients who underwent in-hospital catheter ablation procedures from 2000 to 2013. Among these patients, the annual number of ablation procedures increased by 2.5-fold from 18,096 in 2000 to 44,465 in 2013 ($p = 0.002$). More than one-half of the ablations were performed in low- and medium-volume hospitals (57.64%). There was an increase in the estimated number of hospitals performing ablations from 156 in 2000 to 216 in 2011 ($p = 0.002$). The percentage of high-volume hospitals showed a 2.5-fold increase from 15.19% in 2000 to 53.9% in 2011 ($p = 0.016$). Overall, AF was the most common indication for catheter ablation during these years (n = 190,398; 36.62%), followed by SVT (n = 159,895; 30.75%) (**Figure 1**). The increase in the total number of inpatient ablation cases over the study period was primarily the result of the increase in AF ablation, a nearly 10-fold rise from 2,644 procedures in 2000 to 21,345 procedures in 2013 ($p = 0.001$). Significant increases were also seen in the annual number of inpatient ablation procedures for AFL and VT: AFL from 4,046 in 2000 to 10,465 in 2013; and VT from 1,951 in 2000 to 4,735 in 2013 (**Figure 2**).

FIGURE 1 Frequency of Catheter Ablation Procedures by Indication



Atrial fibrillation was the most common indication for ablation performed from 2000 to 2013. AF = atrial fibrillation; AFL = atrial flutter; SVT = supraventricular tachycardia; VT = ventricular tachycardia.

BASELINE CHARACTERISTICS. Patients' demographic information is shown in **Table 1** (Online Table 3). The median (interquartile range) age for all catheter ablations performed during the study period was 62 years (range 51 to 72 years). The mean age of patients undergoing ablations increased significantly from 57.77 ± 0.59 years in 2000 to 63.2 2 ± 0.21 years

in 2013 (p = 0.001). This trend reflected the significant increase in the age of patients who underwent AFL, VT, and SVT ablations. Overall, patients with AFL had the highest mean age (65.06 ± 0.15 years), followed by patients with AF (62.99 ± 0.19 years). Patients with SVT had the lowest mean age (53.55 ± 0.28 years). Ablations were performed more frequently in male patients (59.35%) and in white patients (66.56%), but female patients comprised the majority group among SVT ablations (58.74%). Private insurance was the most frequent primary payer (46.12%), followed by Medicare (44.26%) and Medicaid (4.63%).

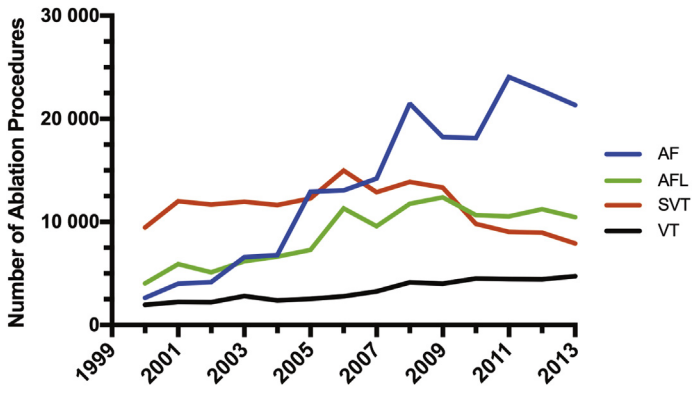
The most common comorbidity across all indications for ablation was hypertension (51.62%), followed by diabetes mellitus (16.63%). The Deyo-CCI for the overall patient cohort was 0.86 ± 0.02; VT was associated with the highest Deyo-CCI (1.28 ± 0.03), and SVT was associated with the lowest (0.58 ± 0.02). Over the study period, there was a significant rise in the mean Deyo-CCI from 0.56 ± 0.03 in 2000 to 1.3 ± 0.02 in 2013 (p = 0.001) (Online Tables 4 and 5).

RATES OF IN-HOSPITAL COMPLICATIONS AND MORTALITY. Of all inpatient ablations during the study period, 5.46% had at least 1 complication. This rate increased from 3.07% in 2000 to 7.04% in 2013 (p = 0.001). Access site-related hemorrhage or hematoma complications occurred most frequently (2.57%), followed by pericardial complications (1.3%). With the exception of pneumothorax or hemothorax complications, which showed a decrease (p = 0.04), and post-procedural stroke or TIA, which showed no uniform trend, the rates of all other complications increased significantly over the 14-year study period (Online Table 6).

The overall in-hospital complication rate and the rates of specific complications varied among procedural indications (**Table 2**). VT ablation was associated with the highest rate of at least 1 complication (9.90%), followed by AF ablation (7.21%), whereas catheter ablations performed for SVT had the lowest rate of complications (3.29%). For all indications for catheter ablation, the rate of ≥1 complication increased significantly over the 14-year period (Online Table 4). This increase was most pronounced in VT ablations, which had an increase in the complication rate from 5.60% in 2000 to 12.88% in 2013 (p = 0.001).

During the study period, the overall in-hospital mortality rate for catheter ablation procedures was 0.34%. A nonsignificant decrease in mortality was observed between 2000 and 2013 (0.52% vs. 0.49%; p = 0.10). Among all indications, VT ablation had the highest in-hospital mortality rate (1.8%), and SVT ablation had the lowest (0.1%) (**Table 2**).

FIGURE 2 Annual Volume of Catheter Ablation Procedures by Indication



Annual volume of ablations performed for atrial fibrillation (AF), atrial flutter (AFL), and ventricular tachycardia (VT) increased significantly from 2000 to 2013. Abbreviation as in **Figure 1**.

LENGTH OF STAY. A majority of procedures (64%) had an associated LOS of <2 days. The mean LOS for all ablation procedures was 2.82 ± 0.05 days. The LOS increased significantly during the study period from 2.67 ± 0.1 days in 2000 to 3.28 ± 0.06 days in 2013. VT ablation was associated with the longest LOS (4.7 ± 0.09 days). Overall, patients who experienced at least 1 complication had a significantly longer LOS than did patients who experienced no complication (6.21 ± 0.12 days vs. 2.82 ± 0.05 days; p < 0.001).

PREDICTORS OF IN-HOSPITAL COMPLICATIONS AND MORTALITY. The results of the multivariable logistic regression model are shown in **Tables 3 and 4**. A gradual increase in complication rates across the age groups was observed (**Figure 3**). Age was found to be an independent predictor of in-hospital complications and death, and it showed a stepwise increase in the odds ratio (OR) with increasing age (p < 0.001). Patients 75 years of age and older had the highest risk of procedural complications and death when compared with the reference group (age <45 years) (OR: 1.88; 95% CI: 1.65 to 2.14; p < 0.001; and 4.38; 95% CI: 1.98 to 9.71; p < 0.001, respectively). Female sex was also a predictor of in-hospital complications (OR: 1.16; 95% CI: 1.09 to 1.24; p < 0.001).

The primary arrhythmia diagnosis was an independent predictor of in-hospital complications and death (**Table 3**). In comparison with the reference group (SVT), patients with AF and VT had higher odds of developing complications (OR: 1.82; 95% CI: 1.68 to 1.97; p < 0.001; and 2.17; 95% CI: 1.96 to 2.41; p < 0.001, respectively) and higher mortality rates (OR:

TABLE 1 Baseline Characteristics of Patients Undergoing Catheter Ablation From 2000 to 2013

	All Catheter Ablations			
	Total	≥1 Complication	No Complication	p Value
Unweighted number of catheter ablations	108,273	6,583	101,690	–
Weighted number of catheter ablations (%)	519,951 (100.0)	31,707 (6.1)	488,244 (93.9)	–
Age group in yrs, %				<0.001
18–44	15.39	7.66	15.90	
45–54	16.03	13.34	16.21	
55–64	24.46	26.03	24.36	
65–74	26.28	30.64	25.99	
≥75	17.83	22.33	17.54	
Race, %				0.80
White	66.56	67.99	66.47	
Black	6.23	6.40	6.22	
Hispanic	4.18	4.12	4.18	
Others	3.95	3.66	3.97	
missing	19.08	17.83	19.16	
Sex, %				0.60
Male	59.35	59.01	59.37	
Female	40.65	40.99	40.63	
Primary payer, %				<0.001
Medicare	44.26	53.64	43.65	
Medicaid	4.63	4.31	4.65	
Private insurance	46.12	37.62	46.67	
Others/missing	4.99	4.43	5.03	
Hospital teaching status, %				0.01
Rural	1.84	1.97	1.83	
Nonteaching	26.39	23.35	26.59	
Teaching	71.77	74.68	71.58	
Hospital region, %				0.80
Northeast	25.93	25.92	25.93	
Midwest	23.56	23.34	23.58	
South	32.59	33.57	32.53	
West	17.92	17.18	17.96	
Hospital bed size, %				0.03
Small or medium	20.82	19.01	20.94	
Large	79.18	80.99	79.06	

Values are n (%) or %.

1.56; 95% CI: 1.03 to 2.37; $p < 0.001$; and 8.09; 95% CI: 5.43 to 12.05; $p < 0.001$, respectively). The odds of in-hospital complications and death also increased with increasing Deyo comorbidity index (**Table 3**).

Among hospital level variables, hospital volume was a significant predictor of in-hospital complications. Compared with high-volume hospitals (≥100 annual catheter ablations), hospitals with low volume (<50 annual procedures) and medium volume (50 to 100 annual procedures) had 1.26 and 1.12 times higher odds of complications, respectively (OR: 1.26; 95% CI: 1.12 to 1.42; $p < 0.001$; and OR: 1.12; 95% CI: 1.01 to 1.25; $p = 0.047$, respectively).

DISCUSSION

This study drew data from the largest all-payer inpatient database in the United States (NIS) to analyze the utilization and associated in-hospital complications of a total of 519,951 catheter ablation procedures performed across the nation from 2000 to 2013. The annual number of catheter ablations increased steadily over the 14-year period. These data demonstrate that the increase in comorbidities, along with an increase in the number and proportions of complex ablations (AF and VT), have resulted in higher in-hospital complication rates and longer hospital LOSs in recent years. Importantly, many ablation procedures (27.5%) were performed in low-volume hospitals, which bore a significantly increased risk of complication.

Our findings agree with the temporal trends observed in published reports regarding the annual number of inpatient ablation procedures (9,15,16). From 2000 to 2013, there was a 2.5-fold increase in the annual number of inpatient ablations, a significant rise in the number of hospitals performing these procedures, and a 2.5-fold increase in the number of high-volume centers performing ablations in the United States. The increase in annual procedure volume was primarily the result of a 7-fold increase in the annual number of AF ablations over the 14-year study period. Overall, AF accounted for 36.6% of all in-hospital ablation procedures. In a prospective study of ablation-related complications at a high-volume center, AF ablation accounted for 46.8% of procedures, thus emphasizing its dominance in the current mix of catheter ablation procedures (17).

Consistent with other reports (18,19), we observed an increase in the mean age of patients undergoing catheter ablation procedures from 2000 to 2013. This trend could be a reflection of the increasing volume of outpatient ablation procedures that are performed in the United States, usually for patients at lower risk for complications (20). Similar to other published reports, we observed that most patients undergoing catheter ablation were white and male (16,17). The exception was SVT ablation, which was found to be more commonly performed in women, a finding consistent with the higher prevalence of SVT in women (21).

Overall, the rate of in-hospital complications was 5.46%. Substantial differences exist in the complication rates of ablations, depending on the target arrhythmia. VT ablation carries the highest overall complication rate (9.9%), which is comparable to earlier reports (17,19,22,23), and it is approximately 3 times higher than the rate seen with ablation

procedures for SVT. This difference is likely explained by a combination of the higher burden of cardiovascular disease and comorbidities among patients with VT, the more complex nature of the ablation procedure, and the often nonelective nature of the procedure in this subgroup. The VT group had the highest comorbidity index (1.28 ± 0.03) in this study and had mostly undergone ablation in a nonelective setting (62%). In addition, compared with other indications, the VT group had a higher rate of chronic kidney disease, which has been previously identified as a significant independent predictor of complications of catheter ablation (17).

The overall in-hospital complication rate increased during the study period from 3.07% in 2000 to 7.04% in 2013 ($p = 0.001$). This increase can be attributed at least in part to changing patient demographics (aging and a greater burden of comorbidities), as well as the increased utilization of complex ablation procedures for AF and VT. Both advancing age and the Deyo-Charlson comorbidity index were independently associated with a stepwise increase in the odds of developing in-hospital complications. In addition, it is likely that an increasing proportion of younger and healthier patients are undergoing catheter ablation procedures on an outpatient basis.

Cardiac perforation is among the most serious and potentially life-threatening complications of catheter ablation. Pericardial complications occurred in 1.3% of all catheter ablations performed during the 14-year period. Previous studies reported rates of pericardial complications ranging from 0.1% to 2.9%, depending on the indication (22–28). In our study, AF and VT were associated with the highest rates (2.02% and 2.47%, respectively), compared with AFL and SVT (0.41% and 0.81%, respectively). This variation is likely a result of the relative complexity of the ablation procedures (e.g., the need for transseptal puncture or epicardial access, duration of the procedure, the number of ablation lesions). Interestingly, a higher rate of pericardial complications was observed for SVT ablations, compared with AFL (0.81% vs. 0.41%; $p = 0.001$). This higher rate may be explained by the larger proportion of female patients in the group with SVT. Consistent with these findings, female sex has been shown to be associated with a higher rate of complications and with increased risk of cardiac perforation, possibly because of a lower cardiac mass (29).

Previous studies reported an incidence of ablation-related vascular complications ranging from 0% to 13% (23,27,30,31). We observed an overall rate of 3.46%, with a statistically significant increase in vascular complications from 2000 to 2013. The variability in vascular complication rates among different studies is likely in part caused by varying definitions of vascular complications. Considering the limitations of administrative databases such as NIS, we defined major vascular complications as those

TABLE 2 Rates of Specific Complications by Indication for Catheter Ablation From 2000 to 2013

	AF	AFL	VT	SVT
Catheter ablation procedures (unweighted)	39,562	25,723	9,642	33,346
Catheter ablation procedures (weighted)	190,398	123,163	46,495	159,895
≥1 complication	7.21	3.91	9.90	3.29
Mortality	0.24	0.20	1.82	0.12
Post-procedural stroke or TIA	0.31	0.19	0.38	0.14
Post-procedural infection	0.26	0.32	1.07	0.18
Cardiac complications[a]	1.15	0.53	1.24	0.68
Pericardial complications	2.02	0.41	2.47	0.81
Vascular complications	1.09	0.64	2.08	0.48
Hemorrhage	3.64	2.04	3.67	1.37
Hemorrhage requiring transfusion	0.69	0.37	0.86	0.18
Diaphragm paralysis	0.11	0.05	0.02	0.04
Pneumothorax or hemothorax	0.14	0.09	0.04	0.15
Length of stay	2.63 ± 0.06	3.18 ± 0.05	4.7 ± 0.09	2.22 ± 0.04

Values are % or mean ± SEM. $p < 0.05$ considered significant. [a]Includes post-operative cardiac block, myocardial infarction, cardiac arrest, and congestive heart failure.

AF = atrial fibrillation; AFL = atrial flutter; SVT = supraventricular tachycardia; TIA = transient ischemic attack; VT = ventricular tachycardia.

TABLE 3 Predictors of In-Hospital Complications of Catheter Ablation From 2000 to 2011

Predictor	Odds Ratio*	p Value	95% CI
Age group, yrs			
18–44	1.00 (reference)	—	N/A
45–54	1.40	<0.001	1.23–1.60
55–64	1.66	<0.001	1.47–1.87
65–74	1.76	<0.001	1.56–1.99
≥75	1.88	<0.001	1.65–2.14
Female	1.16	<0.001	1.09–1.24
Indication for ablation			
SVT	1.00 (reference)	—	N/A
AF	1.87	<0.001	1.72–2.04
AFL	0.89	0.031	0.80–0.99
VT	2.40	<0.001	2.16–2.67
Deyo-CCI			
0	1.00 (reference)	—	N/A
1	1.35	<0.001	1.25–1.46
2	1.53	<0.001	1.42–1.66
Hospital volume			
High (≥100)	1.00 (reference)	—	N/A
Medium (50–100)	1.12	0.047	1.01–1.25
Low (<50)	1.26	<0.001	1.12–1.42

Model C-statistic: 0.71 (0.70–0.72). *Adjusted for weekend admission, hospital region, hospital location (metropolitan vs. nonmetropolitan), hospital teaching status, and calendar year.

CI = confidence interval; Deyo-CCI = Deyo modification of the Charlson comorbidity index; N/A = not applicable; other abbreviations as in Table 2.

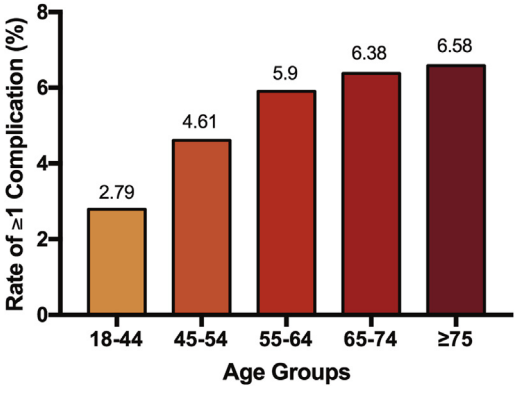
TABLE 4 Predictors of In-Hospital Mortality of Catheter Ablation From 2000 to 2011

Predictor	Odds Ratio*	p Value	95% CI
Age group, yrs			
18–44	1.00 (reference)	—	N/A
45–54	1.32	0.547	0.53–3.28
55–64	2.12	0.071	0.94–4.79
65–74	3.44	0.002	1.56–7.61
≥75	4.38	<0.001	1.98–9.71
Deyo-CCI			
0	1.00 (reference)	—	N/A
1	4.60	<0.001	2.94–7.21
2	9.81	<0.001	6.46–14.89
Indication for ablation			
SVT	1.00 (reference)	—	N/A
AF	1.56	0.035	1.03–2.37
AFL	0.77	0.296	0.48–1.25
VT	8.09	<0.001	5.43–12.05

Model C-statistic: 0.88 (0.86–0.89). *Adjusted for sex, weekend admission, hospital region, hospital location, hospital teaching status, hospital volume, and calendar year.

Abbreviations are as in Tables 2 and 3.

FIGURE 3 In-Hospital Complication Rates of Catheter Ablation Procedures as a Function of Age



The rate of in-hospital complication increased in a stepwise fashion with increasing age.

resulting in hemorrhage or hematoma, hemorrhage requiring transfusion, retroperitoneal hemorrhage, and arteriovenous fistula.

We observed a pooled incidence of stroke and TIA of 0.24%. AF, AFL, and VT ablations had stroke and TIA complication rates of 0.31%, 0.19%, and 0.38%, respectively. These rates are similar to the rates reported by previous studies (9,17,25,32). The lowest rate of thromboembolic complications was observed following SVT ablations (0.14%), a finding consistent with previous reports (17,23,33).

The present study and several previous studies have demonstrated that operator and hospital volumes are inversely correlated with poor outcomes (9,17,34,35). In our analysis, 27.5% of ablation procedures were performed in low-volume centers and were associated with significantly higher rates of complications when compared with high-volume centers. Additional published data suggest that procedural success rates are also positively correlated with operator volumes, and that first-procedure success rates have significant economic implications (24,36). Various strategies to minimize periprocedural complications in patients undergoing catheter ablation have been evaluated in recent years. The following 3-point strategy has been shown to reduce major vascular access complications significantly: 1) performing ablation procedures with uninterrupted therapeutic anticoagulation where clinically indicated; 2) use of a small-gauge micro-puncture needle to obtain vascular access; and 3) elimination of unnecessary femoral arterial access (37). Ultrasound-guided femoral access has also been shown to reduce vascular complications significantly in patients undergoing catheter ablation (38,39). The use of intracardiac echocardiography to guide the transseptal puncture for ablation procedures has been shown to reduce the risk of life-threatening pericardial complications significantly (40). Given the increasing rate of complications observed in this study, especially for complex ablation procedures, the widespread implementation of these strategies carries the potential for significant improvements in procedural safety and associated costs.

STUDY LIMITATIONS. The NIS database is retrospective and includes only inpatient catheter ablation procedures, whereas there has been an increasing trend toward a greater percentage of outpatient catheter ablation procedures in recent years. Hence, there is the potential for selection bias in this study. Second, all administrative databases are susceptible to coding errors. Third, complication rates derived from large databases should be interpreted with caution because they depend on reports from individual institutions, and reporting may not be consistent across institutions of varying sizes. Fourth, we were unable to capture complications that occurred after hospital discharge. As a result, atrioesophageal fistula and pulmonary vein stenosis, 2 major post-ablation complications, were not accounted for because they typically occur after discharge. Fifth, several factors that could affect complication rates are not provided by the NIS: duration of procedure, repeat intervention, and medical

management (e.g., anticoagulants). In addition, we could not include operator volume in our analyses because operator identification was not provided for more than one-half the discharges in this dataset.

CONCLUSIONS

The number of inpatient catheter ablations in the United States increased considerably from 2000 to 2013. This upsurge was driven primarily by a large increase in the number of AF ablations performed in the United States over the study period. This study demonstrates a significant rise in age and the burden of comorbidities among patients who underwent inpatient ablation procedures. These changes occurred in association with an increase in the complexity of the ablation procedure mix (i.e., a higher proportion of AF and VT ablations), which in turn was associated with a significant increase in procedural complication rates and hospital LOS. These findings underscore the need for more widespread implementation of strategies that have been shown to reduce periprocedural complications in patients undergoing catheter ablation.

ADDRESS FOR CORRESPONDENCE: Dr. Jeremy N. Ruskin, Cardiac Arrhythmia Service, Massachusetts General Hospital, 55 Fruit Street, Boston, Massachusetts 02114. E-mail: jruskin@mgh.harvard.edu.

PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: Given the increasing volume of outpatient catheter ablations in the United States, the demographic features of inpatients are undergoing significant change. More attention should be focused on reducing complication rates in older patients and in patients with greater numbers of comorbidities, specifically for complex ablation procedures for AF and VT.

TRANSLATIONAL OUTLOOK: More studies are needed to assess the effect of different strategies (e.g., ultrasound-guided femoral access and intracardiac echocardiography) on reducing periprocedural complications and decreasing costly LOSs in patients undergoing in-hospital catheter ablation procedures. Particular focus is warranted on low-volume hospitals and patients with greater numbers of comorbidities.

REFERENCES

1. Huang SK, Bharati S, Graham AR, Lev M, Marcus FI, Odell RC. Closed chest catheter desiccation of the atrioventricular junction using radiofrequency energy—a new method of catheter ablation. J Am Coll Cardiol 1987;9:349–58.

2. Jai P, Hai M, Shah DC, et al. A focal source of atrial fibrillation treated by discrete radiofrequency ablation. Circulation 1997;95:572–6.

3. Haïssaguerre M, Shoda M, Jais P, et al. Mapping and ablation of idiopathic ventricular fibrillation. Circulation 2002;106:962–7.

4. Natale A, Newby KH, Pisanó E, et al. Prospective randomized comparison of antiarrhythmic therapy versus first-line radiofrequency ablation in patients with atrial flutter. J Am Coll Cardiol 2000;35:1898–904.

5. Page RL, Joglar JA, Caldwell MA, et al. 2015 ACC/AHA/HRS guideline for the management of adult patients with supraventricular tachycardia: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol 2016;67:e27–115.

6. Morillo CA, Verma A, Connolly SJ, et al. Radiofrequency Ablation vs Antiarrhythmic Drugs as First-Line Treatment of Paroxysmal Atrial Fibrillation (RAAFT-2): a randomized trial. JAMA 2014;311:692–700.

7. Stevenson WG, Soejima K. Catheter ablation for ventricular tachycardia. Circulation 2007;115:2750–60.

8. Piccini JP, Sinner MF, Greiner MA, et al. Outcomes of Medicare beneficiaries undergoing catheter ablation for atrial fibrillation. Circulation 2012;126:2200–7.

9. Deshmukh A, Patel NJ, Pant S, et al. Inhospital complications associated with catheter ablation of atrial fibrillation in the United States between 2000 and 2010: analysis of 93,801 procedures. Circulation 2013;128:2104–12.

10. Kumar S, Walters TE, Halloran K, et al. Ten-year trends in the use of catheter ablation for treatment of atrial fibrillation vs. the use of coronary intervention for the treatment of ischaemic heart disease in Australia. Europace 2013;15:1702–9.

11. Healthcare Cost and Utilization Project (HCUP). 2000–2011. Agency for Healthcare Research and Quality, Rockville, MD. Available at: www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed June 8, 2017.

12. Healthcare Cost and Utilization Project (HCUP). 2012–2013. Agency for Healthcare Research and Quality, Rockville, MD. Available at: www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed June 8, 2017.

13. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol 1992;45:613–9.

14. Cuzick J. A Wilcoxon-type test for trend. Stat Med 1985;4:543–7.

15. Ellis ER, Culler SD, Simon AW, Reynolds MR. Trends in utilization and complications of catheter ablation for atrial fibrillation in Medicare beneficiaries. Heart Rhythm 2009;6:1267–73.

16. Curley M, Berger M, Roth J, Benjamin I, Rubenstein J. Predictors of mortality and major in-hospital adverse events associated with electrophysiology catheter ablation. JAMA Intern Med 2014;174:815–7.

17. Bohnen M, Stevenson WG, Tedrow UB, et al. Incidence and predictors of major complications from contemporary catheter ablation to treat cardiac arrhythmias. Heart Rhythm 2011;8:1661–6.

18. Kottkamp H. Catheter ablation of atrial fibrillation: on the pathophysiology of the arrhythmia and the impact of cardiac risk factor management. J Am Coll Cardiol 2014;64:2232–4.

19. Palaniswamy C, Kolte D, Harikrishnan P, et al. Catheter ablation of postinfarction ventricular tachycardia: ten-year trends in utilization, in-hospital complications, and in-hospital mortality in the United States. Heart Rhythm 2014;11:2056–63.

20. Haegeli LM, Duru F, Lockwood EE, et al. Feasibility and safety of outpatient radiofrequency catheter ablation procedures for atrial fibrillation. Postgrad Med J 2010;86:395–8.

21. Rodriguez LM, Smeets JL, De Chillou C, Waleffe A, Wellens HJ, Kulbertus HE. Ablation of accessory bundles using radiofrequency current. Rev Med Liege 1992;47:292–5 [in French].

22. Calkins H, Epstein A, Packer D, et al. Catheter ablation of ventricular tachycardia in patients with structural heart disease using cooled radiofrequency energy. J Am Coll Cardiol 2000;35:1905–14.

23. Hindricks G. The Multicentre European Radiofrequency Survey (MERFS): complications of radiofrequency catheter ablation of arrhythmias. The Multicentre European Radiofrequency Survey (MERFS) investigators of the Working Group on Arrhythmias of the European Society of Cardiology. Eur Heart J 1993;14:1644–53.

24. Cappato R, Calkins H, Chen SA, et al. Worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circulation 2005;111:1100–5.

25. Spragg DD, Dalal D, Cheema A, et al. Complications of catheter ablation for atrial fibrillation: incidence and predictors. J Cardiovasc Electrophysiol 2008;19:627–31.

26. Cappato R, Calkins H, Chen SA, et al. Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. Circ Arrhythm Electrophysiol 2010;3:32–8.

27. Tokuda M, Kojodjojo P, Epstein LM. Outcomes of cardiac perforation complicating catheter ablation of ventricular arrhythmias. Circulation 2011;4:660–6.

28. Hsu LF, Jais P, Hocini M, et al. Incidence and prevention of cardiac tamponade complicating ablation for atrial fibrillation. Pacing Clin Electrophysiol 2005;28 Suppl 1:S106–9.

29. Baman TS, Jongnarangsin K, Chugh A, et al. Prevalence and predictors of complications of radiofrequency catheter ablation for atrial fibrillation. J Cardiovasc Electrophysiol 2011;22:626–31.

30. Scheinman MM, Huang S. The 1998 NASPE prospective catheter ablation registry. Pacing Clin Electrophysiol 2000;23:1020–8.

31. Ghaye B, Szapiro D, Dacher JN, et al. Percutaneous ablation for atrial fibrillation: the role of cross-sectional imaging. Radiographics 2003;23:S19–33.

32. Cappato R, Calkins H, Chen SA, et al. Delayed cardiac tamponade after radiofrequency catheter ablation of atrial fibrillation: a worldwide report. J Am Coll Cardiol 2011;58:2696–7.

33. Calkins H, Yong P, Miller JM, et al. Catheter ablation of accessory pathways, atrioventricular nodal reentrant tachycardia, and the atrioventricular junction. Circulation 1999;99:262–70.

34. Shah RU, Freeman JV, Shilane D, Wang PJ, Go AS, Hlatky MA. Procedural complications, rehospitalizations, and repeat procedures after catheter ablation for atrial fibrillation. J Am Coll Cardiol 2012;59:143–9.

35. Srinivas VS, Hailpern SM, Koss E, Monrad ES, Alderman MH. Effect of physician volume on the relationship between hospital volume and mortality during primary angioplasty. J Am Coll Cardiol 2009;53:574–9.

36. Mansour M, Karst E, Heist EK, et al. The impact of first procedure success rate on the economics of atrial fibrillation ablation. J Am Coll Cardiol EP 2017;3:129–38.

37. Abhishek F, Heist EK, Barrett C, et al. Effectiveness of a strategy to reduce major vascular complications from catheter ablation of atrial fibrillation. J Interv Card Electrophysiol 2011;30:211–5.

38. Gianni M, Dentali F, Grandi AM, Sumner G, Hiralal R, Lonn E. Apical ballooning syndrome or takotsubo cardiomyopathy: a systematic review. Eur Heart J 2006;27:1523–9.

39. Tanaka-Esposito CC, Chung MK, Abraham JM, Cantillon DJ, Abi-Saleh B, Tchou PJ. Real-time ultrasound guidance reduces total and major vascular complications in patients undergoing pulmonary vein antral isolation on therapeutic warfarin. J Interv Card Electrophysiol 2013;37:163–8.

40. Cooper JM, Epstein LM. Use of intracardiac echocardiography to guide ablation of atrial fibrillation. Circulation 2001;104:3010–3.

KEY WORDS arrhythmia, catheter ablation, complication, outcome

APPENDIX For an expanded Methods section including tables, please see the online version of this article.