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ORIGINAL RESEARCH

Institutional Variation in 30-Day Complications Following Catheter Ablation of Atrial Fibrillation

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BACKGROUND: Complications are a measure of procedural quality, yet variation in complication rates following catheter ablation of atrial fibrillation (AF) among hospitals has not been systematically examined. We examined institutional variation in the risk-standardized 30-day complication rates (RSCRs) following AF ablation which may suggest variation in care quality.

METHODS AND RESULTS: This cohort study included all patients >18 years old undergoing AF ablations from 2012 to 2017 in Australia and New Zealand. The primary outcome was procedure-related complications occurring during the hospital stay and within 30 days of hospital discharge. We estimated the hospital-specific risk-standardized complication rates using a hierarchical generalized linear model. A total of 25 237 patients (mean age, 62.5±11.4 years; 30.2% women; median length of stay 1 day [interquartile range, 1–2 days]) were included. Overall, a complication occurred in 1400 (5.55%) patients (4.34% in hospital, 1.46% following discharge, and 0.25% experienced both). Bleeding (3.31%), pericardial effusion (0.74%), and infection (0.44%) were the most common complications while stroke/transient ischemic attack (0.24%), cardiorespiratory failure and shock (0.19%), and death (0.08%) occurred less frequently. Among 46 hospitals that performed ≥25 ablations during the study period, the crude complication rate varied from 0.00% to 21.43% (median, 5.74%). After adjustment for differences in patient and procedural characteristics, the median risk-standardized complication rate was 5.50% (range, 2.89%–10.31%), with 10 hospitals being significantly different from the national average.

CONCLUSIONS: Procedure-related complications occur in 5.55% of patients undergoing AF ablations, although the risk of complications varies 3-fold among hospitals, which suggests potential disparities in care quality and the need for efforts to standardize AF ablation practices among hospitals.

Key Words: atrial fibrillation ■ catheter ablation ■ complication ■ institutional variation

Since its inception in 1998,[1] catheter ablation of atrial fibrillation (AF) has rapidly evolved from an investigational procedure to a guidelines-recommended therapy for drug-refractory symptomatic AF.[2] Paralleling this change, worldwide surveys have shown a rapid increase in the number of AF ablations performed.[3,4] However, this complex and invasive procedure can cause serious complications such as bleeding, stroke, and cardiac tamponade, which may cause substantial harm to patients and may lead to additional invasive treatments.[5] Reducing the risk of complications is therefore highly desirable to minimize patient harm and improve procedural safety.

Although the incidence of procedural complications following AF ablations has been extensively reported,[6–10] little is known about the variation in complication rate among hospitals, which may suggest differences in care quality. Several studies have compared procedural safety in high- versus low-volume ablation centers,[8,9] although variation in complication rates among

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CLINICAL PERSPECTIVE

What Is New?

- Catheter ablation of atrial fibrillation (AF), although superior to medical therapy in restoring sinus rhythm, is associated with a risk of complications. While the incidence and types of complications have been extensively examined, it is uncertain whether complication rates vary among hospitals, which may imply differences in care quality.
- We found that 1 in 18 patients undergoing AF ablation experienced a procedural complication within 30 days of hospital discharge, with bleeding and pericardial effusion being the most common complications.
- More importantly, the risk of complications varied significantly among ablation centers. Using a hierarchical generalized linear model, a method widely used for profiling hospital performance, we found that the hospital-specific risk-standardized complication rate varied nearly 3-fold (range, 2.89%–10.31%) among 46 hospitals, with 10 having a risk-standardized complication rate significantly higher (6) or lower (4) than the national average (5.55%).

What Are the Clinical Implications?

- There was a clinically meaningful and statistically significant institutional variation in complication rates following AF ablation, suggesting that the risk of complications may be related to care quality and modifiable by improving procedural technique (such as more frequent use of vascular ultrasound or intracardiac echocardiography) and by quality improvement initiatives such as clinical audits or safety checklists.
- This institutional variation might be unsurprising, as AF ablation is rapidly disseminating and disparities in the management of AF have been reported before.
- Routine implementation of process and outcomes measures, such as those recommended by the Heart Rhythm Society, across all ablation centers may standardize care, reduce variation, and improve quality.

Nonstandard Abbreviations and Acronyms

CABANA	Catheter Ablation Versus Antiarrhythmic Drug Therapy for Atrial Fibrillation
RSCR	risk-standardized complication rate

individual hospitals has not been examined in the literature. Significant institutional variation has been reported for well-established procedures such as cardiac device implantation,[11,12] raising the possibility that similar variation may exist for AF ablation. Understanding the risk among individual hospitals is also important in the context of the recent studies reporting rising rates of mortality and complications following AF ablation[7,8] which have raised concern about disparities in procedural safety as this procedure disseminates more widely. Indeed, the 2017 consensus guidelines have called for observational data on procedure-related complication rates in the "real world" to inform patients and clinicians considering AF ablation and to inform hospitals and policymakers seeking to improve procedural quality.[13]

In this study, we used population-wide data from hospitals in Australia and New Zealand to determine the incidence of procedure-related complications following AF ablation occurring up to 30 days after discharge. We further estimated the hospital-specific risk-standardized complication rate to identify if there were meaningful differences in complication rates among hospitals that may suggest disparities in care quality.

METHODS

Because of the sensitive nature of the data collected for this study, requests to access the data sets from qualified researchers trained in human subject confidentiality protocols may be sent to the Human Research Ethics Committee of each state and territory in Australia and the New Zealand Ministry of Health.

Data Source

We used hospitalization data from all public and most (80%) of private-sector hospitals and day procedure centers using each Australian state and territory's Admitted Patient Collection and the New Zealand National Minimum Dataset (Hospital Events) from 2012 to 2017. These data sets record all in-patient and day-only admissions, including all outpatient procedures, irrespective of age and payer. A standard set of variables is collected for each patient encounter, including patient demographic characteristics, primary and secondary diagnoses, all procedures performed, and the patient status at discharge. Both countries use the *International Classification of Diseases, Tenth Revision, Australian Modification* (*ICD-10-AM*) and the Australian Classification of Health Interventions for coding of diagnoses and procedures, respectively. Validation against medical records has shown >85% coding accuracy, with cardiovascular diagnoses and procedures being particularly well coded.[14] When such data were used for surveillance of adverse events in other fields, >90% agreement with clinicians was reported.[15] Within each state or territory in Australia, hospitalizations were

linked to subsequent hospitalizations and each region's Registry of Deaths to track hospital readmission and postdischarge deaths. Greater than 99% accuracy is reported for the linkage of health records using probabilistic matching techniques based on multiple patient identifiers.[16] In New Zealand, hospital encounters are linked nationally using a unique National Health Index number, and all deaths are recorded in the National Health Index sociodemographic profile.

Study Cohort

We included patients >18 years old hospitalized with a primary diagnosis of AF (*ICD-10-AM* codes I48, I48.0-2, and I48.9) and underwent catheter ablation as defined by Australian Classification of Health Interventions procedure codes 38287-01, 38287-02 and 38290-01. The use of the AF diagnosis code together with catheter ablation code has shown high specificity (100%) and sensitivity (87.3%) in identifying AF ablation procedures.[17]

We excluded patients who had other arrhythmias as a secondary diagnosis to ensure the catheter ablation was for AF; had an implanted cardiovascular implantable electronic device (*pacemaker, implantable cardioverter defibrillator, or cardiac resynchronization therapy pacemaker or defibrillator*) during the index or previous admissions to avoid including patients undergoing atrioventricular nodal ablation for AF rate control; underwent open (surgical) ablation; were discharged against medical advice; had prior catheter ablation within 30 days since a complication may relate to the previous rather than the index ablation; or lacked at least 30 days follow-up after the procedure to assess complications. We also excluded acute (unplanned) hospitalizations to ensure that the complications were procedure related rather than attributable to the underlying acute illness. Table S1 provides a full description of diagnoses and procedure codes used to define inclusion and exclusion criteria.

Outcome

The primary outcome was the occurrence of ≥1 procedure-related complications identified from the prior literature,[5,8–10] expert clinical opinion, and empirical examination of patient records. Specific complications included (1) death, (2) cardiorespiratory failure and shock, (3) stroke or transient ischemic attack, (4) pericardial effusion, (5) hemothorax or pneumothorax, (6) bleeding (*hemorrhage or hematoma formation, internal organ bleeding [bleeding from the gastrointestinal, pulmonary, or urinary system], or requirement for blood transfusion*), (7) vascular injury or intervention, (8) infection (*pneumonia, sepsis, or endocarditis*), (9) pericarditis, (10) acute myocardial infarction, (11) venous thromboembolism, (12) acute kidney injury, (13) complete atrioventricular block, and (14) complications requiring cardiac surgery. Consistent with prior studies, we considered complications occurring in-hospital and within 30 days after discharge as procedure related.[10] In-hospital complications were identified on the basis of the secondary diagnoses and procedures performed during the hospital stay. Postdischarge complications were defined as postdischarge death or any readmission with a complication coded as the primary discharge diagnosis. Table S2 lists all relevant codes used to define complications.

Statistical Analysis

Categorical variables are presented as frequencies and percentages. Continuous variables are presented as mean±SD or as median and interquartile range. The student *t* test or Mann-Whitney *U* test was used to test differences between groups for continuous variables, and the χ^2 or Fisher's exact test was used for categorical variables. When estimating rate of overall complications, patients who experienced multiple events were counted only once.

To evaluate institutional variation in complication rates, we calculated the risk-standardized complication rate (RSCR) for each hospital using a hierarchical (2-level) generalized linear model, adjusting for differences in hospital case mix and clustering of patients. This method has been widely used to quantify institutional variation in outcomes and public reporting.[11,18–20] First, we identified patient characteristics independently associated with the risk of complications using a logistic regression model. Candidate variables included age, sex, hospitalization for AF in the preceding year, prior AF ablation, ablation of both atria, and comorbidities with a statistically significant ($P<0.25$) association with complications. Comorbidities were identified using the Condition Category classification that grouped *ICD-10-AM* codes into 180 clinically meaningful conditions using secondary diagnosis codes from the index admission and primary and secondary diagnosis codes from admissions within the preceding 12 months[21] (see Table S3 for list of comorbidities used for model development). To select the final variables, we included all candidate variables and then applied purposeful backward elimination as described by Hosmer and Lemeshow[22] until the model contained only variables significant at $P<0.05$. Model performance was evaluated by estimating model discrimination (C-statistic) and calibration. In keeping with best-practice recommendations, model discrimination was validated by calculating the optimism-corrected C-statistic using bootstrapping resampling with 100 replications.[23] The optimism is estimated as the difference between model's performances in bootstrap and original samples, and the corrected C-statistic equates the difference between the original C-statistic (derived from modeling using the original data set) and the average optimism.[24]

We then used the hierarchical generalized linear model to estimate a random-intercept term that reflects each hospital's contribution to the risk of the outcome, based on its actual complication rate, the performance of other hospitals with similar case mix and its sample size. The RSCR is the ratio of predicted complication rate over the expected complication rate multiplied by the cohort average complication rate. The predicted complication rate was calculated on the basis of the hospital's case mix and the estimated random intercept, while the expected complications rate was calculated using the hospital's case mix and the cohort average rate. We used bootstrapping with 1000 replications to empirically construct the 95% CI for each hospital's RSCR using the percentile method. A hospital was classified as significantly different from the national average if the entire 95% CI was above or below the average rate. To ensure robust estimates of the RSCR, all hospital analyses were limited to those that performed at least 25 ablations during the study period. A detailed description of the RSCR calculation and bootstrapping algorithm is provided in Data S1.

A two-sided *P* value <0.05 was considered statistically significant. All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC). The Human Research Ethics Committees of all Australian states and territories provided ethical approval to undertake the study with a waiver of informed consent to use deidentified patient data. Deidentified data from New Zealand were obtained under a data user agreement with the Ministry of Health.

RESULTS

We identified 32 739 eligible patients with a primary diagnosis of AF undergoing catheter ablation. Of these, we excluded 7502 patients (see Figure 1 patient selection flow diagram), and the main reasons for exclusion were having a current or previous cardiovascular implantable electronic device (4104 patients) or unplanned hospitalizations (1972 patients). The final study cohort consisted of 25 237 patients who underwent AF ablation at 67 unique hospitals, of which 46 performed at least 25 procedures in the study period.

Cohort Characteristics

The study cohort had a mean age of 62.5±11.4 years and 30.2% were women (Table 1). The median length of stay was 1 day (interquartile range, 1.0–2.0 days). Of these patients, 62.8% had a prior hospitalization for AF or atrial flutter, and 12.2% had a prior catheter ablation. Hypertension (11.3%) and diabetes (11.3%) were the most common cardiac and noncardiac comorbidities, respectively.

Incidence of Complications

Overall, procedural complications occurred in 1400 (5.55%) patients in-hospital or within 30 days of discharge (Table 2). Patients who experienced a complication were older (64.1 versus 62.5 years; *P*<0.001), were more likely to be women (35.5% versus 29.9%; *P*<0.001), and had higher rates of comorbidities such as hypertension (17.1% versus 10.9%), heart failure (11.6% versus 8.7%), coronary artery disease (13.2% versus 9.3%), chronic obstructive lung disease (2.4% versus 1.1%), and chronic kidney disease (5.9% versus 3.1%) compared with those who did not experience a complication (all *P*<0.001).

When specific complications were considered, bleeding was the most common complication, occurring in 3.31% of procedures. Of the bleeding events, 77.3% were attributable to postprocedural hemorrhage or hematoma, 17.1% was bleeding from internal organs (gastrointestinal, pulmonary, or urinary), and 15.3% required blood transfusion. Pericardial effusion was the second most common complication, which occurred in 0.74% of patients and 56.9% of these cases underwent pericardiocentesis. Death (0.08%), complications that required cardiac surgery (0.10%), and stroke or transient ischemic attack (0.24%) occurred infrequently.

Among patients who experienced a complication, 1095 (4.34%) had the complication during their hospital stay. Bleeding remained the most common complication (2.75%), with 10.4% of these patients requiring a blood transfusion. Pericardial effusion (0.66%) was the second most common, with 54.8% of these cases requiring drainage. Another 368 (1.46%) patients had procedural complications within 30 days of hospital discharge, with 0.25% of patients experiencing both in-hospital and postdischarge complications. Bleeding was the most common cause of a postdischarge complication (0.65%), followed by postprocedural infection (0.25%) and stroke/transient ischemic attack (0.13%). Procedure-related death occurred more frequently after discharge than during the index hospitalization (15 versus 6 deaths) and 5 of the 15 postdischarge deaths occurred in the community.

Risk-Adjustment Model

Patient age, female sex, history of ablation, ablation of both atria, year of ablation, and 5 comorbidities were independently associated with the risk of complications (Table S4) and were used for the hospital-level risk-adjustment. The logistic regression model had moderate discrimination (C-statistic of 0.604) and could predict a range of patient risk from 3.72% to 11.93% that closely approximated the observed risk, suggesting good model calibration (Hosmer-Lemeshow c^2=11.83; *P*=0.159) (Figure S1). Internal validation by

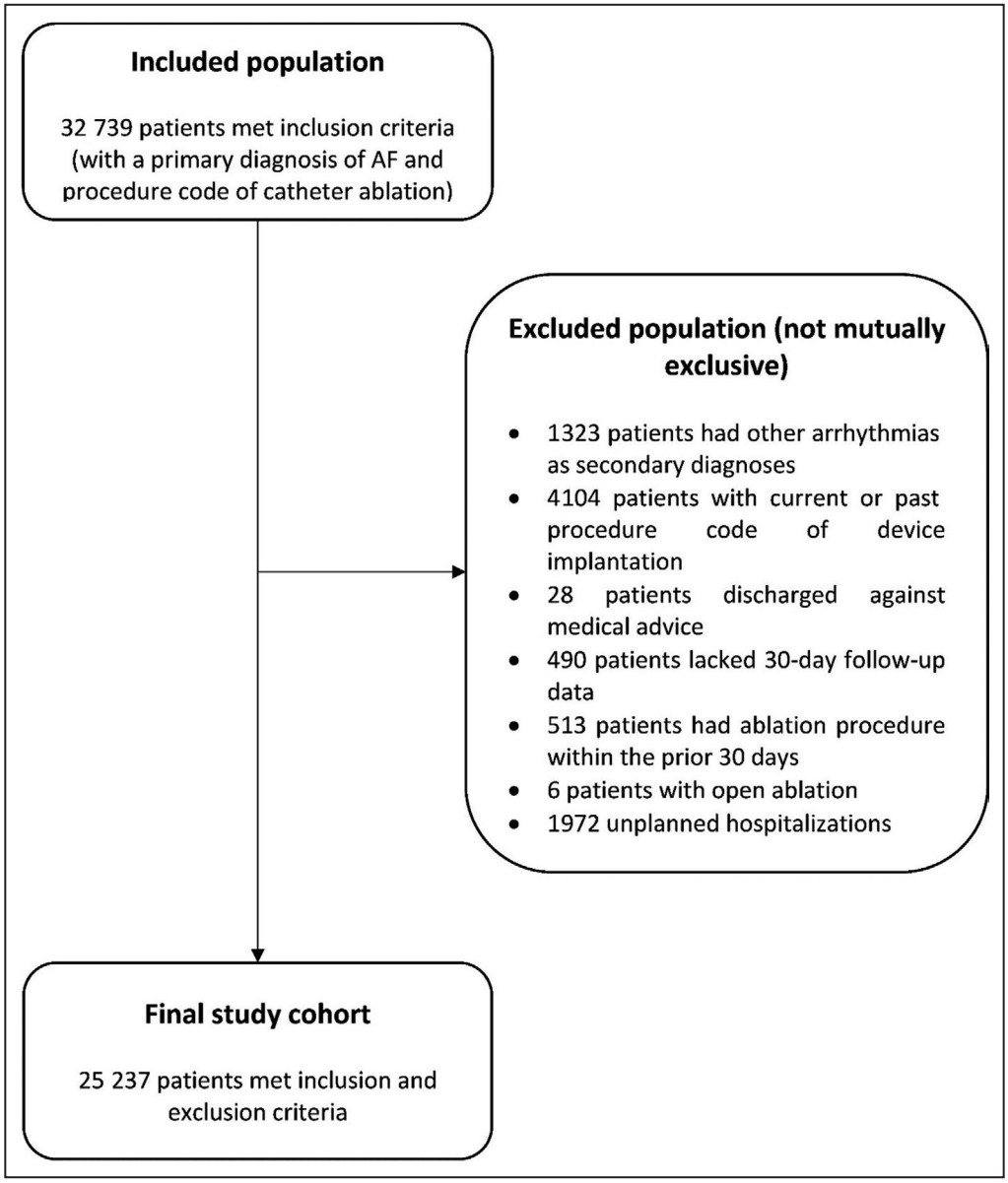


Figure 1. Patient selection flow diagram.
AF indicates atrial fibrillation; and CA, catheter ablation.

bootstrapping with 100 replications revealed an average optimism of 0.005, corresponding to a corrected C-statistic of 0.599.

Hospital Variation in the RSCRs

Among the 46 hospitals that performed at least 25 procedures during the study period, the crude median complication rate was 5.74% and ranged from 0.00% to 21.43% (Table S5). After risk-standardization, the median RSCR was 5.50%, although the rate varied from 2.89% to 10.31% among hospitals (Figure 2A). Of these hospitals, 10 had complication rates significantly different from the cohort average, with 4 having the entire 95% CI below the average rate (indicating a better-than-average complication rate) and 6 with the entire estimated 95% CI above the average (indicating worse-than-average complication rate). There was no correlation between RSCR and the hospital's annual ablation volume (Spearman correlation coefficient, −0.02; P=0.892; Figure 2B).

Sensitivity Analysis

We performed several analyses to test the robustness of our findings. As most existing studies report in-hospital complications exclusively and because these events may be more closely related to procedural

Table 1. Characteristics of the Study Cohort

Variables	Overall (N=25 237) n (%)	Any complication (N=1400) n (%)	No complication (N=23 837) n (%)	*P* value
Patients' demographics				
Age (mean±SD)	62.5±11.4	64.1±11.0	62.5±11.4	<0.001
Age group, y				
18–34	497 (2.0)	20 (1.4)	477 (2.0)	<0.001
35–49	2657 (10.5)	121 (8.6)	2536 (10.6)	
50–64	10 419 (41.3)	540 (38.6)	9879 (41.4)	
65–79	10 438 (41.4)	627 (44.8)	9811 (41.2)	
≥80	1226 (4.9)	92 (6.6)	1134 (4.8)	
Female (%)	7621 (30.2)	497 (35.5)	7124 (29.9)	<0.001
Median length of stay (IQR)	1.0 (1.0–2.0)	2.0 (1.0–3.5)	1.0 (1.0–2.0)	<0.001
Cardiac history				
Prior AF hospitalizations	15 839 (62.8)	884 (5.6)	516 (5.5)	0.761
Prior AF ablation	3088 (12.2)	142 (10.1)	2946 (12.4)	0.014
Hypertension	2842 (11.3)	240 (17.1)	2602 (10.9)	<0.001
Heart failure	2239 (8.9)	162 (11.6)	2077 (8.7)	<0.001
Valvular and rheumatic heart disease	919 (3.6)	74 (5.3)	845 (3.5)	0.001
Coronary artery disease	2401 (9.5)	185 (13.2)	2216 (9.3)	<0.001
Vascular disease	382 (1.5)	28 (2.0)	354 (1.5)	0.125
Noncardiac comorbidities				
Diabetes	2849 (11.3)	153 (10.9)	2696 (11.3)	0.661
Chronic obstructive lung disease	304 (1.2)	34 (2.4)	270 (1.1)	<0.001
Chronic kidney disease	819 (3.3)	82 (5.9)	737 (3.1)	<0.001
Stroke or TIA	318 (1.3)	18 (1.3)	300 (1.3)	0.929
Hematologic disorders	1070 (4.2)	154 (11.0)	916 (3.8)	<0.001
Pneumonia	508 (2.0)	74 (5.3)	434 (1.8)	<0.001
Musculoskeletal and connective tissue disorders	1846 (7.3)	155 (11.0)	1691 (7.1)	<0.001
Dementia and senility	38 (0.2)	5 (0.4)	33 (0.1)	0.040

AF indicates atrial fibrillation; IQR, interquartile range; and TIA, transient ischemic attack.

technique and care quality, we repeated the RSCR estimation, limiting to in-hospital complications only. We found persisting variation in RSCR (median, 4.15%; range, 2.07%–10.20%), with 7 hospitals having higher-than-average and 3 having lower-than-average in-hospital complication rates (Figure 2C). Seven of these 10 hospitals were also outliers based on the 30-day outcome. To determine the potential for unmeasured confounders to influence the results, we assessed the minimum strength of association that an unmeasured confounder would need to shift the interval estimate of the most outlying hospital (hospital 45 in Figure 2A—RSCR, 10.11%; 95% CI, 7.31%–13.29%) to cross the cohort average rate by calculating the E-value[25] for the lower 95% CI (7.31%), which yielded 1.97. This means that an unmeasured confounder would need to be 1.97 times more common in the outlier hospital compared with the national average *and* be associated with a 1.97-times higher rate of complications to explain away the difference so that the hospital is no longer an outlier, while a weaker confounder could not.[25] Moreover, to assess whether the observed variation could have occurred by chance, we repeated the analysis applying the Bonferroni correction, which tests the global null hypothesis that all hospitals have a risk-standardized outcome rate similar to the national average.[26] When a corrected *P* value of 0.001 (≈0.05/46) was applied (equivalent to 99.9% CIs) and 10 000 bootstrapped samples were used, 2 hospitals remained significantly different than average (all above the national average), making it unlikely that the observed variation was attributable to chance. Finally, the funnel plot of RSCRs (Figure S2), an alternative methodology for displaying variation in performance, also showed 7 hospitals with RSCRs exceeding the 95% limit of the average complication rate.[27] These hospitals were also classified as

Table 2. Incidence of Complications After Catheter Ablation of AF

Procedural complications	Overall N (%)	In-hospital n (%)	Postdischarge n (%)
Primary outcome—any complication*	1400 (5.55)	1095 (4.34)	368 (1.46)
Death	21 (0.08)	6 (0.02)	15 (0.06)
Cardiorespiratory failure and shock	47 (0.19)	43 (0.17)	4 (0.02)
Stroke/TIA	60 (0.24)	28 (0.11)	34 (0.13)
Pericardial effusion	188 (0.74)	166 (0.66)	25 (0.10)
Pericardiocentesis	107 (0.42)	91 (0.36)	16 (0.06)
Hemothorax/pneumothorax	33 (0.13)	19 (0.08)	15 (0.06)
Bleeding	835 (3.31)	693 (2.75)	165 (0.65)
Postprocedural hemorrhage/hematoma	645 (2.56)	582 (2.31)	74 (0.29)
Internal organ bleeding†	143 (0.57)	105 (0.42)	40 (0.16)
Blood transfusion	128 (0.51)	72 (0.29)	61 (0.24)
Vascular injury or intervention	56 (0.22)	32 (0.13)	26 (0.10)
Postprocedural infection	112 (0.44)	50 (0.20)	62 (0.25)
Pericarditis	71 (0.28)	56 (0.22)	16 (0.06)
Procedure-related AMI	27 (0.11)	10 (0.04)	17 (0.07)
Venous thromboembolism	18 (0.07)	7 (0.03)	11 (0.04)
Acute kidney injury	73 (0.29)	66 (0.26)	7 (0.03)
Complications requiring cardiac surgery	25 (0.10)	15 (0.06)	10 (0.04)
Complete atrioventricular block	55 (0.22)	53 (0.21)	4 (0.02)

Therefore, the incidence across rows or columns may not sum to group totals. AF indicates atrial fibrillation, AMI indicates acute myocardial infarction; and TIA, transient ischemic attack.

*When estimating the primary outcome, patients with multiple complications were counted only once. For all other outcomes, patients may have >1 complication.

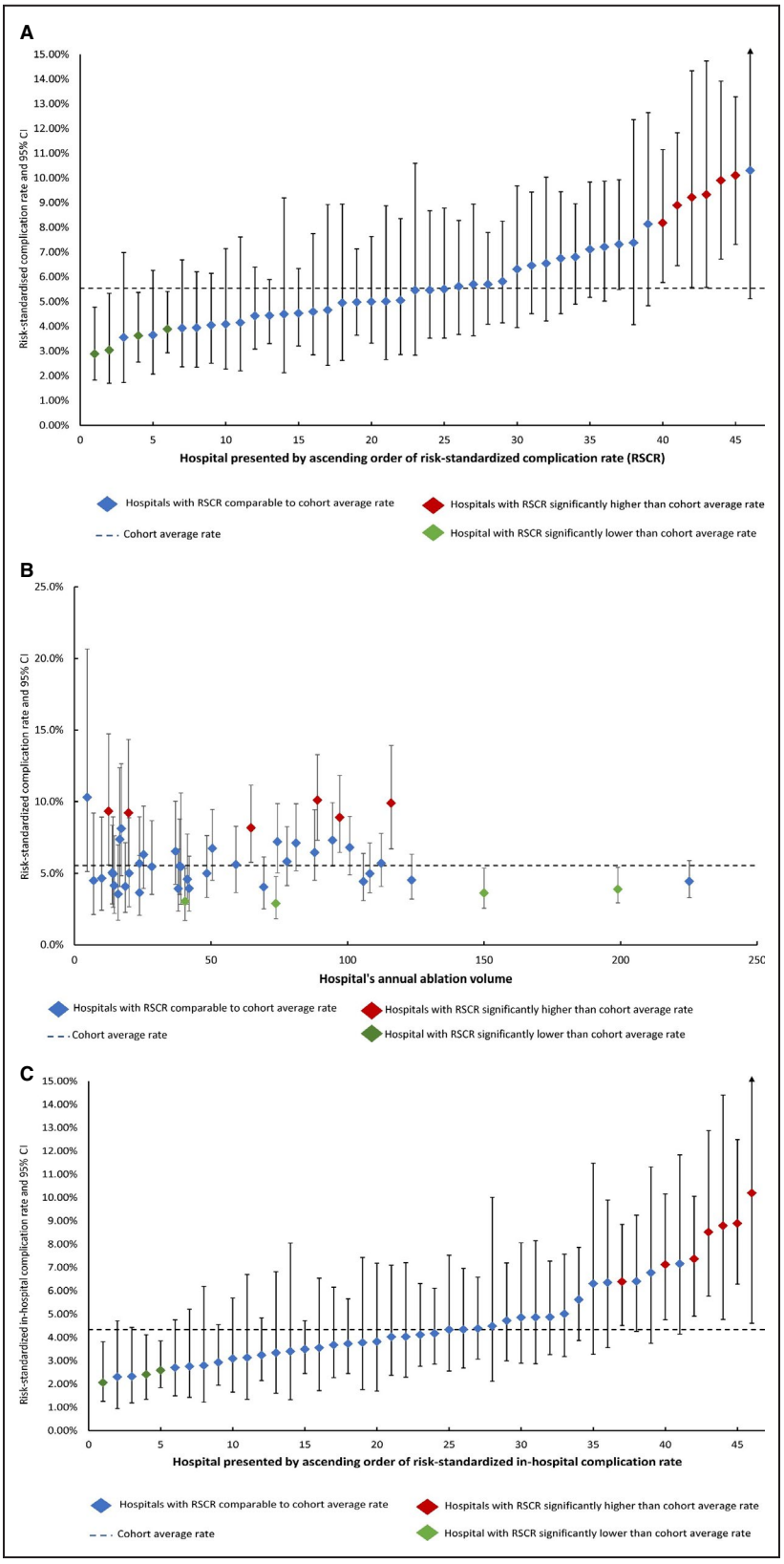
†Bleeding from the gastrointestinal, pulmonary, or urinary system. Intracranial bleeding was counted as stroke.

having a higher- (4 hospitals) and lower-than-average (3 hospitals) complication rate using the bootstrapping method. The calculated φ and $\hat{\phi}$ were 1.51 and 1.13, respectively, suggesting that we could assume φ=1 and that adjustment for possible overdispersion was not needed.[27] But even if 10% winsorization is applied to adjust for possible overdispersion, the winsorized plot still shows 3 hospitals with RSCRs higher than the upper border of the 95% control limits (Figure S3). Collectively, these findings suggest that statistically significant and clinically meaningful institutional variation likely existed.

DISCUSSION

In this population-wide study of 25 237 patients undergoing AF ablation, we found that about 1 in 18 patients experienced a procedure-related complication within 30 days of hospital discharge. However, the incidence of complications was highly dependent on the ablation center, with complication rates varying more than 3-fold among hospitals even after adjusting for differences in patient and procedure characteristics, implying institutional disparities in care processes and quality control measures. Of all complications, 76.3% were attributable to bleeding, pericardial effusion, and infection—complications that can be reduced or avoided with established interventions such as vascular ultrasound, intracardiac echocardiography, or prophylactic antibiotics. Collectively, these findings call for concerted clinical and policy intervention to inform patients, improve procedural safety, and standardize care among hospitals.

Population studies with unselected cohorts (all age, all payer) that capture the full range of ablation facilities are sparse. Most existing studies report in-hospital complications only[7–9] and often fail to capture outpatient procedures,[7–9] even though they could account for 37% to >90% of all AF ablations.[28] We extend the literature by providing estimates from a national cohort that includes both inpatient and outpatient procedures and captures all complications including those that occurred following discharge. Although comparisons of complication rates among studies are often challenging because of differences in designs, data sources, and definitions of complications, our overall complication rate of 5.55% is consistent with the 3.5% to 7.4% range reported in population studies, including the Get With The Guidelines AF Registry.[6–10] Our result is also comparable to the ≈6.9% rate reported in the multicenter CABANA (Catheter Ablation Versus Antiarrhythmic Drug Therapy for Atrial Fibrillation) trial.[29] Our rate, however, is higher than the 2.9% (95% CI,



2.6%–3.2%) rate reported in a prior systematic review,[5] in which most included studies assessed in-hospital events only and may explain the discrepancy. Indeed, we found that nearly 30% of complications presented after discharge, highlighting the need for continued vigilance for complications after discharge.

Figure 2. Institutional variation in the risk-standardized complication rate (RSCR).
A, shows the RSCR with the corresponding 95% CI of the 46 hospitals. **B**, presents RSCR based on hospital's annual ablation volume. **C**, shows the RSCR with the corresponding 95% CI when the outcome was limited to in-hospital complications only. Analysis was limited to hospitals that performed ≥25 procedures during the study period with hospitals presented by ascending order of the RSCR in **A**, of hospital's annual ablation volume in **B**, and of risk-standardized in-hospital complication rate in **C**.

We also extend the literature by demonstrating the institutional heterogeneity in AF ablation outcomes by showing clinically meaningful and statistically significant variation in complication rates among hospitals. Prior studies have compared procedural safety among hospitals by volume-based grouping of ablation centers and found higher complications rates in low-volume strata,[8,9] yet such studies do not provide insights into the performance of individual hospitals. Our study quantified hospital performance individually and did not find a significant relationship between a hospital's ablation volume and its RSCR. The >3-fold variation in overall complication rates suggests disparities in procedural quality among ablation centers. Such variation is perhaps unsurprising given the rapid dissemination of AF ablation and the highly heterogeneous nature of the procedure that relies on a wide variety of techniques, equipment, and resources. Indeed, marked institutional differences have been found in compliance with quality measures for AF management.[30] Thus, it is conceivable that similar variation in care quality may occur for AF ablation. Recently, the fifth Atrial Fibrillation Network/European Heart Rhythm Association conference recommends defining and monitoring quality standards in AF care, including implementing a range of process and outcomes measures for AF ablation.[31] The Heart Rhythm Society has also recently developed harmonized outcomes measures for use in AF, including AF ablation.[32] Our findings firmly support implementing such measures across all ablation centers to standardize care and to guide targeted quality improvement efforts.

These findings have several additional implications for quality improvement efforts. Current consensus guidelines emphasize minimizing clinically important but rare complications such as atrio-esophageal fistula formation.[13] While this is important, our results imply that efforts to improve patient safety should also focus on reducing more common complications such as bleeding, pericardial effusion, and infection, which constitute 76.3% of all complications. Moreover, these complications are potentially preventable with existing interventions. For example, uninterrupted dabigatran has been shown to be associated with significantly fewer major bleeding events compared with warfarin.[33] Similarly, good visualization during transseptal puncture by multiple fluoroscopic views or intracardiac ultrasound may help to avoid cardiac perforation.[34] Among patients undergoing AF ablation under general anesthesia and routine urinary catheter placement, rates of urinary tract infection, which is significantly associated with risk of sepsis,[35] could be reduced by 80% with prophylactic antibiotics.[36] Moreover, the routine use of a urinary catheter could be safely avoided, as need-based catheterization is shown to be associated with nearly 8 times lower odds of experiencing adverse outcomes, including cystitis, hematuria, dysuria, and urethral damage, compared with routine use.[37] More broadly, implementing procedural safety checklists can reduce complications from cardiac catheterization procedures, including ablations.[38] From a policy perspective, our observations support reporting of hospital-specific complication rates to better inform decision making, guide quality improvement efforts, and standardize care among hospitals. Reporting hospital-specific rates may be particularly important for true informed consent, as the average complication rate may have little meaning when discussing procedural risk with patients in the context of marked variation among hospitals.

Several limitations should be considered when interpreting our results. Administrative data are less granular than data collected specifically for research, however, validation studies have reported good accuracy (>85%) of diagnoses and procedures coding.[14] We also focused on coding definitions used by prior studies to minimize the risk of erroneous coding influencing our results.[5,8–10] Data were available from all regions at up to 2017 only, after which new advances in techniques and technology may have occurred and impacted the contemporary complication rates. Similar to other population studies, atrio-esophageal fistula, pulmonary vein stenosis, and phrenic nerve injury could not be reliably identified using administrative data because of a lack of specific codes.[8–10] These complications can also present beyond 30 days; thus, our study is likely to underestimate the true complication rate. Nevertheless, atrio-esophageal fistula is rare and may be captured under other categories such as sepsis, stroke, or death,[39] while only a few cases with pulmonary vein stenosis and phrenic nerve injury cause symptoms or require treatment.[40,41] We also could not distinguish between different types of ablation used, although no technique is proven to have a superior safety profile.[42,43] Data regarding ablation lesions were also not available, and patients may have had additional ablations other than pulmonary vein isolation. Nevertheless, our sensitivity analyses suggest

that the observed variation is unlikely to be explained either by chance or an unmeasured confounder.

CONCLUSIONS

Complications following catheter ablation of AF occur in ≈1 in 18 patients undergoing ablation, although the rate of complications is highly variable among hospitals, suggesting that clinically meaningful differences may exist in procedural quality and after-care practices. Concerted clinical and policy efforts are needed to better inform patients, to improve care practices, and to standardize outcomes across ablation centers.

ARTICLE INFORMATION

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Supplemental Material

Data S1
Tables S1–S5
Figures S1–S3

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SUPPLEMENTAL MATERIAL

Data S1.

Supplemental Methods

Risk-Standardized Complication Rate Calculation Algorithm

We fitted a hierarchical generalized linear model (HGLM), which accounts for the clustering of observations within hospitals. We assume the outcome is a known exponential family distribution and is related linearly to the covariates via a known linked function, *h*. For our model, we assumed a binomial distribution and a logit link function. Further, we accounted for the clustering within facility by estimating a facility-specific effect, α_i, which is assumed to follow a normal distribution with mean μ and variance τ^2, the between-facility variance component. The HGLM is defined by the following equations:

$$h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij} \quad (1)$$

$$\alpha_i = \mu + \omega_i;\ \omega_i \sim N(0, \tau^2) \quad (2)$$

$$i = 1 \ldots I; j = 1 \ldots n_i$$

Where Y_{ij} denotes the outcome (equal to 1 if patient has a complication, 0 otherwise) for the *j-th* patient who had an AF ablation at the *i-th* hospital; $\mathbf{Z}_{ij} = (Z_{1ij}, Z_{2ij}, \ldots, Z_{pij})$ is a set of *p* patient-specific covariates derived from the data; and *I* denotes the total number of hospitals and n_i the number of ablations performed at hospital *i*. The hospital-specific intercept of the *i-th* hospital, α_i , defined above, is comprised of μ, the adjusted average intercept over all hospitals in the sample and ω_i the facility-specific intercept deviation from μ. A point estimate of ω_i, greater or less than 0, determines if hospitals performance is worse or better compared to the adjusted average outcome.

The HGLM was estimated using SAS version 9.4 (SAS Institute Inc., Cary, NC) GLIMMIX procedure. To estimate the covariance matrix, we used the default estimation technique (Residual Log Pseudo-Likelihood).

Provider Performance Reporting

Using the HGLM defined by Equations (1) - (2), we estimate the parameters $\hat{\mu}$, $\{\hat{\alpha}_1, \hat{\alpha}_2, \ldots, \hat{\alpha}_I\}$, $\hat{\beta}$, and $\hat{\tau}^2$. We calculate a standardized complication rate, s_i, for each hospital by computing the ratio of the number of predicted complications to the number of expected complications, multiplied by the unadjusted overall complication rate, $\bar{y}$. Specifically, we calculate:

Predicted $$\hat{y}_{ij}(Z) = h^{-1}(\hat{\alpha}_i + \hat{\beta}\mathbf{Z}_{ij}) \quad (3)$$

Expected $$\hat{e}_{ij}(Z) = h^{-1}(\hat{\mu} + \hat{\beta}\mathbf{Z}_{ij}) \quad (4)$$

$$\hat{s}_i(Z) = \frac{\sum_{j=1}^{n_i} \hat{y}_{ij}(Z)}{\sum_{j=1}^{n_i} \hat{e}_{ij}(Z)} \times \overline{y} \quad (5)$$

If the "predicted" number of complications is higher (lower) than the "expected" number of complications, then that facility's $\hat{s}_i$ will be higher (lower) than the unadjusted average.

Outlier Evaluation

Because the statistic described in Equation (5) is a complex function of parameter estimates, we use re-sampling and simulation techniques to derive an interval estimate to determine if a hospital is performing better than, worse than, or no different from its expected rate. A hospital is considered as better than expected if its entire confidence interval falls below the expected rate, and considered worse if the entire confidence interval falls above the expected rate. It is considered no different if the confidence interval overlaps the expected rate.

More specifically, we use a bootstrapping procedure to compute confidence intervals. Because the theoretical-based standard errors are not easily derived, and to avoid making unnecessary assumptions, we use the bootstrap to empirically construct the sampling distribution for each hospital-level risk-standardized rate. The bootstrapping algorithm is described below.

Bootstrapping Algorithm

Let *I* denote the total number of hospitals in the sample. We repeat steps 1 – 4 below for b = 1,2,…B times:

1. Sample *I* hospitals with replacement.
2. Fit the hierarchical logistic regression model using all patients within each sampled hospital. We use as starting values the parameter estimates obtained by fitting the model to all hospitals. If some hospitals are selected more than once in a bootstrapped sample, we treat them as distinct so that we have *I* random effects to estimate the variance components. At the conclusion of Step 2, we have:
   a. $\hat{\beta}^{(b)}$ (the estimated regression coefficients of the risk factors).
   b. The parameters governing the random effects, hospital adjusted outcomes, distribution, $\hat{\mu}^{(b)}$ and $\hat{\tau}^{2(b)}$.
   c. The set of hospitals-specific intercepts and corresponding variances:

$\{\hat{\alpha}_i^{(b)}, \hat{\text{var}}(\alpha_i^{(b)}); i = 1,2,...,I\}$.

3. We generate a hospitals random effect by sampling from the distribution of the hospital-specific distribution obtained in Step 2c. We approximate the distribution for each random effect by a normal distribution. Thus, we draw $\alpha_i^{(b^*)} \sim N(\hat{\alpha}_i^{(b)}, \hat{\text{var}}(\hat{\alpha}_i^{(b)}))$ for the unique set of hospitals sampled in Step 1.

4. Within each unique hospital *i* sampled in Step 1, and for each case *j* in that hospital, we calculate $\hat{y}_{ij}^{(b)}$, $\hat{e}_{ij}^{(b)}$, and $\hat{s}_i(Z)^{(b)}$ where $\hat{\beta}^{(b)}$ and $\hat{\mu}^{(b)}$ are obtained from Step 2 and $\hat{\alpha}_i^{(b^*)}$ is obtained from Step 3.

Ninety-five percent interval estimates (or alternative interval estimates) for the hospital-standardized outcome can be computed by identifying the 2.5th and 97.5th percentiles of randomly half of the B estimates (or the percentiles corresponding to the alternative desired intervals).

The methods outline above are similar to methods we have previously used to profile institutional variation in procedural outcomes (Reference 20 in the main text).

Table S1. ICD-10 AM and ACHI codes used to identify patients undergoing catheter ablation of atrial fibrillation.

GROUP	DISEASE/PROCEDURE	ICD10-AM/ACHI codes
Inclusion	Atrial fibrillation	I48, I48.0, I48.1, I48.2, I48.9
	Catheter ablation of arrhythmia circuit or focus, not elsewhere classified	38287-01
	Catheter ablation of arrhythmia circuit or focus involving left atrial chamber	38287-02
	Catheter ablation of arrhythmia circuit or focus involving both atrial chambers	38290-01
Exclusion	Atrial flutter	I48.3, I48.4
	Pre-excitation syndrome	I45.6
	Supra-ventricular tachycardia	I47.1
	Ventricular tachycardia	I47.2, I49.0
	Premature beats	I49.1, I49.2, I49.3, I49.4
	Other arrhythmias	I47, I47.0, I48, I49.8, I49.9, R00.0
	Presence of a cardiac device	Z95.0
	Pacemaker implantation	38353-00
	Cardiac defibrillator implantation	38393-00
	Open ablation	38287-03, 38287-04, 38290-02

Table S2. Diagnoses and procedure codes used to identify in-hospital and post-discharge complications.

COMPLICATIONS	ICD-10 AM or ACHI codes	Code description
Cardiopulmonary failure and shock		
Cardiac arrest	I46	Cardiac arrest
	I46.0	Cardiac arrest with successful resuscitation
	I46.9	Cardiac arrest, unspecified
	I46.1	Sudden cardiac death, so described
Acute respiratory failure	J96.0	Acute respiratory failure
	J96.00	Acute respiratory failure, type I
	J96.01	Acute respiratory failure, type II
	J96.09	Acute respiratory failure type unspecified
Shock	R57.x	Cardiogenic shock
	T81.1	Shock during or resulting from a procedure, not elsewhere classified
	T88.2	Shock due to anaesthesia
	T78.2	Anaphylactic shock, unspecified
	T80.5	Anaphylactic shock due to serum
	T88.6	Anaphylactic shock due to adverse effect of correct drug or medicament properly administered
Cardiorespiratory resuscitation	92052-00	Cardiopulmonary resuscitation
Stroke/Transient ischemic attack		
Stroke	I64	Stroke, not specified as haemorrhage or infarction
	I63	Cerebral infarction
	I63.0	Cerebral infarction due to thrombosis of precerebral arteries
	I63.1	Cerebral infarction due to embolism of precerebral arteries
	I63.2	Cerebral infarction due to unspecified occlusion or stenosis of precerebral arteries
	I63.3	Cerebral infarction due to thrombosis of cerebral arteries
	I63.4	Cerebral infarction due to embolism of cerebral arteries
	I63.5	Cerebral infarction due to unspecified occlusion or stenosis of cerebral arteries
	I63.6	Cerebral infarction due to cerebral venous thrombosis, nonpyogenic
	I63.8	Other cerebral infarction
	I63.9	Cerebral infarction, unspecified
	I61	Intracerebral haemorrhage

	I61.0	Intracerebral haemorrhage in hemisphere, subcortical
	I61.1	Intracerebral haemorrhage in hemisphere, cortical
	I61.2	Intracerebral haemorrhage in hemisphere, unspecified
	I61.3	Intracerebral haemorrhage in brain stem
	I61.4	Intracerebral haemorrhage in cerebellum
	I61.5	Intracerebral haemorrhage, intraventricular
	I61.6	Intracerebral haemorrhage, multiple localised
	I61.8	Other intracerebral haemorrhage
	I61.9	Intracerebral haemorrhage, unspecified
	I62	Other nontraumatic intracranial haemorrhage
	I62.0	Subdural haemorrhage (acute)(nontraumatic)
	I62.1	Nontraumatic extradural haemorrhage
	I62.9	Intracranial haemorrhage (nontraumatic), unspecified
	I60	Subarachnoid haemorrhage
	I60.0	Subarachnoid haemorrhage from carotid siphon and bifurcation
	I60.1	Subarachnoid haemorrhage from middle cerebral artery
	I60.2	Subarachnoid haemorrhage from anterior communicating artery
	I60.3	Subarachnoid haemorrhage from posterior communicating artery
	I60.4	Subarachnoid haemorrhage from basilar artery
	I60.5	Subarachnoid haemorrhage from vertebral artery
	I60.6	Subarachnoid haemorrhage from other intracranial arteries
	I60.7	Subarachnoid haemorrhage from intracranial artery, unspecified
	I60.8	Other subarachnoid haemorrhage
	I60.9	Subarachnoid haemorrhage, unspecified
Transient ischemic attack	G45	Transient cerebral ischaemic attacks and related syndromes
	G45.0	Vertebro-basilar artery syndrome
	G45.1	Carotid artery syndrome (hemispheric)
	G45.2	Multiple and bilateral precerebral artery syndromes
	G45.3	Amaurosis fugax
	G45.4	Transient global amnesia
	G45.8	Other transient cerebral ischaemic attacks and related syndromes
	G45.9	Transient cerebral ischaemic attack, unspecified

Pericardial effusion		
Pericardial effusion	I31.2	Haemopericardium, not elsewhere classified
	I31.3	Pericardial effusion (noninflammatory)
Pericardiocentesis	3835900	Pericardiocentesis
	3845000	Transthoracic drainage of pericardium
	3845001	Thoracoscopic drainage of pericardium
	3845200	Subxyphoid drainage of pericardium
Haemothorax or pneumothorax		
Haemothorax	J94.2	Haemothorax
Pneumothorax	J93	Pneumothorax
	J93.2	Iatrogenic pneumothorax
	J93.8	Other pneumothorax
	J93.9	Pneumothorax, unspecified
Thoracentesis	3880000	Diagnostic thoracentesis
	3880300	Therapeutic thoracentesis
	3880600	Insertion of intercostal catheter for drainage
Atrio-oesophageal fistula		
Oesophageal perforation	K22.3	Perforation of oesophagus
Mediastinitis	J85	Abscess of lung and mediastinum
	J85.3	Abscess of mediastinum
Any bleeding		
Post-procedural haemorrhage/hematoma	R58	Haemorrhage, not elsewhere classified
	T81.0	Haemorrhage and haematoma complicating a procedure, not elsewhere classified
	Y60.5	Unintentional cut, puncture, perforation or haemorrhage during heart catheterisation
Internal organ bleeding (bleeding from the gastro-intestine, pulmonary, or urinary system)	K92.2	Gastrointestinal haemorrhage, unspecified
	I98.3	Esophageal varices with bleeding
	K22.6	Gastro-oesophageal laceration-haemorrhage syndrome
	K25.0, 25.2, 25.4, 25.6	Gastric ulcer with haemorrhage
	K26.0, 26.2, 26.4, 26.6	Duodenal ulcer with haemorrhage
	K27.0, 27.2, 27.4, 27.6	Peptic ulcer with haemorrhage
	K28.0, 28.4, 28.6	Gastrojejunal ulcer with haemorrhage

	K29.0	Acute haemorrhagic gastritis
	K62.5	Haemorrhage of anus and rectum
	K66.1	Hemoperitoneum
	K92.0	Hematemesis
	K92.1	Melena
	R04.0	Epistaxis
	R04.1	Haemorrhage from throat
	R04.2	Haemoptysis
	R04.8	Haemorrhage from other sites in respiratory passages
	R04.9	Haemorrhage from respiratory passages, unspecified
	N02.x	Recurrent and persistent haematuria
	R31.0	Unspecified haematuria
	D62	Acute post haemorrhagic anaemia
Bleeding requiring blood transfusion	Z51.3	Blood transfusion without reported diagnosis
	13706-01	Administration of whole blood
	13706-02	Administration of packed cells
Vascular injury		
Vascular injury	I72.4	Aneurysm and dissection of artery of lower extremity
	I77.0	Arteriovenous fistula, acquired
	T81.7	Vascular complications following a procedure, not elsewhere classified
Surgical repair	33142-00	Repair of false aneurysm in femoral artery
	33139-00	Repair of false aneurysm in iliac artery
	34121-00	Repair of simple arteriovenous fistula of extremity with restoration of continuity
	34121-01	Repair of complex arteriovenous fistula of extremity with restoration of continuity
Vascular intervention	45027-01	Administration of agent into vascular anomaly
	33116-00	Endovascular repair of aneurysm
Post-procedural infections		
Sepsis	T81.42	Sepsis following a procedure
	U90	Healthcare associated infections
	U90.0	Healthcare associated Staphylococcus aureus bacteraemia
Pneumonia	J13	Pneumonia due to Streptococcus pneumoniae
	J14	Pneumonia due to Haemophilus influenzae

	J15	Bacterial pneumonia, not elsewhere classified
	J15.0	Pneumonia due to Klebsiella pneumoniae
	J15.1	Pneumonia due to Pseudomonas
	J15.2	Pneumonia due to staphylococcus
	J15.3	Pneumonia due to streptococcus, group B
	J15.4	Pneumonia due to other streptococci
	J15.5	Pneumonia due to Escherichia coli
	J15.6	Pneumonia due to other Gram-negative bacteria
	J15.7	Pneumonia due to Mycoplasma pneumoniae
	J15.8	Other bacterial pneumonia
	J15.9	Bacterial pneumonia, unspecified
	J18	Pneumonia, organism unspecified
	J18.0	Bronchopneumonia, unspecified
	J18.1	Lobar pneumonia, unspecified
	J18.2	Hypostatic pneumonia, unspecified
	J18.8	Other pneumonia, organism unspecified
	J18.9	Pneumonia, unspecified
Endocarditis	I33	Acute and subacute endocarditis
	I33.0	Acute and subacute infective endocarditis
	I33.9	Acute endocarditis, unspecified
	I38	Endocarditis, valve unspecified
Pericarditis		
Pericarditis	I30	Acute pericarditis
	I30.0	Acute nonspecific idiopathic pericarditis
	I30.1	Infective pericarditis
	I30.8	Other forms of acute pericarditis
	I30.9	Acute pericarditis, unspecified
	I24.1	Dressler's syndrome
Post-procedural acute myocardial infarction		
Acute myocardial infarction	I21	Acute myocardial infarction
	I21.0	Acute transmural myocardial infarction of anterior wall
	I21.1	Acute transmural myocardial infarction of inferior wall

	I21.2	Acute transmural myocardial infarction of other sites
	I21.3	Acute transmural myocardial infarction of unspecified site
	I21.4	Acute subendocardial myocardial infarction
	I21.9	Acute myocardial infarction, unspecified
Venous thromboembolism		
Pulmonary embolism	I26	Pulmonary embolism
	I26.0	Pulmonary embolism with mention of acute cor pulmonale
	I26.8	Iatrogenic pulmonary embolism
	I26.9	Pulmonary embolism without mention of acute cor pulmonale
Deep vein thrombosis	I82	Other venous embolism and thrombosis
	I82.2	Embolism and thrombosis of vena cava
	I82.3	Embolism and thrombosis of renal vein
	I82.8	Embolism and thrombosis of other specified veins
	I82.9	Embolism and thrombosis of unspecified vein
Post-procedural acute kidney injury		
Acute kidney injury	N99.0	Postprocedural kidney failure
	N17	Acute kidney failure
	N17.0	Acute kidney failure with tubular necrosis
	N17.1	Acute kidney failure with acute cortical necrosis
	N17.2	Acute kidney failure with medullary necrosis
	N17.8	Other acute kidney failure
	N17.9	Acute kidney failure, unspecified
Complete atrioventricular block		
Complete heart block	I44.2	Atrioventricular block, complete
Complications requiring cardiac surgery		
Coronary artery bypass graft	38497-00	Coronary artery bypass, using 1 saphenous vein graft
	38497-01	Coronary artery bypass, using 2 saphenous vein grafts
	38497-02	Coronary artery bypass, using 3 saphenous vein grafts
	38497-03	Coronary artery bypass, using >= 4 saphenous vein grafts
	38497-04	Coronary artery bypass, using 1 other venous graft
	38497-05	Coronary artery bypass, using 2 other venous grafts
	38497-06	Coronary artery bypass, using 3 other venous grafts

	38497-07	Coronary artery bypass, using >= 4 other venous grafts
	38500-00	Coronary artery bypass, using 1 LIMA graft
	38503-00	Coronary artery bypass, using >= 2 LIMA grafts
	38500-01	Coronary artery bypass, using 1 RIMA graft
	38503-01	Coronary artery bypass, using >= 2 RIMA grafts
	38500-02	Coronary artery bypass, using 1 radial artery graft
	38503-02	Coronary artery bypass, using >= 2 radial artery grafts
	38500-03	Coronary artery bypass, using 1 epigastric artery graft
	38503-03	Coronary artery bypass, using >= 2 epigastric artery grafts
	38500-04	Coronary artery bypass, using 1 other arterial graft
	38503-04	Coronary artery bypass, using >= 2 other arterial grafts
	38500-05	Coronary artery bypass, using 1 composite graft
	38503-05	Coronary artery bypass, using >= 2 composite grafts
	90201-00	Coronary artery bypass, using 1 other graft, not elsewhere classified
	90201-01	Coronary artery bypass, using 2 other grafts, not elsewhere classified
	90201-02	Coronary artery bypass, using 3 other grafts, not elsewhere classified
	90201-03	Coronary artery bypass, using >= 4 other grafts, not elsewhere classified
	38456-19	Other intrathoracic procedures on arteries of heart without cardiopulmonary bypass
Surgeries with cardiopulmonary bypass	38653-01	Other intrathoracic procedures on atrium with cardiopulmonary bypass
	38653-02	Other intrathoracic procedures on ventricle of heart with cardiopulmonary bypass
	38653-03	Other intrathoracic procedures on septum with cardiopulmonary bypass
	38653-04	Other intrathoracic procedures on aortic valve with cardiopulmonary bypass
	38653-05	Other intrathoracic procedures on mitral valve with cardiopulmonary bypass
	38653-06	Other intrathoracic procedures on tricuspid valve with cardiopulmonary bypass
	38653-07	Other intrathoracic procedures on pulmonary valve with cardiopulmonary bypass
	38653-08	Other intrathoracic procedures on arteries of heart with cardiopulmonary bypass
	38600-00	Cardiopulmonary bypass, central cannulation
	38603-00	Cardiopulmonary bypass, peripheral cannulation
	38627-01	Adjustment of cannula for cardiopulmonary bypass
	38653-00	Other intrathoracic procedures on heart with cardiopulmonary bypass

In-hospital complications were identified by procedure codes and secondary diagnoses of the index hospitalisation. Post-discharge complications were identified by the procedure codes and the primary discharge diagnosis of hospital readmissions. ACHI = Australian Classification of Health Interventions; AMI = acute myocardial infarction; ICD10-AM = International Classification of Diseases, 10th Revision, Australian Modification.

Table S3. Candidate variables considered for the risk adjustment model.

Variables	Description	P value
CC2	Septicemia/Shock	0.012
CC3	Central Nervous System Infection	0.195
CC6	Other Infectious Diseases	<0.001
CC7	Metastatic Cancer and Acute Leukemia	0.001
CC8	Lung, Upper Digestive Tract, and Other Severe Cancers	0.001
CC9	Lymphatic, Head and Neck, Brain, and Other Major Cancers	0.023
CC15	Diabetes with Renal or Peripheral Circulatory Manifestation	<0.001
CC19	Diabetes without Complication	0.159
CC21	Protein-Calorie Malnutrition	0.000
CC22	Other Significant Endocrine and Metabolic Disorders	0.009
CC23	Disorders of Fluid/Electrolyte/Acid-Base Balance	<0.001
CC24	Other Endocrine/Metabolic/Nutritional Disorders	<0.001
CC28	Acute Liver Failure/Disease	0.004
CC29	Other Hepatitis and Liver Disease	0.001
CC33	Inflammatory Bowel Disease	0.080
CC34	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders	0.061
CC36	Other Gastrointestinal Disorders	0.000
CC39	Disorders of the Vertebrae and Spinal Discs	0.031
CC41	Osteoporosis and Other Bone/Cartilage Disorders	0.124
CC43	Other Musculoskeletal and Connective Tissue Disorders	<0.001
CC45	Disorders of Immunity	0.080
CC46	Coagulation Defects and Other Specified Hematological Disorders	<0.001
CC47	Iron Deficiency and Other/Unspecified Anemias and Blood Disease	<0.001
CC48	Delirium and Encephalopathy	0.076
CC49	Dementia	0.045
CC53	Drug/Alcohol Abuse, Without Dependence	0.248
CC58	Depression	0.239
CC60	Other Psychiatric Disorders	0.164
CC69	Spinal Cord Disorders/Injuries	0.009
CC70	Muscular Dystrophy	0.089
CC75	Coma, Brain Compression/Anoxic Damage	0.193
CC76	Mononeuropathy, Other Neurological Conditions/Injuries	0.006
CC77	Respirator Dependence/Tracheostomy Status	0.031
CC79	CardioRespiratory Failure & Shock	0.005
CC80	Congestive Heart Failure	<0.001
CC81	Acute Myocardial Infarction	0.018
CC82	Unstable Angina and Other Acute Ischemic Heart Disease	0.105
CC83	Angina Pectoris/Old Myocardial Infarction	<0.001
CC84	Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease	<0.001
CC85	Heart Infection/Inflammation, Except Rheumatic	0.020
CC86	Valvular and Rheumatic Heart Disease	0.001

CC89	Hypertensive Heart and Renal Disease or Encephalopathy	<0.001
CC91	Hypertension	<0.001
CC93	Other Heart Rhythm and Conduction Disorders	<0.001
CC94	Other and Unspecified Heart Disease	0.001
CC98	Cerebral Atherosclerosis and Aneurysm	0.094
CC102	Speech, Language, Cognitive, Perceptual Deficits	0.151
CC104	Vascular Disease with Complications	0.041
CC106	Other Circulatory Disease	0.033
CC108	Chronic Obstructive Pulmonary Disease	<0.001
CC109	Fibrosis of Lung and Other Chronic Lung Disorders	0.004
CC110	Asthma	0.004
CC111	Aspiration and Specified Bacterial Pneumonias	0.098
CC113	Viral and Unspecified Pneumonia, Pleurisy	0.000
CC114	Pleural Effusion/Pneumothorax	0.007
CC115	Other Lung Disorders	<0.001
CC120	Diabetic and Other Vascular Retinopathies	0.033
CC124	Other Eye Disorders	0.054
CC127	Other Ear, Nose, Throat, and Mouth Disorders	0.001
CC128	Kidney Transplant Status	0.031
CC131	Renal Failure	<0.001
CC134	Incontinence	0.019
CC135	Urinary Tract Infection	0.055
CC136	Other Urinary Tract Disorders	0.004
CC139	Other Female Genital Disorders	0.194
CC142	Miscarriage/Abortion	0.195
CC143	Completed Pregnancy With Major Complications	0.013
CC144	Completed Pregnancy With Complications	0.006
CC145	Completed Pregnancy Without Complications (Normal Delivery)	0.033
CC146	Uncompleted Pregnancy With Complications	0.080
CC147	Uncompleted Pregnancy With No or Minor Complications	0.006
CC152	Cellulitis, Local Skin Infection	0.122
CC156	Concussion or Unspecified Head Injury	0.028
CC158	Hip Fracture/Dislocation	0.242
CC160	Internal Injuries	<0.001
CC162	Other Injuries	<0.001
CC164	Major Complications of Medical Care and Trauma	0.001
CC165	Other Complications of Medical Care	0.024
CC166	Major Symptoms, Abnormalities	<0.001
CC167	Minor Symptoms, Signs, Findings	<0.001
CC179	Post-Surgical States/Aftercare/Elective	0.003
	Female sex	<0.001
	Age	0.011
	Ablation of both atria	0.002
	Hypertension	<0.001

Haematological disorders	<0.001
History of pneumonia	<0.001
Musculo-skeletal and connective tissue disorders	<0.001

Comorbidities are defined using the Condition Categories (CC) classification system (18). P value derived from bivariate analysis with an outcome of major complications as the dependent variable.

Table S4. Variables included in the risk-adjustment model.

Variables	OR	SE	P value	95% CI
Female	1.22	0.07	0.001	1.08 – 1.36
Age	1.01	0.00	0.002	1.00 – 1.01
Year of ablation	0.96	0.16	0.013	0.93 – 0.99
History of ablation in the preceding year	0.77	0.07	0.003	0.64 – 0.92
Ablation of both atria	1.32	0.08	<0.001	1.18 – 1.47
Hypertension	1.34	0.11	<0.001	1.15 – 1.56
Haematological disorders	2.46	0.24	<0.001	2.03 – 2.98
History of pneumonia	2.09	0.29	<0.001	1.60 – 2.73
Musculoskeletal and connective tissue disorders	1.33	0.12	0.002	1.11 – 1.59
Other lung disorders	1.40	0.19	0.013	1.07 – 1.83

OR = adjusted odd ration,CI = confidence intervals, SE = standard error

Table S5. Crude hospital's complication rates.

Complications	Median (Range)
Primary outcome	5.74% (0.00% - 21.43%)
Mortality	0.00% (0.00% - 1.08%)
Cardiorespiratory failure	0.00% (0.00% - 1.68%)
Stroke/TIA	0.17% (0.00% - 1.20%)
Pericardial effusion	0.69% (0.00% - 4.82%)
Haemothorax/pneumothorax	0.00% (0.00% - 3.57%)
Bleeding	3.75% (0.00% - 17.86%)
Vascular injury	0.07% (0.00% - 2.56%)
Infections	0.43% (0.00% - 2.56%)
Pericarditis	0.00% (0.00% - 1.94%)
Procedure-related AMI	0.00% (0.00% - 1.20%)
Venous thromboembolism	0.00% (0.00% - 1.20%)
Acute kidney injury	0.00% (0.00% - 4.00%)
Complications requiring cardiac surgery	0.00% (0.00% - 3.57%)
Complete AV block	0.00% (0.00% - 3.53%)

AMI = acute myocardial infarction, AV = atrioventricular, TIA = transient ischemic attack.

Figure S1. Model calibration per decile of patient's risks.

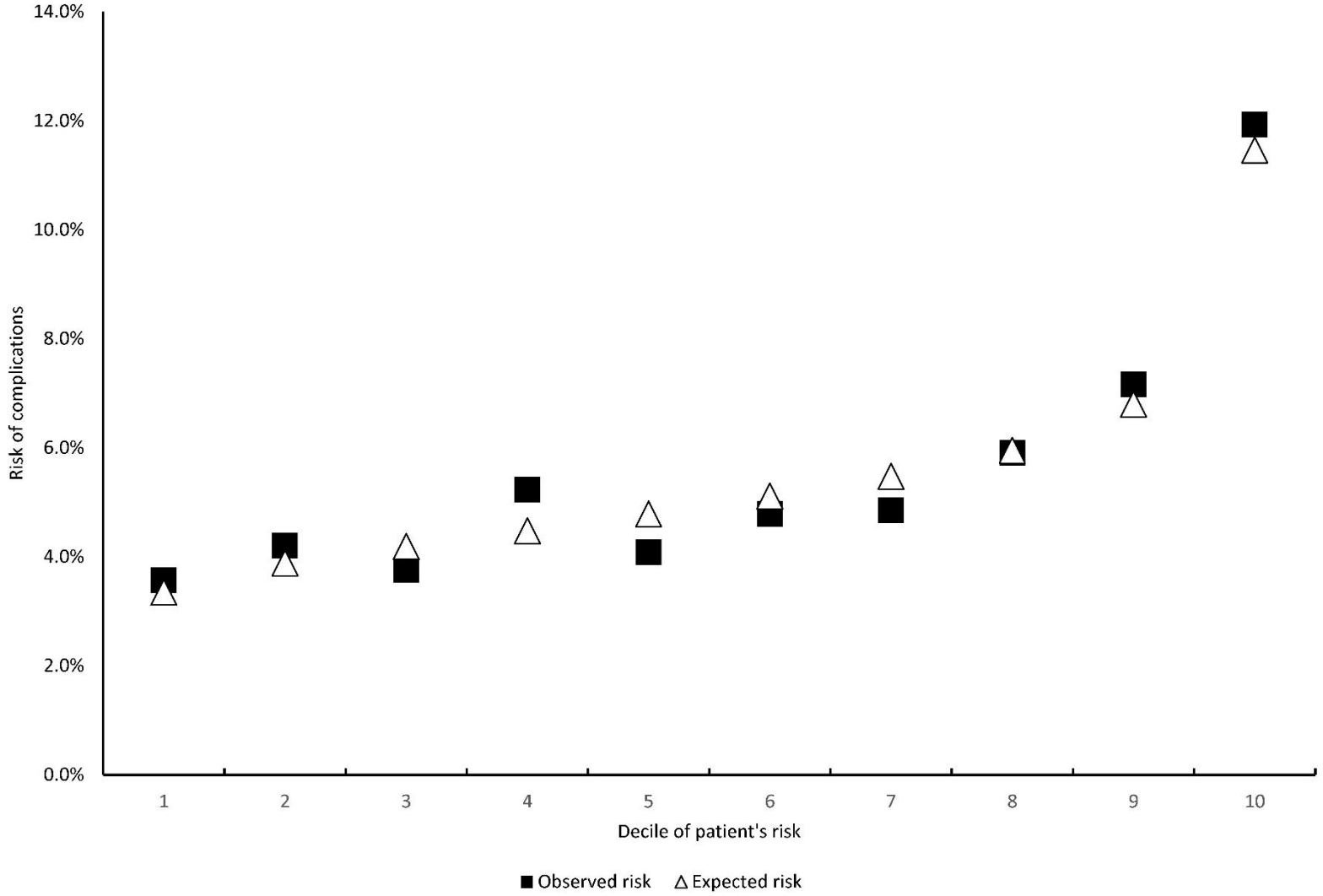

Figure S2. Funnel plot of hospital's risk-standardized complication rates without Winsorisation.

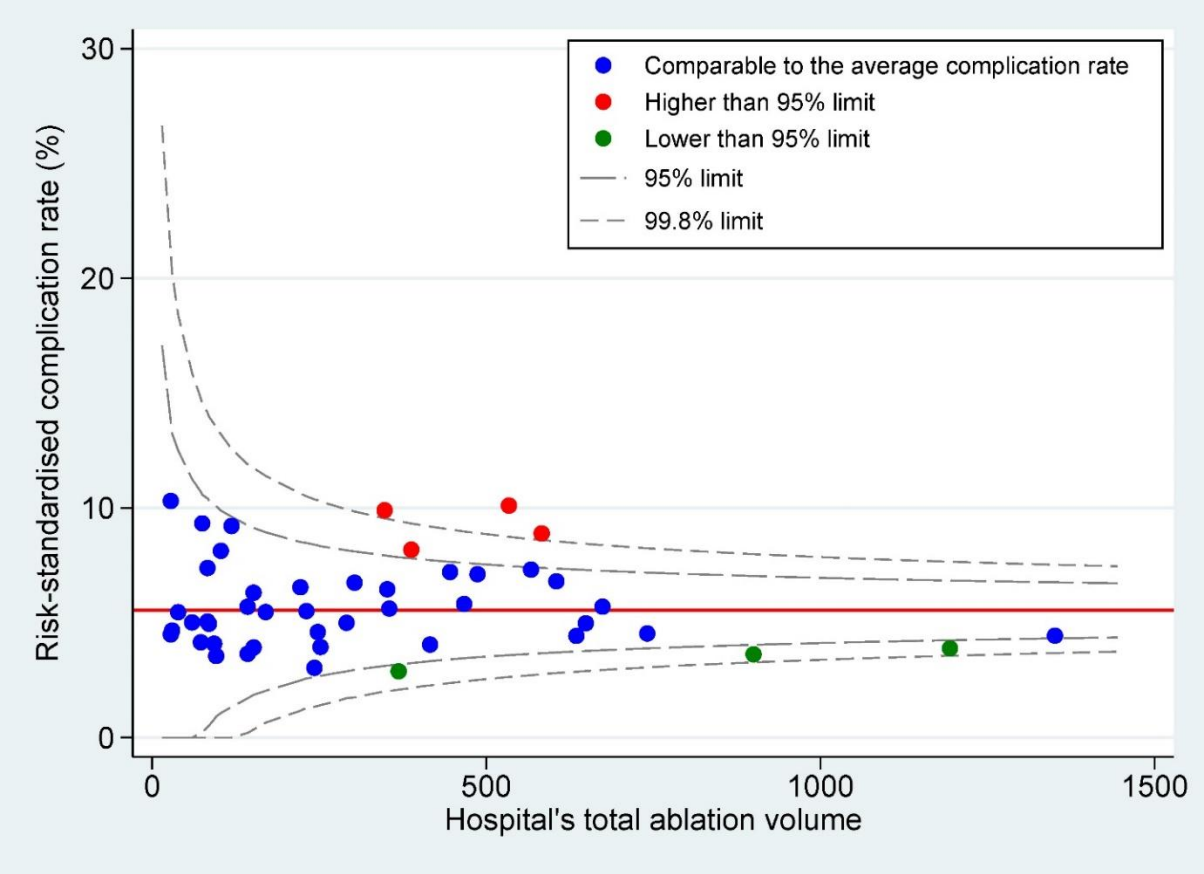

Figure S3. Funnel plot of hospital's risk-standardized complication rate with 10% Winsorisation.