Surgical ablation of atrial fibrillation concomitant to coronary-artery bypass grafting provides cost-effective mortality reduction

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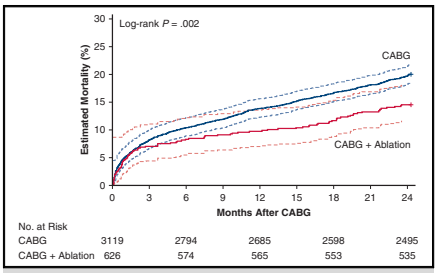
ABSTRACT

Background: Data on the longitudinal impact of surgical ablation (SA) for atrial fibrillation (AF) in patients undergoing coronary artery bypass grafting (CABG) remain limited. This study examined 2-year risk-adjusted mortality and total hospital costs in Medicare beneficiaries with AF requiring CABG with or without SA.

Methods: CABG was performed in 3745 Medicare beneficiaries with AF in 2013, with concomitant SA in 17% (626 of 3745). Risk-adjusted mortality, morbidity, and cost during the first 2 postoperative years for patients with SA and those without SA were compared. A piecewise Cox proportional hazard model (0-90 days and 91-729 days) was used to risk-adjust mortality.

Results: Compared with the no SA group, the SA group had lower rates of heart failure before surgery (31% vs 36%), chronic lung disease (27% vs 33%), renal failure (4% vs 7%), and urgent or emergent presentation (34% vs 49%) (all $P < .05$). Risk-adjusted index admission costs were higher with SA (rate ratio [RR], 1.11; $P < .01$), as were readmissions for AF (hazard ratio [HR], 1.14; 95% confidence interval [CI], 1.00-1.29; $P = .04$) and pacemaker/defibrillator implantation (HR, 1.37; 95%, 1.08-1.74; $P = .01$). Risk-adjusted inpatient days and inpatient costs were similar after 2 years (RR, 0.97; $P = .31$ and RR = 1.04; $P = .17$, respectively); however, the risk-adjusted hazard for late mortality (91-729 days) was significantly lower with SA (HR, 0.71; 95% CI, 0.52-0.97; $P = .03$).

Conclusions: In patients with AF requiring CABG, SA was associated with a 29% lower risk-adjusted hazard for late mortality. Index hospital costs were higher with SA, but total inpatient costs were not different in the 2 groups after 2 years. SA appears to be a cost-effective intervention to enhance late 2-year survival in patients with AF undergoing CABG. (J Thorac Cardiovasc Surg 2020;160:675-86)



Kaplan-Meier mortality curves for patients with preoperative atrial fibrillation who underwent coronary artery bypass grafting with and without concomitant surgical ablation.

Central Message

Surgical ablation in patients with atrial fibrillation undergoing coronary artery bypass grafting is associated with reductions in 2-year unadjusted mortality and risk-adjusted hazard of late mortality (90 days to 2 years) without an increase in total risk-adjusted inpatient cost.

Perspective

Perceptions of increased cost without long-term benefit may have limited surgical ablation for atrial fibrillation during coronary artery bypass grafting. This study reveals that surgical ablation is not only cost-effective, but also associated with a 29% reduction in the risk-adjusted hazard of late mortality (90 days to 2 years).

See Commentaries on pages 687 and 689.

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In patients with atrial fibrillation (AF) undergoing cardiac surgical procedures, emerging data are indicating that concomitant surgical ablation (SA) may be associated

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Abbreviations and Acronyms

AF = atrial fibrillation
CABG = coronary artery bypass grafting
CMS = Centers for Medicare and Medicaid Services
HR = hazard ratio
KM = Kaplan-Meier
MI = myocardial infarction
OR = odds ratio
PAD = peripheral arterial disease
PH = proportional hazard
RR = rate ratio
SA = surgical ablation
SAF = Medicare standard analytic file
STS = Society of Thoracic Surgeons
TIA = transient ischemic attack
ZINB = zero-inflated negative binomial

with reduced mortality.[1,2] Patients undergoing multiple valve procedures have a 15% lower risk-adjusted operative mortality with SA.[1] For patients with AF undergoing isolated mitral valve replacement/repair procedures, operative mortality was 8% lower with SA.[2] In the general cardiac surgical population, late mortality has been shown to be significantly lower in patients achieving sinus rhythm after SA.[3-6]

Few data exist specifically for patients with AF undergoing coronary artery bypass grafting (CABG), however. A previous analysis demonstrated a reduction in the risk-adjusted hazard for late mortality, but an increased cost of risk-adjusted inpatient care per patient at 1 year following surgery.[7] The present analysis was undertaken to examine these issues with follow-up into the intermediate term at 2 years.

METHODS

A total of 3745 Medicare beneficiary admissions for CABG were identified in the 2013 Medicare Standard Analytic File (SAF) of inpatient admissions using International Classification of Diseases, Ninth Revision-Clinical Modification (ICD-9-CM) codes (Table E1), as described previously.[7] Patients were required to have at least 2 previous inpatient or outpatient admissions with a diagnosis of AF over the previous 12 months, and a subsequent CABG discharge date between January 1, 2013, and December 31, 2013. Exclusion criteria were age <18 years, major cardiac procedure other than CABG, redo operations, valvular AF (defined as rheumatic mitral stenosis, mitral valve repair, or prosthetic cardiac valve placement), previous endovascular or surgical AF ablation or left atrial appendage procedure, mechanical circulatory support, or heart transplantation (Figure 1 and Table E2). Patients also were excluded if they were not continuously eligible for Medicare Part A and B benefits during all of 2012 to 2014, had insufficient demographic claims data, had no record in the Medicare denominator file, had total CABG admission costs greater than 3 standard deviations (SD) from the geometric mean, or had insufficient data to standardize admission costs (ie, prevailing wage, hospital teaching status, and hospital indigent care load). If a beneficiary was discharged following CABG more than once in 2013, only the first admission was included. The unit of analysis was the individual discharge.

Comorbidities and procedure characteristics used in Society of Thoracic Surgeons (STS) risk models for CABG[8] that had corresponding ICD-9-CM and/or Current Procedure Terminology (CPT) codes were collected from Medicare SAF claims[8-10] (Table E3). In addition, administrative codes for comorbidities associated with mortality and resource utilization developed by Elixhauser and colleagues[11] for use with administrative data from inpatient admissions and later validated for risk adjustment of administrative data from inpatient admissions[12] were collected from the Medicare SAF claims using software distributed by the Agency for Healthcare Research and Quality (version 3.7).[13]

The risk of stroke was estimated using the CHA_2DS_2-VASc score,[14] calculated based on age, sex, and comorbidities present on inpatient claims in the year before CABG (ie, congestive heart failure, hypertension, age 65-74 years, diabetes mellitus, previous stroke/transient ischemic attack [TIA]/thromboembolism, vascular disease, age ≥75 years, and female sex) in a manner described previously[15,16] (Table E4). The risk of bleeding following CABG was estimated using a modified HAS-BLED score,[17] calculated from age at CABG and the presence of hypertension, abnormal renal function, abnormal liver function, previous stroke/TIA, bleeding, and alcohol abuse identified on Medicare SAF claims from the year before and including the CABG admission (Table E4). The HAS-BLED scores were reported with a maximal value of 7 points rather than 9, because antiplatelet agent use and lability of International Normalized Ratio values could not be ascertained from the Center for Medicare and Medicaid Services (CMS) SAF hospital claims (Table E5).

All deaths in the 2 years following CABG were identified using the CMS denominator file, regardless of the patient's Medicare enrollment status after the first post-CABG year. Unadjusted survival was estimated using Kaplan-Meier (KM) analysis stratified by SA status. Risk-adjusted survival was estimated using a piecewise (Heaviside function) Cox proportional hazard (PH) model that incorporated the independent covariates as described in detail in Appendix E1. A piecewise Cox PH model was used because the PH assumption was not satisfied for surgical ablation and several other covariates during the first year after CABG (Appendix E1). The first 2 years following CABG were divided into 2 intervals, 0 to 90 days and 91 to 729 days, chosen because 0 to 90 days represented the extended postoperative period and 91 to 730 days represented follow-up from the postoperative period to 2 years. Data were fit to separate Cox PH models for each interval, and the hazard ratio (HR) for each covariate was constant within, but not between, the 2 intervals. For each independent variable, the risk-adjusted HR for death was calculated by exponentiation of the corresponding estimated variable coefficient for each of the 2 intervals (Appendix E1). The unadjusted ablation HR for death was calculated using the same specification with ablation as the sole independent variable. Risk-adjusted survival curves were generated using the piecewise Cox PH model derived for the 3745 patient cohort, with a baseline survival function defined as the mean value for each independent variable in that cohort, except ablation, which was assigned the status of present or absent to generate the corresponding survival estimates.

The first occurrence of all other clinical endpoints was identified from hospital inpatient and outpatient claims using ICD-9-CM and CPT codes (Table E5). Freedom from occurrence for each endpoint was estimated using KM analysis stratified by SA status. Patients were censored if they were lost to follow-up after 1 year, died, or were event-free 2 years after CABG. A Cox PH model with independent variables similar to the PH model for mortality was used for each of the clinical endpoints to estimate risk-adjusted HRs for each covariate in the specification. Terms for the CHA_2DS_2-VASc and HAS-BLED scores were included in the Cox PH specifications for stroke and bleeding, respectively (Table E4). Risk-adjusted HRs were generated by exponentiating the estimated coefficient for each of the covariates in the Cox PH models. Hospital inpatient

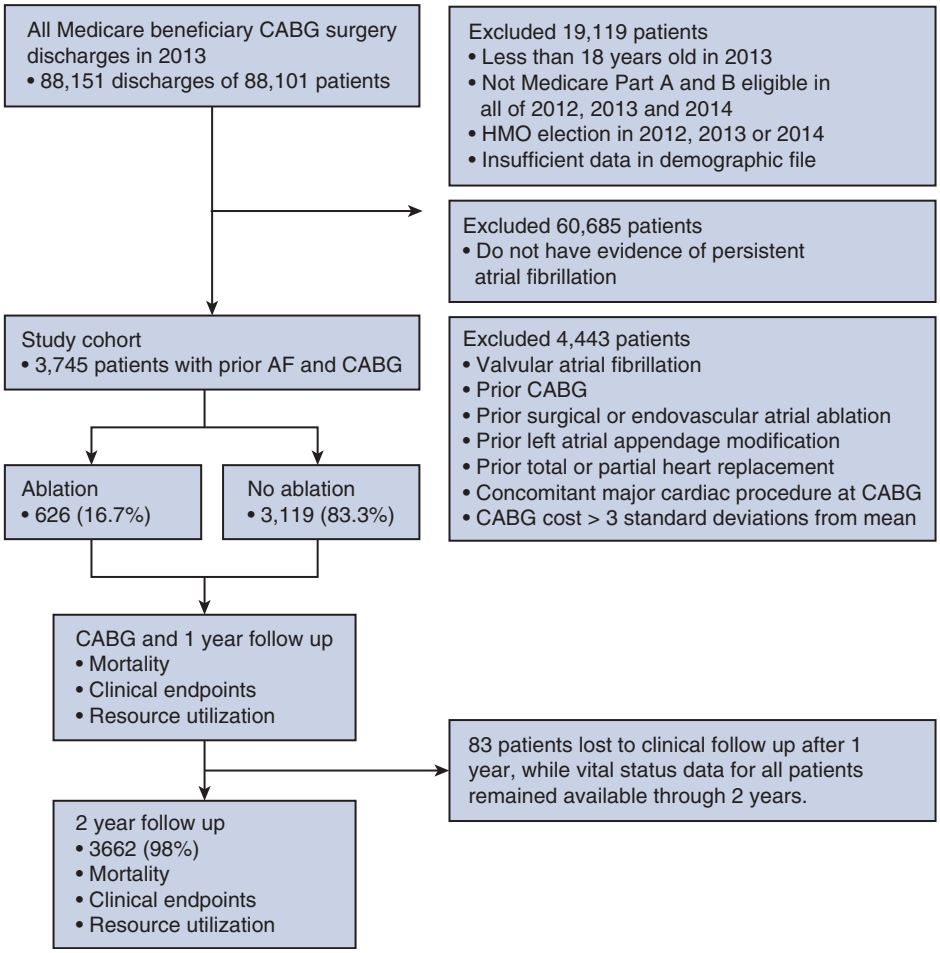


FIGURE 1. Patient flow diagram. The study cohort of 3745 Medicare beneficiaries with prior atrial fibrillation (*AF*) who underwent coronary artery bypass grafting (*CABG*) was derived from the 2013 Medicare 100% Standard Analytic File of hospital discharge claims according to predefined inclusion and exclusion criteria. *HMO*, Healthcare maintenance organization.

admission data in the second post-CABG year were not available for 83 of the 3745 patients (2.2%). Because the missing data represented a very small proportion of the total cohort data, they were ignored in analysis of clinical endpoints

Unadjusted costs for the index CABG admission and subsequent hospital inpatient admissions were calculated using a charges-reduced-to-cost methodology. Before cost calculation, charges were standardized using factors for prevailing wage, teaching status and indigent care load. Charges for each of 18 cost centers (ie, routine care, intensive care, pharmacy, supplies and equipment, therapy, laboratory, operating room, cardiology, radiology, emergency, blood, other, delivery, inhalation therapy, anesthesia, implantable devices, cardiac catheterization, magnetic resonance imaging, and computed tomography) then were multiplied by national average departmental cost-to-charge ratios derived from Medicare cost reports for the fiscal year ending in 2013[18] to generate costs. Patients with readmissions for which standardization factors were not available were excluded from the study.

A generalized linear model with a negative binomial distribution and log link was used to estimate the risk-adjusted rate ratios (RRs) with and without ablation for cost and inpatient days, except where noted below. The models contained the same independent variable used in the piecewise Cox PH model for mortality, along with an additional term for evaluable days. The unadjusted RRs were estimated using the same model but with ablation as the sole independent variable. A similar approach was used to estimate the unadjusted and risk-adjusted RRs with and without ablation for the cost center allocations during the index CABG admission.

A zero-inflated negative binomial (ZINB) regression specification was used to model cost and inpatient days if they equaled 0 for >10% of index patients. The risk-adjusted odds ratio (OR) of having a zero value was estimated as the exponential function of the parameter estimate in a logistic regression for the presence or absence of a zero value. The unadjusted and risk-adjusted RR for cost or hospital days that were not 0 was estimated as exponential function of the parameter estimates from the zero-inflated negative binomial regression. The negative binomial and ZINB regression analyses are described in detail in Appendix E1.

Year 2 follow-up data for clinical endpoints other than death and for cost and hospital days were not available for 83 of 3745 (2.2%) index patients. Analyses of inpatient cost and inpatient days that included data from year 2 were performed on the remaining 3662 complete cases.

Continuous variables with a normal distribution were described by the mean and standard deviation (SD) and the mean, median, and quartile 1 to quartile 3 range (IQR) if the data were skewed. Categorical variables were presented as counts with percentages and compared using the χ^2 test. KM survival estimates were compared using a log-rank test and presented with 95% Hall-Wellner confidence bands. Adjusted mortality curves were presented with 95% confidence intervals for the estimated

mortality. The significance threshold for all tests was .05. Patient counts of <11 or that permitted calculation of patient counts of <11 were not reported due to CMS privacy regulations. Calculations were performed using SAS version 9.4 (SAS Institute, Cary, NC).

The Sterling Institutional Review Board (Atlanta, Ga) determined that this study was exempt from Institutional Review Board review, pursuant to the terms of the US Department of Health and Human Services' Policy for Protection of Human Research Subjects (45 C.F.R. §46.101(b)).

RESULTS

The study cohort comprised 3745 Medicare beneficiaries with prior AF who underwent CABG and were discharged in 2013. Concomitant SA ablation was performed in 626 patients (16.7%) (Figure 1). Unadjusted baseline characteristics generally were more favorable in SA patients, including age ≥75 years (45% vs 50%; $P = .02$), emergency presentation (15% vs 22%; $P < .01$), heart failure in the 2 weeks before surgery (31% vs 36%; $P = .02$), renal failure (4% vs 7%; $P < .01$), chronic lung disease (27% vs 33%; $P = .01$), and peripheral arterial disease (PAD) (20% vs 29%; $P < .01$) (Table 1). After risk adjustment, baseline characteristics associated with absence of SA were age ≥75 years (OR, 0.75; 95% CI, 0.62-0.90), race other than white or black (OR, 0.51; 95% CI, 0.26-0.99), myocardial infarction (MI) >21 days before CABG (OR, 0.51; 95% CI, 0.30-0.87), PAD (OR, 0.67; 95% CI, 0.53-0.83), urgent (OR, 0.58; 95% CI, 0.46-0.73), and emergency admission (OR, 0.58; 95% CI, 0.45-0.74) (Table 1).

After 2 years, the SA group had a higher adjusted risk of admission for AF (HR, 1.14; 95% CI, 1.00-1.29), atrial flutter (HR, 1.63; 95% CI, 1.14-2.35), all atrial tachyarrhythmias (HR, 1.15; 95% CI, 1.02-1.30), and pacemaker/defibrillator implantation (HR, 1.37; 95% CI, 1.08-1.74) (Table 2). No significant difference existed in the adjusted risk of admission for stroke, heart failure, MI, bleeding, or revascularization.

In the unadjusted analysis of mortality, 2-year KM estimated mortality was lower in SA patients (14.5% vs 20.0%; $P < .002$) (Figure 2). The risk-adjusted hazard for mortality, estimated using a piecewise Cox PH model, was not significantly different in the first 90 days after surgery (HR, 1.03; 95% CI, 0.74-1.43) (Figure 2 and Table 3). After 90 days, however, the SA group had a significantly lower risk-adjusted hazard for mortality through 729 days compared with the no-SA group (HR, 0.71; 95% CI, 0.52-0.97) (Figure 2 and Table 3).

The median length of stay for the index CABG admission was 9 days for both the SA and no-SA groups, but the median inpatient cost was $1738 higher for the SA group ($33,455 vs $31,717), and the risk-adjusted inpatient cost rate ratio was 1.11 ($P < .0001$) (Table 4).

In the 2 years following the index CABG admission, the median number of subsequent inpatient days per index patient was lower in the SA group (2 vs 3 days), and the median inpatient cost of subsequent hospital admissions per index patient was 45% less in the SA group ($2959 vs $5443) (Table 4). After risk adjustment, however, the OR of having subsequent inpatient days and the RR for the number of those inpatient days in patients who were readmitted were not significant (Table 4). Similarly, the OR of having subsequent inpatient costs and the RR for those inpatient costs were not significant (Table 4).

Combining the index CABG admission and readmissions in the subsequent 2 years, the median number of inpatient days and inpatient costs were lower in the SA group (12 vs 14 days and $42,816 vs $43,472) (Table 4). After risk adjustment, the RRs for total inpatient days and total inpatient costs were not significant (0.97; $P = .31$ and 0.97; $P = .17$, respectively) (Table 4).

To better understand why the index CABG admission was more expensive for SA patients, costs assigned to individual hospital cost centers during the index CABG admission were compared. The cost center with the largest absolute median cost difference between the SA and no-SA groups was supplies and equipment, where the median cost per index CABG patient was $7105 for SA patients vs $4531 for no-SA patients, with a risk-adjusted cost rate ratio of 1.42 ($P < .0001$). The median cost per index CABG patient of implantable devices was higher for the SA group, although the absolute difference was small ($179 vs $143), and while the OR of being assigned a cost for an implantable device was not significant, the RR for that cost (1.24) was significant. Finally, median operating room costs per index CABG patient were higher for the SA group ($7042 vs $6221), with a significant risk-adjusted cost RR of 1.14. The risk-adjusted cost RRs for the other cost centers were not significant.

DISCUSSION

The findings of this study clarify many important issues in SA. In the Medicare population examined, operative mortality risk was not increased by SA during CABG, similar to previous findings.[19] At 2 years, the risk-adjusted hazard for late mortality was 29% lower in SA patients compared with non-SA patients, a treatment effect that is clinically important. Although the index admission was more expensive in SA patients, by 2 years, the initial cost of the ablation equipment was recouped, and the total cost of inpatient care was not significantly different between SA and non-SA patients. Thus, the survival benefit of SA appears to have been achieved at no significant additional cost, suggesting meaningful cost-efficacy of SA in CABG patients with AF.

Operative 30-day mortality may be modestly diminished after SA in multiple valve and mitral valve replacement/repair patients,[1,2] supporting procedural safety. In the first long-term assessment of a specific CABG population, the current analysis also showed a reduced late hazard for mortality after SA, but the treatment effect was not modest.

TABLE 1. Demographic, comorbidity, and procedural characteristics for patients with prior atrial fibrillation who underwent CABG, with or without surgical ablation

Characteristic	CABG n (%)	Ablation n (%)	No ablation n (%)	*P* value*	Risk-adjusted OR†, ablation vs no ablation OR (95% CI)	*P* value‡
Patients	3745 (100)	626 (100	3119 (100)			
Demographics						
Age <65 y	243 (6)	27 (4)	216 (7)	.02	0.71 (0.43-1.16)	.17
Age ≥75 y	1853 (49)	283 (45)	1570 (50)	.02	0.75 (0.62-0.90)	<.01
Female	967 (26)	146 (23)	821 (26)		0.93 (0.75-1.16)	.52
Black	133 (4)	15 (2)	118 (4)	.09	0.72 (0.41-1.26)	.25
Other nonwhite or nonblack	117 (3)				0.51 (0.26-0.99)	.05
Medicaid-eligible	462 (12)	69 (11)	393 (13)	.30	1.14 (0.85-1.53)	.39
Medicare eligibility: disability or ESRD	675 (18)	94 (15)	581 (19)	.04	0.93 (0.70-1.25)	.63
Comorbidities						
Heart failure in previous 2 wk	1309 (35)	192 (31)	1117 (36)	.02	0.95 (0.78-1.15)	.57
Diabetes mellitus	1886 (50)	301 (48)	1585 (51)	.23	0.95 (0.80-1.15)	.62
Hypertension	3602 (96)	600 (96)	3002 (96)	.72	1.01 (0.65-1.58)	.97
Cerebrovascular disease	909 (24)	154 (25)	755 (24)	.87	1.04 (0.84-1.28)	.74
Peripheral arterial disease	1019 (27)	127 (20)	892 (29)	<.01	0.67 (0.53-0.83)	<.01
Valve disease: AI	167 (4)	30 (5)	137 (4)	.74	0.83 (0.40-1.72)	.61
Valve disease: MR	221 (6)	41 (7)	180 (6)	.51	1.36 (0.72-2.58)	.34
Prior PCI	204 (5)	18 (3)	186 (6)	<.01	0.64 (0.38-1.08)	.09
Chronic lung disease	1196 (32)	171 (27)	1025 (33)	.01	0.89 (0.73-1.09)	.26
Renal failure-dialysis	225 (6)	22 (4)	203 (7)	<.01	0.78 (0.48-1.28)	.33
Pulmonary circulation disease	362 (10)	47 (8)	315 (10)	.05	0.78 (0.56-1.09)	.15
Other neurologic disorders	189 (5)	35 (6)	154 (5)	.56	1.18 (0.80-1.74)	.40
Hypothyroidism	549 (15)	91 (15)	458 (15)	.97	1.00 (0.78-1.29)	.98
Rheumatoid arthritis/CVD	112 (3)	16 (3)	96 (3)	.57	0.83 (0.48-1.44)	.51
Coagulopathy	805 (21)	137 (22)	668 (21)	.84	1.07 (0.86-1.33)	.54
Obesity	828 (22)	138 (22)	690 (22)	.99	0.98 (0.79-1.22)	.84
Weight loss	210 (6)	38 (6)	172 (6)	.65	1.21 (0.83-1.76)	.33
Fluid and electrolyte disorders	1407 (38)	231 (37)	1176 (38)	.74	1.06 (0.88-1.28)	.53
Anemia of deficiency	765 (20)	114 (18)	651 (21)	.15	1.01 (0.80-1.27)	.97
Psychoses	98 (3)	12 (2)	86 (3)	.29	0.73 (0.39-1.35)	.31
Depression	284 (8)	51 (8)	233 (7)	.62	1.10 (0.79-1.52)	.58
Procedural						
Admission type, urgent	976 (26)	122 (19)	854 (27)	<.01	0.58 (0.46-0.73)	<.01
Admission type, emergency	771 (21)	93 (15)	678 (22)	<.01	0.58 (0.45-0.74)	<.01
MI ≤7 d prior to CABG	240 (6)	30 (5)	210 (7)	.09	0.80 (0.53-1.21)	.29
MI 8-21 d prior to CABG	130 (3)	16 (3)	114 (4)	.21	0.82 (0.48-1.42)	.48
MI >21 d prior to CABG	219 (6)	17 (3)	202 (6)	<.01	0.51 (0.30-0.87)	.01
Arterial-coronary bypass	3476 (93)	588 (94)	2888 (93)	.27	1.19 (0.83-1.71)	.35
Aortocoronary graft, 1 vessel	746 (20)	113 (18)	633 (20)	.22	1.14 (0.73-1.78)	.56
Aortocoronary graft, 2 vessels	1420 (38)	239 (38)	1181 (38)	.92	1.26 (0.83-1.92)	.28
Aortocoronary graft, 3 vessels	1006 (27)	180 (29)	826 (26)	.26	1.32 (0.86-2.03)	.21
Aortocoronary graft, 4 vessels	357 (10)	64 (10	293 (9)	.57	1.31 (0.81-2.13)	.28
IABP on day of CABG or after	196 (5)	22 (4)	174 (6)	.04	0.69 (0.44-1.10)	.12

CABG, Coronary-artery bypass grafting; *OR*, odds ratio; *CI*, confidence interval; *ESRD*, end-stage renal disease; *AI*, aortic valve insufficiency; *MR*, mitral valve regurgitation; *PCI*, percutaneous coronary intervention; *CVD*, collagen vascular disease; *MI*, myocardial infarction; *IABP*, intra-aortic balloon pump. **P* value for χ^2 test comparing the prevalence of each characteristic in the ablation vs no ablation groups. †Risk adjustment of ORs for association with ablation was done using a logistic regression model for ablation with independent variables for demographic, comorbidity, and procedural characteristics as described in Methods. ‡*P* value for logistic regression coefficient estimates.

Many previous studies of chronic AF patients undergoing CABG have shown an association between chronic AF and inferior long-term outcomes.[20-23] In the present analysis, these deleterious effects seemed to be at least partially mitigated by SA. Although technical details of ablation are not available in the CMS dataset, other studies from this period have shown that 58% of CABG patients had only left atrial lesion sets, 56% had only

TABLE 2. Patients with prior atrial fibrillation who experienced clinical endpoints in the 2 years following CABG, with or without surgical ablation

Clinical endpoint	CABG n (%)	Ablation n (%)	No ablation n (%)	Unadjusted HR*, ablation vs no ablation HR (95% CI)	*P* value†	Risk-adjusted HR*, ablation vs no ablation HR (95% CI)	*P* value†
Index surgery patients	3745 (100)	626 (100)	3119 (100)				
Lost to follow up after 1 y	83 (2)	11 (2)	72 (2)				
Index surgery patients with 2 y of follow-up	3662 (98)	615 (98)	3047 (98)				
Events at 2 y	0	0	0				
Admission for atrial tachyarrhythmias	1689 (45)	315 (50)	1368 (44)	1.20 (1.06-1.35)	.004	1.15 (1.02-1.30)	.03
Admission for atrial fibrillation	1645 (44)	305 (49)	1334 (43)	1.18 (1.04-1.34)	.01	1.14 (1.00-1.29)	.04
Admission for atrial flutter	156 (4)	40 (6)	115 (4)	1.75 (1.22-2.49)	.002	1.63 (1.14-2.35)	.01
Admission for other atrial tachyarrhythmias	17 (0)	‡	‡	‡		‡	
Intervention for atrial fibrillation§	72 (2)	17 (3)	55 (2)	1.46 (0.85-2.51)	.17	1.32 (0.76-2.29)	.33
Stroke or TIA	466 (12)	84 (13)	382 (12)	1.06 (0.84-1.34)	.63	1.13 (0.89-1.44)	.31
Implantation of a pacemaker/defibrillator	436 (12)	88 (14)	348 (11)	1.25 (0.99-1.58)	.06	1.37 (1.08-1.74)	.01
Admission for heart failure	1033 (28)	161 (26)	872 (28)	0.89 (0.75-1.05)	.16	0.98 (0.82-1.16)	.78
Admission for myocardial infarction	172 (5)	22 (4)	150 (5)	0.70 (0.45-1.09)	.11	0.88 (0.56-1.39)	.58
Admission for bleeding	489 (13)	83 (13)	406 (13)	0.98 (0.77-1.24)	.85	1.06 (0.83-1.34)	.65
Admission for revascularization	115 (3)	13 (2)	102 (3)	0.60 (0.34-1.08)	.09	0.63 (0.35-1.13)	.12

CABG, Coronary artery bypass grafting; *HR*, hazard ratio; *CI*, confidence interval; *TIA*, transient ischemic attack. *HR estimates derived using Cox proportional hazard models that included independent variables for ablation (unadjusted) or ablation, demographics, comorbidities, and procedure characteristics (risk-adjusted) for 3745 index CABG admissions. †*P* value for the ablation parameter estimates in the proportional hazard models. ‡Counts <11 or that permit calculation of counts <11 cannot be reported because of Centers for Medicare and Medicaid privacy restrictions. §Global null hypothesis not rejected with significance ($P = .09$) indicates Cox proportional hazard model not informative.

epicardial application, and the energy source was radiofrequency in most.[24] The left atrial appendage was obliterated in 89% of SA patients. Thus, it is probable that most CABG patients in the current study received predominant radiofrequency pulmonary vein isolation, a procedure that has been associated with sinus conversion rates of 60% to 80%.[25,26] It is also possible that additional surgical experience, along with routine

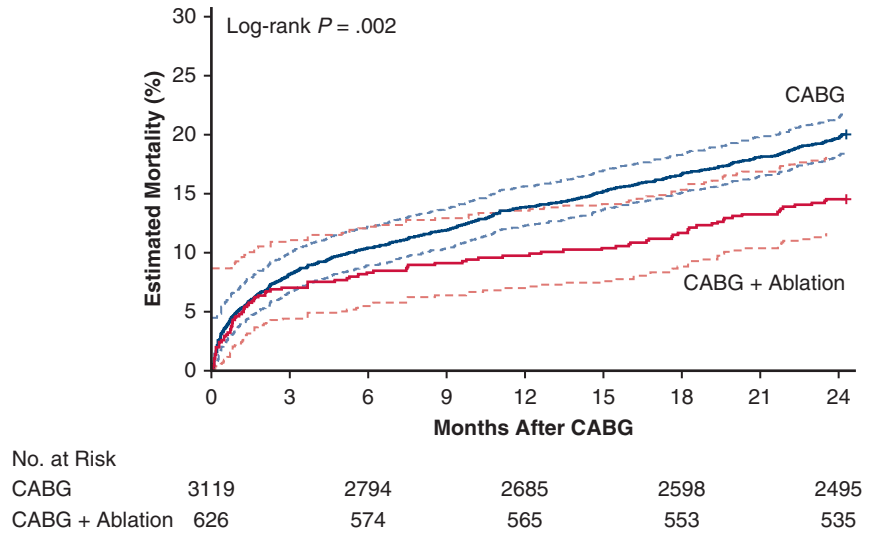


FIGURE 2. Estimated mortality curves for 3745 Medicare beneficiaries with prior atrial fibrillation (AF) who underwent coronary artery bypass grafting (*CABG*) with (n = 626) or without (n = 3119) concomitant surgical atrial ablation. Kaplan-Meier estimated mortality at 24 months was significantly lower with surgical ablation than without (14.5% vs 20.0%; $P = .0019$, log-rank test). *Dashed lines* are Hall-Wellner 95% confidence bands. The difference in mortality curves was evaluated by the log-rank test. The study cohort was derived from the 2013 Medicare 100% Standard Analytic File of hospital discharge claims according to predefined inclusion and exclusion criteria. *No.*, number at risk.

TABLE 3. Risk-adjusted hazard ratios for death in the first 2 years after patients with prior atrial fibrillation underwent CABG, with or without surgical ablation

Parameter	0-3 mo (300 deaths)		3-24 mo (220 deaths)	
	HR* (95% CI)	*P* value†	HR* (95% CI)	*P* value†
Surgical ablation	1.03 (0.74-1.43)	.86	0.71 (0.52-0.97)	.03
Demographics				
Age <65 y	0.85 (0.49-1.50)	.58	0.99 (0.64-1.53)	.97
Age ≥75 y	1.52 (1.18-1.96)	.001	1.47 (1.18-1.82)	.001
Female	1.64 (1.28-2.11)	.0001	1.01 (0.80-1.27)	.93
Black	0.74 (0.41-1.34)	.31	0.98 (0.63-1.53)	.93
Other nonwhite/nonblack	0.60 (0.29-1.26)	.18	0.59 (0.32-1.08)	.09
Medicaid-eligible	0.91 (0.64-1.29)	.60	1.39 (1.05-1.83)	.02
Medicare eligibility: ESRD or disability	1.21 (0.85-1.72)	.30	1.06 (0.78-1.43)	.71
Comorbidities				
Heart failure in prior 2 wk	1.21 (0.96-1.54)	.11	1.36 (1.11-1.67)	.003
Diabetes mellitus	0.96 (0.76-1.23)	.77	1.02 (0.83-1.25)	.87
Hypertension	1.10 (0.54-2.25)	.79	0.95 (0.54-1.66)	.86
Cerebrovascular disease	0.98 (0.75-1.29)	.91	0.75 (0.58-0.96)	.02
Peripheral arterial disease	1.29 (1.00-1.66)	.05	1.41 (1.13-1.75)	.002
Valve disease: AI	2.30 (0.89-16.13)	.08	0.55 (0.27-1.12)	.10
Valve disease: MR	0.83 (0.35-1.98)	.67	1.81 (1.03-3.18)	.04
Previous PCI	1.00 (0.60-1.69)	.99	0.59 (0.34-1.00)	.05
Chronic lung disease	1.47 (1.16-1.87)	.002	1.60 (1.31-1.97)	<.0001
Renal failure-dialysis	1.94 (1.30-2.90)	.001	2.44 (1.75-3.41)	<.0001
Pulmonary circulation disorders	1.22 (0.87-1.70)	.25	1.25 (0.93-1.67)	.14
Other neurologic disorders	1.16 (0.72-1.88)	.54	1.12 (0.75-1.68)	.57
Hypothyroidism	0.70 (0.49-0.99)	.04	0.87 (0.65-1.15)	.33
Rheumatoid arthritis/CVD	0.76 (0.36-1.62)	.48	1.22 (0.71-2.09)	.48
Coagulopathy	1.56 (1.22-2.00)	.0004	1.16 (0.93-1.46)	.20
Obesity	0.93 (0.69-1.24)	.61	0.84 (0.65-1.08)	.18
Weight loss	2.16 (1.55-3.00)	<.0001	1.64 (1.16-2.33)	.01
Fluid and electrolyte disorders	1.58 (1.24-2.00)	.0002	1.29 (1.06-1.58)	.01
Deficiency anemias	1.29 (0.99-1.68)	.06	1.10 (0.87-1.40)	.41
Psychoses	0.83 (0.37-1.87)	.65	1.25 (0.74-2.11)	.40
Depression	0.59 (0.36-0.97)	.04	1.09 (0.78-1.53)	.61
Procedural				
Admission type: urgent	0.94 (0.70-1.26)	.68	1.06 (0.83-1.35)	.66
Admission type: emergency	1.18 (0.89-1.57)	.25	1.27 (0.99-1.62)	.06
MI ≤7 d prior to CABG	1.13 (0.74-1.75)	.57	0.74 (0.47-1.17)	.20
MI 8-21 d prior to CABG	1.38 (0.82-2.32)	.23	1.26 (0.80-1.98)	.32
MI >21 d prior to CABG	1.07 (0.66-1.75)	.78	1.05 (0.69-1.59)	.82
Arterial-coronary graft	0.76 (0.52-1.12)	.16	0.96 (0.66-1.40)	.84
Aortocoronary graft, 1 vessel	1.28 (0.75-2.21)	.37	0.70 (0.46-1.06)	.09
Aortocoronary graft, 2 vessels	0.97 (0.57-1.65)	.90	0.69 (0.46-1.02)	.06
Aortocoronary graft, 3 vessels	0.81 (0.46-1.42)	.46	0.66 (0.44-0.99)	.04
Aortocoronary graft, 4 vessels	0.88 (0.46-1.66)	.68	0.63 (0.39-1.03)	.07
IABP on day of CABG or after	3.63 (2.64-4.99)	<.0001	1.25 (0.81-1.92)	.31

HR, Hazard ratio; *CI*, confidence interval; *ESRD*, end-stage renal disease; *AI*, aortic valve insufficiency; *MR*, mitral valve regurgitation; *PCI*, percutaneous coronary intervention; *CVD*, collagen vascular disease; *MI*, myocardial infarction; *CABG*, coronary-artery bypass grafting; *IABP*, intra-aortic balloon pump. *Risk adjustment of HRs for mortality was done using a piecewise Cox proportional hazard model for mortality that included independent variables for demographic, comorbidity, and procedural characteristics as described in Methods. †*P* value for proportional hazard model coefficient estimates.

performance of more complete lesion sets, could improve results further.[27] With the development of simpler and more efficacious techniques, even better sinus conversion rates and survival benefits might be achievable.[28,29]

The merits of SA and its impact on outcome have been summarized in recent clinical practice guidelines.[30,31] Surgical ablation for AF at the time of CABG now is a class I recommendation. The present study corroborates these recommendations and adds information on the

TABLE 4. Resource utilization by patients with prior atrial fibrillation who underwent CABG with or without surgical atrial ablation

Clinical endpoint	Ablation (n = 626)	No ablation (n = 3119)	Risk-adjusted OR		Unadjusted RR*		Risk-adjusted RR§	
			OR	*P* value†	RR	*P* value†	RR	*P* value†
Index admission								
Inpatient days/index patient								
Median	9.0	9.0						
Mean	10.6	10.9						
IQR	6.0-12.0	7.0-13.0						
Ablation vs no ablation					0.97	.17	1.04	.09
Cost/index patient, US$								
Median	33,455	31,717						
Mean	40,845	38,620						
IQR	25,883-47,807	22,916-46,410						
Ablation vs no ablation					1.06	.02	1.11	<.0001
All readmissions in year 1‡								
Inpatient days/index patient								
Median	0.0	0.0						
Mean	4.3	5.6						
IQR	0-5.0	0-7.0						
Ablation vs no ablation			1.01	.89	0.78	.002	0.87	.06
Cost/index patient, US$								
Median	0	0						
Mean	9200	11,630						
IQR	0-9711	0-13,625						
Ablation vs no ablation			1.04	.65	0.82	.002	0.88	.06
All readmissions in year 2‡								
Inpatient days/index patient								
Median	0.0	0.0						
Mean	2.4	3.2						
IQR	0.0-2.0	0.0-2.0						
Ablation vs no ablation			1.06	.64	0.77	.02	0.92	.40
Cost/index patient, US$								
Median	0	0						
Mean	5286	7129						
IQR	0-3008	0-4442						
Ablation vs no ablation			1.07	.51	0.80	.01	0.90	.23
All readmissions from 0-2 y‡								
Inpatient days/index patient								
Median	2.0	3.0						
Mean	6.5	8.8						
IQR	0.0-8.0	0.0-11.0						
Ablation vs no ablation			1.16	.19	0.80	<.001	0.91	.16
Cost/index patient, US$								
Median	2959	5443						
Mean	14,086	18,705						
IQR	0-16,686	0-22,422						
Ablation vs no ablation			1.15	.14	0.83	.002	0.92	.16
Total inpatient care to 2 y‡								
Inpatient days/index patient								
Median	12.0	14.0						
Mean	17.1	19.7						
IQR	8.0-20.0	8.0-25.0						
Ablation vs no ablation					0.87	<.0001	0.97	.31
Cost/index patient, US$								
Median	42,816	43,472						
Mean	54,895	57,314						

(Continued)

TABLE 4. Continued

Clinical endpoint	Ablation (n = 626)	No ablation (n = 3119)	Risk-adjusted OR		Unadjusted RR*		Risk-adjusted RR§	
			OR	*P* value†	RR	*P* value†	RR	*P* value†
IQR	30,023-67,360	28,120-71,129						
Ablation vs no ablation					0.96	.14	1.04	.17

OR, Odds ratio; *RR*, rate ratio; *IQR*, interquartile range. *RR estimates for length of stay and cost were made using a generalized linear model with a negative binomial distribution and a log link that included independent variables for ablation (unadjusted) or ablation, demographic, comorbidity, and procedural characteristics (risk-adjusted) for the 3745 index surgery admissions as described in Methods. †*P* value for the ablation parameter estimates in the generalized linear models. ‡For analyses of readmission costs or hospital days with a zero value for more than 10% of index patients, a zero-inflated negative binomial specification was used to estimate the risk-adjusted OR of having a zero value and the unadjusted and risk-adjusted RRs for the costs or hospital days that were not 0. §RRs that included year 2 data were calculated using the 3662 complete cases (3662/3745 = 97.8% of all cases), as described in Methods.

benefits of SA to late outcomes and cost efficacy. In all studies, selection of less ill patients for SA has been evident. In this series, the SA group was younger and generally had fewer adverse risk factors for surgical morbidity and mortality. However, recent evidence suggests that the relative survival advantage of SA is consistent across all baseline risk levels,[2] and thus higher-risk patients actually may receive the greatest absolute clinical benefits, even though SA is now being selected less often. Several independent analyses suggest the appropriateness of broader SA application into higher-risk groups, and further studies of this ''selection paradox'' seem warranted.[32-34]

In the present analysis, the adjusted hazard of pacemaker/defibrillator implantation was approximately 37% higher in patients receiving SA compared with those without SA. Certainly, some devices were required for arrhythmias caused or unmasked by SA, but this finding also may reflect more aggressive efforts to maintain sinus rhythm electrically or pharmacologically in SA patients. Although it is not possible to determine the indications for pacemaker/defibrillator placement from the CMS data, this is an important topic for future analyses.

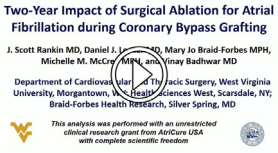
This study has several limitations. First, the claims-based Medicare SAF is designed to accurately capture the occurrence, duration, and cost of hospital admissions, but it is not optimized to capture specific details of clinical care. Second, the sensitivity and specificity of the administrative codes used to identify diagnoses and procedures, including surgical ablation, are imperfect.[35] The validity of these codes may be diminished by systematic and idiosyncratic errors in the applicability of the codes and/or utilization of the codes by the provider. Third, inpatient and outpatient physicians' fees are not recorded, so the data may underestimate total costs associated with the procedure. Fourth, patients with costs greater than 3 standard deviations from the mean were excluded from this study, which could bias the results. Fifth, follow-up data for the second post-CABG year were not available for 83 of the 3745 patients (2.22%), because they were no longer receiving Medicare fee-for-service benefits. Finally, cost data are based on calculations made from charges and cost-to-charge ratios, rather than direct costs. Despite these potential limitations, this observational study provides potentially important insights into the cost-efficacy of concomitant SA during CABG in the Medicare population.

In conclusion, an analysis of US Medicare beneficiaries with AF who underwent CABG with and without SA indicated that early postoperative risk was not increased after SA; however, the late risk-adjusted hazard for mortality was 29% lower. Although the initial cost in SA patients was approximately 11% higher, likely attributable in part to device expenses, total costs after 2 years were similar in the 2 groups. These findings suggest significant long-term survival benefits and cost-efficacy associated with SA in AF patients who undergo CABG.

A clinical video of a current CABG procedure with concomitant Bi-Atrial CryoMaze can be downloaded from: http://www.jsrmd.com/ftp/257_SA-CABGc.mp4. Ablations performed in 2013 probably were different, and likely were predominant pulmonary vein isolations. However, this video illustrates current techniques that have been shown to produce >90% sinus conversion rates.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/18May01/Theater%201%20Booth%20134/S84%20-%20Update%20of%20surgical%20Ablation/S84_2_webcast_125954400.mp4.



Conflict of Interest Statement

Dr Rankin serves as a consultant for AtriCure and BioStable Inc. Dr Lerner, Ms Braid-Forbes, and Ms McCrea received a restricted grant from AtriCure to support the statistical analysis. Dr Badhwar has nothing to disclose with regard to commercial support. All authors had complete academic freedom in study design and execution, data analysis and interpretation, and manuscript generation and take

complete responsibility for the integrity of the information and the accuracy of the analysis.

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Key Words: surgical ablation, atrial fibrillation, coronary artery bypass grafting

Discussion

Dr Niv Ad *(Falls Church, Va)*. I'll start with a question in line of what I just told Chris, that the endpoint of surgical ablation I think is somewhat relying on the entire finding. But you had the admission data. Can you tell us anything about the reason, the cause of the admission, because you can say if it was for atrial arrhythmia, if it was for cardioversion, if

it was for any of those things. Any differences between the groups?

Dr J. Scott Rankin *(Morgantown, WVa)*. Yes. The readmissions (early in the first 90 days) were higher in the ablation group by about 15%, mainly for the diagnosis of atrial arrhythmias: flutter, fibrillation, and unspecified atrial arrhythmias. There was not a difference for repeat ablation in the cath; it was the same in both groups. But after the 90 days, the readmissions were 15% less in the patients who had ablations, and that may be related to multiple different factors.

Our study has a much different design than Dr Malaisrie's. First of all, we were looking only at patients who had admissions with defined AF twice in the preceding year in the CMS database. So these are all persistent AF patients. And then secondly, there advantages to a propensity matched study in some situations, but one of the problems is examining only the center of the Gaussian distribution, and from other studies, we know that the relative benefit of ablation for mortality is probably pretty constant across all baseline risks. Thus, the absolute mortality benefit may be greater in those higher risk patients that are eliminated from the propensity matching, and with propensity matching, differences tend to go to the null. We believe regression analysis is better for large data sets with established covariates and risk models, such as these.

Dr Ad. I completely agree, but I would like maybe if Ralph can jump in and say there is a push now from the industry to have a study that is going to do pulmonary vein isolation and exclusion of the left atrial appendage in all CABG patients to reduce the risk of stroke due to perioperative A-fib. What you are telling us, it's kind of interesting, is that actually by applying surgical ablation, which I completely agree, you may actually increase A-fib, because we don't really know if it's a tendency to treat A-fib or there was more A-fib postoperatively and what was happening afterwards.

Dr Rankin. Then you are talking about the early readmissions?

Dr Ad. Yes. So basically, and I just want your opinion about it. We know that virtually postsurgical ablation patients do have about 30% A-fib within the first 30 days. I don't know much about the 90 days.

So what is your comment about this study design as a preventive measure for A-fib to apply pulmonary vein isolation and appendage exclusion based on your findings?

Dr Rankin. I would not be in favor of doing prophylactic ablation in patients with no preoperative atrial fibrillation and prefer transient amiodarone prophylaxis in these patients, as validated in the PAPABEAR trial. Dr Badhwar published a paper on trends in the STS database, and looked at the 2014 US coronary bypass population. The vast majority of the CABG patients with AF ablation probably had simple pulmonary vein isolation, and about 89% had left atrial appendage occlusion. So that's probably the dominant operation applied to the patients in the current study.

Dr Ralph J. Damiano *(St Louis, Mo)*. Scott, congratulations. You are certainly adding to the body of evidence. It's still hard in this study, and I agree with you, propensity matching is not ideal, but they were clearly selecting the lower-risk patients to have surgical ablation in this, and there may have been some selection bias for that that you couldn't risk-adjust for.

Dr Rankin. You say that, but I have incredible confidence in the ability of current STS regression models to adjust for differences in baseline characteristics. We can go over this aspect later, but we have multiple examples of the accuracy of regression modeling in recent studies. For sure, there is no perfect technique, but I think regression analysis of an entire real-world population is the best current approach, even better than randomized trials, where there are a lot of problems, as you know. Thus, I would stand by the accuracy of STS regression data.

Dr Damiano. I like it, and I agree with your conclusions. We did a lot of big STS studies which showed that off-pump was better than on-pump surgery in the early days, if you can remember that, with "risk-adjusted," but then when the randomized trials came, we got different results.

Dr Rankin. Yes, you are right, but there are multiple other factors involved that would have to be considered.

Dr Damiano. I agree with your conclusion. I just think you always have to be a little careful. But arguing back with me, I would have said that the one thing that would suggest that they got adjusted, because it didn't affect the early phase mortality, that makes it really compelling that it was something about the operation, because if you thought if they were really high-risk patients, then the early-phase mortality would be different in the nonablation group, but they were pretty similar.

Dr Rankin. Well, as you taught me, most of the coronary bypass patients don't have enlarged left atria, so PVI is more effective in those, and most of the studies show a 60 to 80% conversion rate. That is probably the conversion rate we are dealing with here in this population.

Dr Damiano. Though I would say just as an aside, it is not with your study, this was a short study. We have seen that virtually in the CABG population also, and this was more of a persistent but even paroxysmal, the failure rate with PVI alone if done just with the clamps, once you get out to 5 years, is dramatic; it's over a 50% failure rate. So, I would hate for people to leave to think that PVI and clipping is a good thing.

Dr Rankin. We agree with you; you have taught us that; and a biatrial maze is our current approach for all patients with A-fib. But that's probably not what was done here.

Dr Damiano. This is important, because I do agree with you. As great as it would be to do a randomized trial—and we know the problems and it's never going to get done and we keep getting told, well, I just don't want to do ablation—but I think this is adding, and the same with Chris's study, this is adding to some evidence to suggest there are some real long-term benefits to the patient.

Dr Jack Sun *(Orange, Calif)*. I do want to start off by saying there are few patients that I operate on that if they have A-fib that I don't do a full Cox-Maze on. So, I believe in it. I would say that my concern is that for those of us who really believe in it and are aggressive about it, sometimes I feel like we are a little too gung-ho about wanting to make sure everybody is doing it. And part of that, and my concern is, I do look at Dr Madry's study, and I can believe it. We have been all trained that there are decades of data that if we had longer clamp times and longer pump times there is higher mortality. So how can we come out and say we are doing a procedure that takes longer and increases those times with no increase in mortality?

So, my concern is that we are kind of trying to convince everyone that there is no increased risk at all by doing a Cox-Maze procedure, and by doing so it's actually hurting the cause, because a lot of surgeons aren't going to believe that, number one. And, number two, it actually may hurt us, because then we start, like those of us in California and New York where we have isolated CABG being publicly reported and then they are saying, well, look at these studies that show CABG and Cox-Maze shows no difference in operative mortality, so we are going to include all those patients now in isolated CABG. And then, if it's not really true, it ends up hurting our data.

So, if you could add some comments about that, I would really appreciate it.

Dr Rankin. Well, I think you make a very good point, but we need to stay focused on what happens to the patient long-term—and I believe the evidence is mounting that if the patient has atrial fibrillation and requires a coronary bypass, then, the outcomes at 5 years are very significantly better. So, we have all these political problems and public reporting problems, but the key is the patient. If we do better for the patient, those other problems will take care of themselves. We are now performing biatrial ablations in virtually all coronary bypass patients with preoperative AF.

Dr Sun. Agree. So, we are looking at long-term benefit, which is why we do it, but I do worry about us saying there is no increase in risk.

Dr Rankin. I agree, but we have shown that in fact there may be a small early mortality benefit for ablation in mitral patients, and the cause could relate to better postoperative cardiac output in sinus rhythm, less thromboembolism, etc.

APPENDIX E1. METHODS

Logistic Regression Model of Surgical Atrial Ablation

A logistic regression specification was used to estimate risk-adjusted ORs for the association of patient demographics, patient comorbidities, and procedure characteristics with surgical ablation. The independent variable terms in the model were the same as for the piecewise Cox PH model for mortality following CABG. The risk-adjusted OR for each independent variable was calculated by exponentiation of the estimated coefficient for that variable. The model met the prespecified convergence criterion of 1×10^{-8}, the global null hypothesis was rejected with a P value <.0001, and the Hosmer-Lemeshow P value was >.05 (.25). Together, these indicate the model has meaningful predictive value and reasonable goodness of fit.

Piecewise Cox PH Model of Mortality

A Cox PH specification was initially used to estimate the risk-adjusted HR for death following CABG in patients who did and did not undergo SA. It contained independent variable terms for patient demographics, including age (<65 years, ≥75 years; 65-74 years as the reference), sex (female; male as the reference), race/ethnicity (black, all other nonwhite or nonblack; white as the reference), original basis of Medicare eligibility (end-stage renal disease and/or disability; age as the reference), Medicaid eligibility, heart failure 2 weeks before the CABG admission, renal failure/dialysis, presentation status (urgent, emergent; elective or unspecified as the reference), MI before the CABG procedure (8-21 days, >21 days; 0-7 days as the reference), chronic lung disease, cerebrovascular disease, PAD, diabetes mellitus, hypertension, arterial-coronary graft, aortocoronary bypass graft with number of vessels (1, 2, 3, ≥4; 0 or unspecified as the reference), prior PCI, IABP use the day before CABG, IABP use the day of or after CABG, aortic valve stenosis, aortic valve insufficiency, mitral valve insufficiency, endocarditis, and the subset of 21 comorbidities identified by Elixhauser and colleagues.[E1] In the final model, terms with counts <11 on the univariate comparisons were omitted (IABP use before the date of CABG, endocarditis, paraplegia, and 10 of the Elixhauser comorbidities (paralysis, liver disease, peptic ulcer disease, acquired immunodeficiency syndrome, lymphoma, solid tumor without metastases, metastatic cancer, anemia of blood loss, alcohol abuse, and drug abuse).

The PH assumption for each of the covariates was tested by visual inspection to validate proportionality between the covariate strata on a log (-log [survival probability]) vs log (survival time following CABG) plot of the KM survival function. The PH assumption for each of the covariates also was tested quantitatively using cumulative Martingale residuals with a Kolmogorov-type supremum test based on a sample of 1000 simulated residual patterns,[E2] with a P value <.05 taken as evidence that the PH assumption was not satisfied. Using this approach, we found the PH assumption for several STS risk model covariates was not satisfied during the first year after CABG, similar to others.[E3-E6] As a result, it was necessary to use a piecewise Cox PH model for mortality, as described previously.[E3-E6]

To construct a piecewise Cox PH model, the first 2 years following CABG were divided into 2 intervals, 0 to 90 days and 91 to 729 days. A separate Cox PH model was then developed for each interval. The independent variables included in that model are listed in Table 3. These intervals were chosen because 0 to 90 days represented the extended postoperative period and 91 to 729 days represented follow-up from the postoperative period to 2 years. For each independent variable, the risk-adjusted HR for death was calculated by exponentiation of the corresponding estimated variable coefficient.

The PH assumption for the 0- to 90-day interval was evaluated quantitatively using the Kolmogorov-type supremum test as above, and no evidence of rejection was present for 39 of 40 model variables in the 0- to 90-day interval. A sensitivity analyses was performed for the 91- to 729-day interval, and removing the 1 variable that violated the PH assumption at a Kolmogorov-type supremum test P value of .05 from the piecewise Cox model (aortocoronary graft of 1 vessel) did not change the parameter estimate for ablation or the associated P value (HR, 0.72; $P = .03$) in a meaningful way compared with the complete model (HR, 0.71; $P = .03$). Even when the Kolmogorov-type supremum test P value rejection criterion was relaxed from a .05 to .20, and 7 terms were removed from the model, the ablation parameter estimate and its P value were not changed substantially (HR, 0.70; $P = .02$).

Potential interactions also were examined between independent variables in the PH specifications for the 0- to 90-day and 91- to 729-day intervals. We identified the 5 independent variables with parameter estimates with the highest χ^2 statistic for each of the 2 intervals. We then added all 10 possible pairwise product interaction terms created from these 5 to the original specification for each interval, and finally solved for the parameter estimates in the revised specification. Only 2 of the 10 interaction terms for the revised 0-90 interval model were significant, and the interaction terms did not substantially improve the goodness of fit. Only 1 of the 10 interaction terms for the revised 91-729 interval model was significant, and the interaction term did not substantially improve the goodness of fit. For this reason, interaction terms were not added to the final piecewise PH specifications.

Incomplete Cost Standardization Data

A total of 72 patients (1.9%) were excluded from the study cohort because of insufficient data to standardize costs, leaving a total starting cohort of 3745 patients (Figure 1). There were insufficient data to standardize costs for a total of 46 of the 2187 patient readmission claims in year 2 (38 patients with 36 providers). These claims remained in the study using the following procedure to locate or impute the missing data required for charge standardization for the 36 providers. Using the provider ZIP code, the county for each urban provider that did not have a match in the FY 2016 Inpatient Final Rule Correction Notice Impact File was used with the county to core-based statistical area (CBSA) crosswalk provided with the FY 2016 Inpatient Final Rule to determine the provider's CBSA code. Rural providers were mapped to the rural state code. The data provided in the Wage Index (WI) by the CBSA table found in the FY 2016 Inpatient Final Rule Correction Notice was then used to look up the matching value for the WI and geographic adjustment factor (GAF) by the CBSA. For the factors listed below, the median value for all providers with less than 100 beds included in the FY 2016 Inpatient Final Rule Correction Notice Impact File was used:

- Capital cost-to-charge ratio: the ratio of Medicare capital costs to Medicare-covered charges
- Operating cost-to-charge ratio: the ratio of Medicare operating costs to Medicare- covered charges
- Indirect medical education adjustment factor for capital prospective payment systems
- Indirect medical education adjustment factor for operating prospective payment systems
- Disproportionate share hospital patient percentage as determined from the most recent cost report data and Social Security Administration data
- Operating disproportionate share hospital adjustment
- Capital cost of living adjustment for hospitals located in Alaska and Hawaii
- Cost of living adjustment factor obtained from the US Office of Personnel Management for IPPS providers located in Alaska or Hawaii.

These values were used for the 36 providers with missing impact data and then the 46 affected claims were added back to the dataset to arrive at 2187 claims with provider information to calculate standardized charges (Table 4).

Negative Binomial Regression Models of Inpatient Days and Inpatient Cost

A generalized linear model with a binomial distribution and log link was used to estimate the risk-adjusted RRs with and without ablation for the inpatient cost and inpatient days for the Index CABG admission and total inpatient care to 2 years (Table 4). The models contained the same independent variables used in the piecewise Cox PH model for mortality, and an additional term for evaluable days. The comorbidities identified by Elixhauser and colleagues[E1] were retained because they have been shown to be associated with hospital charges, length of stay, and mortality. The unadjusted RRs were estimated using the same model but with ablation as the sole independent variable. RRs were estimated as the exponential function of the parameter estimates. These adjusted and unadjusted models of inpatient cost and inpatient days met convergence criteria. Deviance per degree of freedom was close to 1 for the risk-adjusted inpatient cost and inpatient days models for the index CABG admission (1.05 and 0.95, respectively) and inpatient cost and inpatient days for total inpatient care to 2 years (1.07 and 1.04, respectively), consistent with reasonable goodness of fit for these models.

In a similar manner, a generalized linear model with a binomial distribution and log link was used to estimate the unadjusted and risk-adjusted RRs with and without ablation for the cost center allocations where <10% of patients had a zero value. These adjusted and unadjusted models of cost all met the convergence criteria. Deviance per degree of freedom was close to 1 for these risk-adjusted cost models (1.05 to 1.24).

Zero-Inflated Negative Binomial Regression Models of Inpatient Days and Inpatient Cost

A ZINB regression specification was used to model inpatient cost and inpatient days for all readmissions in year 1, all readmissions in year 2, and all readmissions from 0 to 2 years because they equaled 0 for >10% of index patients. The model used the same variables as the standard negative binomial models. An offset was not used in the ZINB analysis, because there was already a term for evaluable days in the negative binomial regression specification. For these 6 analyses, the Vuong scores[E7] and Clarke scores[E8] both suggested that the data were better fit by the ZINB model than by the negative binomial model, and that the Akaike and Bayesian information criteria were lower for the ZINB models than the for negative binomial model. The scaled Pearson χ^2 per degree of freedom for these 6 analyses ranged from 1.16 to 1.48. The risk-adjusted OR of having a zero value was estimated as the exponential function of the parameter estimate in a logistic regression for the presence or absence of a zero value. The unadjusted and risk-adjusted RRs for inpatient cost or inpatient days that were not 0 were estimated as the exponential functions of the parameter estimates from the zero-inflated negative binomial regression.

In a similar manner, a ZINB regression specification was used to model the risk-adjusted RRs with and without ablation for the cost center allocations where >10% of patients had a zero value: routine care, implantable devices, cardiac catheterization, MRI, CT scan, ER, blood and blood products, and other services. For these 8 analyses, the Vuong scores[E7] and Clarke scores[E8] both suggested that the data were better fit by the ZINB model than by the negative binomial model, except for the implantable device cost center, where the Clarke score suggested that the negative binomial model was more suitable, and the blood and blood products cost center, where the Vuong score suggested that the negative binomial model was more suitable. In all 8 cases, the Akaike and Bayesian information criteria were lower for the ZINB models than for the negative binomial model. The scaled Pearson χ^2 per degree of freedom for these 8 analyses ranged from 0.91 to 2.59.

E-References

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TABLE E1. Inclusion criteria and corresponding administrative codes and claim positions

Inclusion criteria	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
Coronary artery bypass grafting surgery	ICD-9-CM Px	36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19	Any Px		
Persistent atrial fibrillation	ICD-9-CM Dx	427.31	Any 2, more than 7 d apart: 1. Index admission claim: any Dx and POA 2. IP hospitalization claim in 12 mo prior to CABG: any Dx 3. OP hospitalization claim in 12 mo prior to CABG: any Dx		
Atrial fibrillation ablation-surgical	ICD-9-CM Px	37.33, 37.37	Any Px		

ICD-9-CM, International Classification of Diseases, Ninth Revision-Clinical Modification; *Px*, procedure; *Dx*, diagnosis; *POA*, present on admission; *IP*, inpatient; *CABG*, coronary artery bypass grafting; *OP*, outpatient.

TABLE E2. Exclusion criteria and corresponding administrative codes and claim positions

Exclusion criteria	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
<18 y old			x		
Other major cardiovascular procedures during index admission	ICD-9-CM Px	35.05, 35.06, 35.07, 35.08, 35.09, 35.10, 35.11, 35.12, 35.13, 35.14, 35.20, 35.21, 35.22, 35.23, 35.24, 35.25, 35.26, 35.27, 35.28, 35.41, 35.42, 35.81, 35.82, 35.83, 35.84, 35.91, 35.92, 35.93, 35.94, 35.95, 35.96, 35.97, 35.98, 35.99, 36.03, 36.06, 36.07, 36.09, 37.41, 37.51, 37.52, 37.53, 37.54, 37.55, 38.10, 38.11, 38.12, 38.13, 38.14, 38.15, 38.16, 38.18, 39.71, 39.72, 39.73, 39.74, 39.75, 39.76, 39.78, 39.90	Any Px		
Prior coronary artery bypass grafting surgery	ICD-9-CM Dx ICD-9-CM Px	V45.81 36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19	Any Dx	Any Dx Any Px	Any Dx
Prior surgical or endovascular atrial fibrillation ablation	ICD-9-CM Px CPT	37.33, 37.34, 37.37 2013: 93656, 93657; 2012: 93651		Any Px	Any CPT
Prior left atrial appendage excision, destruction or exclusion	ICD-9-CM Px CPT	37.36, 37.90 0281T		Any Px	Any CPT
Prior or current valvular disease: 1. Mitral stenosis 2. Valve replacement 3. Mitral valve repair	Mitral stenosis; ICD-9-CM Dx	394.0, 394.2, 394.9, 396.0, 396.1, 396.8, 746.5	Any Dx	Any Dx	Any Dx
	Mitral stenosis; ICD-9-CM Px	35.00, 35.02, 35.12	Any Px	Any Px	
	Mechanical or bioprosthetic valve; ICD-9-CM Px	35.05, 35.06, 35.07, 35.08, 35.09, 35.20, 35.21, 35.22, 35.23, 35.24, 35.25, 35.26, 35.27, 35.28	Any Px	Any Px	
	Mechanical or bioprosthetic aortic valve (TAVR) CPT	2013: 33361, 33362, 33363, 33364, 33365, 0138T; 2012: 0256T, 0257T, 0258T, 0259T	Any Dx	Any Dx	Any CPT Any Dx
	Mechanical or bioprosthetic valve; ICD-9-CM Dx	V42.2, V43.3			
	Endovascular or closed mitral valvotomy or valvuloplasty CPT	33420, 92987			Any CPT
	Mitral valve repair; ICD-9-CM Px	35.31, 35.32, 35.33, 35.97	Any Px	Any Px	
Prior or current total or partial heart replacement	ICD-9-CM Dx ICD-9-CM Px	V42.1 37.51, 37.52, 37.53, 37.54	Any Dx Any Px	Any Dx Any Px	Any Dx

ICD-9-CM, International Classification of Diseases, Ninth Revision-Clinical Modification; *Px*, procedure; *Dx*, diagnosis; *CPT*, Current Procedure Terminology; *TAVR*, transcutaneous aortic valve replacement.

TABLE E3. Comorbidities and corresponding administrative codes and claim positions

Comorbidity	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
Heart failure within 2 wk of surgery	ICD-9-CM Dx	398.91, 402.01, 402.11, 402.91, 404.01, 404.11, 404.91, 404.03, 404.13, 404.93, 428.0, 428.1, 428.20, 428.21, 428.22, 428.23, 428.30, 428.31, 428.32, 428.33, 428.40, 428.41, 428.42, 428.43, 428.9	Any Dx AND POA	Principal Dx AND within 2 wk of index admission	Principal Dx AND within 2 wk of index admission
Renal failure/dialysis	ICD-9-Dx	585.6, V45.11, V45.12, V56.0, V56.8	Any Dx AND POA	Any Dx	Any Dx
	ICD-9-CM Px	39.95, 54.98		Any Px	
	CPT	90935, 90937, 90945, 90947, 90960, 90961, 90962, 90966, 99512			Any CPT
Prior myocardial infarction	ICD-9-CM Dx	410.10, 410.11, 410.12, 410.20, 410.21, 410.22, 410.30, 410.31, 410.32, 410.40, 410.41, 410.42, 410.50, 410.51, 410.52, 410.60, 410.61, 410.62, 410.70, 410.71, 410.72, 410.80, 410.81, 410.82, 410.90, 410.91, 410.92	Any Dx AND POA	Principal Dx	Principal Dx
Chronic lung disease	ICD-9-CM Dx	490, 491.0, 491.1, 491.20, 491.21, 491.22, 491.8, 491.9, 492.0, 492.8, 494.0, 494.1, 496	Any Dx AND POA	Any Dx	Any Dx
Ischemic stroke	ICD-9-CM Dx	433.00, 433.01, 433.10, 433.11, 433.20, 433.21, 433.30, 433.31, 433.80, 433.81, 433.90, 433.91, 434.00, 434.01, 434.10, 434.11, 434.90, 434.91, 436	Any Dx AND POA	Any Dx	Any Dx
Intracranial hemorrhage or subarachnoid hemorrhage	ICD-9-CM Dx	430, 431, 432.0, 432.1, 432.9	Any Dx AND POA	Any Dx	Any Dx
Transient ischemic attack	ICD-9-CM Dx	362.34, 435.0, 435.1, 435.2, 435.3, 435.8, 435.9	Any Dx AND POA	Any Dx	Any Dx
Peripheral arterial disease	ICD-9-CM Dx	440.1, 440.20, 440.21, 440.22, 440.23, 440.24, 440.29, 440.30, 440.31, 440.32, 440.4, 440.8, 440.9, 443.9, 445.01, 445.02, 445.81, 445.89, 557.1	Any Dx AND POA	Any Dx	Any Dx
	ICD-9-CM Px	17.56, 38.10, 38.11, 38.12, 38.14, 38.15, 38.16, 38.18, 39.22, 39.23, 39.24, 39.25, 39.26, 39.28, 39.29, 39.50, 39.90, 39.73, 00.55, 00.63, 00.65, 00.64	Any Px	Any Px	
	CPT	34800, 34802, 34803, 34804, 34805, 34820, 34825, 34830, 34831, 34832, 34833, 34834, 35001,35021, 35045, 35081, 35091, 35102, 35121, 35131, 35141, 35151, 35301, 35302, 35303, 35304, 35305, 35311, 35321, 35331, 35341, 35351, 35355, 35361, 35363, 35371,			Any CPT

(Continued)

TABLE E3. Continued

Comorbidity	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
		35372, 35450, 35452, 35458, 35471, 35472, 35475, 35476, 35501, 35506, 35508, 35509, 35510, 35511, 35512, 35515, 35516, 35518, 35521, 35522, 35523, 35525, 35526, 35531, 35533, 35535, 35536, 35537, 35538, 35539, 35540, 35556, 35558, 35560, 35563, 35565, 35566, 35570, 35571, 35572, 35583, 35585, 35587, 35601, 35606, 35612, 35616, 35621, 35623, 35626, 35631, 35632, 35633, 35634, 35636, 35637, 35638, 35642, 35645, 35646, 35647, 35650, 35654, 35656, 35661, 35663, 35665, 35666, 35671, 35691, 35693, 35694, 35695, 35875, 35876, 35879, 35881, 35883, 35884, 35903, 35905, 35907, 37205, 37207, 37220, 37221, 37224, 37225, 37226, 37227, 37228, 37229, 37230, 37231, 75952, 75953, 75954, 75956, 75957, 75958, 75959, 75960, 75962, 75966, 0236T			
Diabetes mellitus	ICD-9-CM Dx	249.00, 249.01, 249.10, 249.11, 249.20, 249.21, 249.30, 249.31, 249.40, 249.41, 249.50, 249.51, 249.60, 249.61, 249.70, 249.71, 249.80, 249.81, 249.90, 249.91, 250.00, 250.01, 250.02, 250.03, 250.10, 250.11, 250.12, 250.13, 250.20, 250.21, 250.22, 250.23, 250.30, 250.31, 250.32, 250.33, 250.40, 250.41, 250.42, 250.43, 250.50, 250.51, 250.52, 250.53, 250.60, 250.61, 250.62, 250.63, 250.70, 250.71, 250.72, 250.73, 250.80, 250.81, 250.82, 250.83, 250.90, 250.91, 250.92, 250.93, 357.2, 362.01, 362.02, 362.03, 362.04, 362.05, 362.06, 362.07, 366.41, V58.67	Any Dx AND POA	Any Dx	Any Dx
Hypertension	ICD-9-CM Dx	401.0, 401.1, 401.9, 402.00, 402.01, 402.10, 402.11, 402.90, 402.91, 403.00, 403.01, 403.10, 403.11, 403.9, 403.91, 404.00, 404.01, 404.02, 404.03, 404.10, 404.11, 404.12, 404.13, 404.90, 404.91,	Any Dx AND POA	Any Dx	Any Dx

(Continued)

TABLE E3. Continued

Comorbidity	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
		404.92, 404.93, 405.01, 405.09, 405.11, 405.19, 405.91, 405.99			
Endocarditis	ICD-9-CM Dx	424.90, 424.91,424.99	Any Dx AND POA	Any Dx	Any Dx
Previous PCI	ICD-9-CM Px CPT	00.66, 36.06, 36.07, 36.09 92920, 92921, 92924, 92925, 92928, 92929, 92933, 92934, 92937, 92938, 92941, 92943, 92944		Any Px	Any CPT
Valve disease-aortic stenosis	ICD-9-CM Dx	395.0 395.2, 396.2, 396.8, 746.3	Any Dx AND POA	Any Dx	Any Dx
Valve disease-aortic insufficiency	ICD-9-CM Dx	395.1, 395.2, 396.1, 396.3, 746.4	Any Dx AND POA	Any Dx	Any Dx
Valve disease-mitral insufficiency	ICD-9-CM Dx	746.6, 394.1, 396.2, 396.3	Any Dx AND POA	Any Dx	Any Dx
Arterial bypass	ICD-9-CM Px	36.15, 36.16, 36.17	Any Px		
Aortocoronary bypass grafts (number of arteries)	ICD-9-CM Px	36.10, 36.11, 36.12, 36.13, 36.14	Any Px		
Admission type (elective, emergency, urgent, unknown)			x		
Prior MI (0-7 d, 8-21 d, or >21 d prior to surgery)	ICD-9-CM Dx	410.10, 410.11, 410.12, 410.20, 410.21, 410.22, 410.30, 410.31, 410.32, 410.40, 410.41, 410.42, 410.50, 410.51, 410.52, 410.60, 410.61, 410.62, 410.70, 410.71, 410.72, 410.80, 410.81, 410.82, 410.90, 410.91, 410.92		Principal Dx	
Intra-aortic balloon pump (prior to day of surgery, on day of surgery, or after)	ICD-9-CM Px	37.61	Any Px		

ICD-9-CM, International Classification of Diseases, Ninth Revision-Clinical Modification; *Dx*, diagnosis; *POA*, present on admission; *Px*, procedure; *CPT*, Current Procedure Terminology; *PCI*, percutaneous coronary intervention; *MI*, myocardial infarction.

TABLE E4. Risk score criteria and corresponding administrative codes and claim positions for the CHA_2DS_2-Vasc and HAS-BLED scores

Risk score and criteria	Points	Code type	Codes	Claim positions		
				Index admission	Inpatient admission	Outpatient admission
CHA_2DS_2-VASc score*						
Heart failure	1	ICD-9-CM Dx	398.91, 402.01, 402.11, 402.91, 404.01, 404.11, 404.91, 404.03, 404.13, 404.93, 428.0, 428.1, 428.20, 428.21, 428.22, 428.23, 428.30, 428.31, 428.32, 428.33, 428.40, 428.41, 428.42, 428.43,428.9	Any Dx	Any Dx	Any Dx
Hypertension	1	ICD-9-CM Dx	401.0, 401.1, 401.9, 402.00, 402.01, 402.10, 402.11, 402.90, 402.91, 403.00, 403.01, 403.10, 403.11, 403.90, 403.91, 404.00, 404.01, 404.02, 404.03, 404.10, 404.11, 404.12, 404.13, 404.90, 404.91, 404.92, 404.93, 405.01, 405.09, 405.11, 405.19, 405.91, 405.99	Any Dx	Any Dx	Any Dx
Age ≥75 y	2			x		
Diabetes mellitus	1	ICD-9-CM Dx	249.00, 249.01, 249.10, 249.11, 249.20, 249.21, 249.30, 249.31, 249.40, 249.41, 249.50, 249.51, 249.60, 249.61, 249.70, 249.71, 249.80, 249.81, 249.90, 249.91, 250.00, 250.01, 250.02, 250.03, 250.10, 250.11, 250.12, 250.13, 250.20, 250.21, 250.22, 250.23, 250.30, 250.31, 250.32, 250.33, 250.40, 250.41, 250.42, 250.43, 250.50, 250.51, 250.52, 250.53, 250.60, 250.61, 250.62, 250.63, 250.70, 250.71, 250.72, 250.73, 250.80, 250.81, 250.82, 250.83, 250.90, 250.91, 250.92, 250.93, 357.2, 362.01, 362.02, 362.03, 362.04, 362.05, 362.06, 362.07, 366.41, V58.67	Any Dx	Any Dx	Any Dx
Stroke/TIA/TE	2					
Ischemic stroke		ICD-9-CM Dx	433.00, 433.01, 433.10, 433.11, 433.20, 433.21, 433.30, 433.31, 433.80, 433.81, 433.90, 433.91, 434.00, 434.01, 434.10, 434.11, 434.90, 434.91, 436	Any Dx	Any Dx	Any Dx
TIA		ICD-9-CM Dx	362.34, 435.0, 435.1, 435.2, 435.3, 435.8, 435.9	Any Dx	Any Dx	Any Dx
Peripheral embolism		ICD-9-CM Dx	444.01, 444.09, 444.1, 444.21, 444.22, 444.81, 444.89, 444.9, 593.81	Any Dx	Any Dx	Any Dx
		ICD-9-CM Px	38.00, 38.01, 38.02, 38.04, 38.05,38.06, 38.08, 39.74	Any Px	Any Px	
		CPT	34001, 34051, 34101, 34111, 34151, 34201, 34203, 37184, 37211 (2013 only), 37213 (2013 only), 37201 (2012 only)			Any CPT

(Continued)

TABLE E4. Continued

Risk score and criteria	Points	Code type	Codes	Claim positions: Index admission	Claim positions: Inpatient admission	Claim positions: Outpatient admission
Pulmonary embolism		ICD-9-CM Dx	415.12, 415.13, 415.19, 416.2, V12.55	Any Dx	Any Dx	Any Dx
Vascular disease	1					
Myocardial infarction		ICD-9-CM Dx	410.10, 410.11, 410.12, 410.20, 410.21, 410.22, 410.30, 410.31, 410.32, 410.40, 410.41, 410.42, 410.50, 410.51, 410.52, 410.60, 410.61, 410.62, 410.70, 410.71, 410.72, 410.80, 410.81, 410.82, 410.90, 410.91, 410.92	Any Dx	Any Dx	Any Dx
Aortic plaque		ICD-9-CM Dx	440.0	Any Dx	Any Dx	Any Dx
Peripheral arterial disease		ICD-9-CM Dx	440.1, 440.20, 440.21, 440.22, 440.23, 440.24, 440.29, 440.30, 440.31, 440.32, 440.4, 440.8, 440.9, 443.9, 445.01, 445.02, 445.81, 445.89, 557.1	Any Dx	Any Dx	Any Dx
		ICD-9-CM Px	17.56, 38.10, 38.11, 38.12, 38.14, 38.15, 38.16, 38.18, 39.22, 39.23, 39.24, 39.25, 39.26, 39.28, 39.29, 39.50, 39.90, 39.73, 00.55, 00.63, 00.65, 00.64	Any Px	Any Px	
		CPT	34800, 34802, 34803, 34804, 34805, 34820, 34825, 34830, 34831, 34832, 34833, 34834, 35001,35021, 35045, 35081, 35091, 35102, 35121, 35131, 35141, 35151, 35301, 35302, 35303, 35304, 35305, 35311, 35321, 35331, 35341, 35351, 35355, 35361, 35363, 35371, 35372, 35450, 35452, 35458, 35471, 35472, 35475, 35476, 35501, 35506, 35508, 35509, 35510, 35511, 35512, 35515, 35516, 35518, 35521, 35522, 35523, 35525, 35526, 35531, 35533, 35535, 35536, 35537, 35538, 35539, 35540, 35556, 35558, 35560, 35563, 35565, 35566, 35570, 35571, 35572, 35583, 35585, 35587, 35601, 35606, 35612, 35616, 35621, 35623, 35626, 35631, 35632, 35633, 35634, 35636, 35637, 35638, 35642, 35645, 35646, 35647, 35650, 35654, 35656, 35661, 35663, 35665, 35666, 35671, 35691, 35693, 35694,			Any CPT

(Continued)

TABLE E4. Continued

Risk score and criteria	Points	Code type	Codes	Claim positions: Index admission	Claim positions: Inpatient admission	Claim positions: Outpatient admission
			35695, 35875, 35876, 35879, 35881, 35883, 35884, 35903, 35905, 35907, 37205, 37207, 37220, 37221, 37224, 37225, 37226, 37227, 37228, 37229, 37230, 37231, 75952, 75953, 75954, 75956, 75957, 75958, 75959, 75960, 75962, 75966, 0236T			
Age 65-74 y	1			x		
Sex	1		Female	x		
HAS-BLED score†						
Hypertension	1	ICD-9-CM Dx	401.0, 401.1, 401.9, 402.00, 402.01, 402.10, 402.11, 402.90, 402.91, 403.00, 403.01, 403.10, 403.11, 403.9, 403.91, 404.00, 404.01, 404.02, 404.03, 404.10, 404.11, 404.12, 404.13, 404.90, 404.91, 404.92, 404.93, 405.01, 405.09, 405.11, 405.19, 405.91, 405.99	Any Dx	Any Dx	Any Dx
Abnormal renal function (dialysis or renal transplant)	1	ICD-9-CM Dx	585.6, V42.0, V45.11, V45.12, V56.0, V56.8	Any Dx	Any Dx	Any Dx
		ICD-9-CM Px	39.95, 54.98, 55.61, 55.69	Any Px	Any Px	
		CPT	90935, 90937, 90945, 90947, 90960, 90961, 90962, 90966, 99512			Any CPT
Abnormal liver function (chronic liver disease or liver transplant)	1	ICD-9-CM Dx	070.44, 070.54, 571.0, 571.1, 571.2, 571.3, 571.40, 571.41, 571.42, 571.49, 571.5, 571.6, 571.8, 571.9, 572.2, 572.3, 572.4, 572.8, 996.82, V42.7	Any Dx	Any Dx	Any Dx
		ICD-9-CM Px	50.59	Any Px	Any Px	
		CPT	37140, 37145, 37160, 37180, 37181, 37182, 37183			Any CPT
Stroke/TIA	1					
Ischemic stroke		ICD-9-CM Dx	433.00, 433.01, 433.10, 433.11, 433.20, 433.21, 433.30, 433.31, 433.80, 433.81, 433.90, 433.91, 434.00, 434.01, 434.10, 434.11, 434.90, 434.91, 436	Any Dx	Principal Dx	Principal Dx
Transient ischemic attack			362.34, 435.0, 435.1, 435.2, 435.3, 435.8, 435.9	Any Dx	Principal Dx	Principal Dx
Bleeding	1	ICD-9-CM Dx	459.0, 530.82, 531.00, 531.01, 531.20, 531.21, 531.40, 531.41, 531.60, 531.61, 532.00, 532.01, 532.20, 532.21, 532.40, 532.41, 532.60, 532.61, 533.00, 533.01, 533.20, 533.21, 533.40, 533.41, 533.60, 533.61, 534.00, 534.01, 534.20, 534.21, 534.40, 534.41, 534.60, 534.61, 568.81, 569.3, 578.0, 578.1, 578.9, 599.70, 599.71, 623.8, 626.8, 719.10,	Any Dx	Principal Dx	Principal Dx

(Continued)

TABLE E4. Continued

Risk score and criteria	Points	Code type	Codes	Claim positions		
				Index admission	Inpatient admission	Outpatient admission
			719.11, 719.12, 719.13, 719.14, 719.15, 719.16, 719.17, 719.18, 719.19, 729.92, 784.7, 784.8, 786.30, 786.39, 784.7, 998.11, 998.12			
Age >65 y	1			x		
Alcohol excess	1	ICD-9-CM Dx	291.0, 291.1, 291.2, 291.3, 291.4, 291.5, 291.81, 291.82, 291.89, 291.9, 303.00, 303.01, 303.02, 303.03, 303.90, 303.91, 303.92, 303.93, 305.00, 305.01, 305.02, 305.03, 357.5, 425.5, 535.30, 535.31, 571.0, 571.1, 571.2, 571.3, 760.71, 980.0	Any Dx	Principal Dx	Principal Dx

ICD-9-CM, International Classification of Diseases, Ninth Revision-Clinical Modification; *Dx*, diagnosis; *TE*, thromboembolism; *TIA*, transient ischemic attack; *Px*, procedure; *CPT*, Current Procedure Terminology. *CHA_2DS_2-VASc score (from Lip et al,[14] Refining clinical risk stratification for predicting stroke and thromboembolism in atrial fibrillation using a novel risk factor-based approach: The Euro heart survey on atrial fibrillation. *Chest* 2010;137:263-72) allocates points as follows: congestive heart failure (1 point), hypertension (1 point), age 65-74 y (1 point), diabetes mellitus (1 point), stroke/TIA/thromboembolism (2 points), vascular disease (1 point), age ≥75 y (2 point), female sex (1 point). †HAS-BLED score (from Pisters R et al,[17] A novel user-friendly score (HAS-BLED) to assess 1-y risk of major bleeding in patients with atrial fibrillation: The Euro Heart Survey. *Chest* 2010;138:1093-100) allocates points as follows: hypertension (1 point), abnormal renal function (1 point), abnormal liver function (1 point), stroke (1 point), bleeding (1 point), labile International Normalized Ratio (INR) (1 point), age >65 y (1 point), drug (antiplatelet agents, nonsteroidal anti-inflammatory) use (1 point), and alcohol use (1 point). In this study, points were not assigned for labile INR and drug use because they could not be reliably assessed from the administrative dataset used in this study.

TABLE E5. Clinical endpoints and corresponding administrative codes and claim positions

Study endpoint	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
Atrial tachyarrhythmias					
Admission for AF	ICD-9-CM Dx	427.31		Principal Dx	Principal Dx
Admission for AFL	ICD-9-CM Dx	427.32		Principal Dx	Principal Dx
Admission for AT (other)	ICD-9-CM Dx	427.0		Principal Dx	Principal Dx
AF-related interventions					
AF ablation (surgical-open)	ICD-9-CM Px	37.33		Any Px	
AF ablation (surgical - thoracoscopic)	ICD-9-CM Px	37.37		Any Px	
AF ablation (percutaneous)	ICD-9-CM Px	37.34		Any Px	
	CPT	93656, 93657			Any CPT
Exclusion, destruction, excision of atrial appendage, or device	ICD-9-CM Px	37.36, 37.90		Any Px	
	CPT	0281T			Any CPT
Stroke or TIA					
Ischemic stroke	ICD-9-CM Dx	433.00, 433.01, 433.10, 433.11, 433.20, 433.21, 433.30, 433.31, 433.80, 433.81, 433.90, 433.91, 434.00, 434.01, 434.10, 434.11, 434.90, 434.91, 436	Any Dx AND NOT POA	Principal Dx	Principal Dx
Intracranial hemorrhage and subarachnoid hemorrhage	ICD-9-CM Dx	430, 431, 432.0, 432.1, 432.9	Any Dx AND NOT POA	Principal Dx	Principal Dx
TIA	ICD-9-CM Dx	362.34, 435.0, 435.1, 435.2, 435.3, 435.8, 435.9	Any Dx AND NOT POA	Principal Dx	Principal Dx
Implantation of a CIED					
Single/dual PM	ICD-9-CM Px	37.81, 37.82, 37.83	Any Px	Any Px	
	CPT	33206, 33207, 33208, 33212, 33213, 33221			Any CPT
Single/dual ICD	ICD-9-CM Px	37.94	Any Px	Any Px	
	CPT	33230, 33231, 33240, 33249			Any CPT
Single/dual CRT-P	ICD-9-CM Px	00.50	Any Px	Any Px	
	CPT	33206+33225, 33207+33225, 33208+33225, 33212+33225, 33213+33225, 33202+33221, 33203+33221, 33212, 33213, 33221, 33229			Any CPT
Single/dual CRT-D	ICD-9-CM Px	0.51	Any Px	Any Px	
	CPT	33230+33225, 33231+33225, 33240+33225, 33249+33225			Any CPT
Bleeding	ICD-9-CM Dx	459.0, 530.82, 531.00, 531.01, 531.20, 531.21, 531.40, 531.41, 531.60, 531.61, 532.00, 532.01, 532.20, 532.21, 532.40, 532.41, 532.60, 532.61,		Principal Dx	Principal Dx

(Continued)

TABLE E5. Continued

Study endpoint	Code type	Codes	Claim positions		
			Index admission	Inpatient admission	Outpatient admission
		533.00, 533.01, 533.20, 533.21, 533.40, 533.41, 533.60, 533.61, 534.00, 534.01, 534.20, 534.21, 534.40, 534.41, 534.60, 534.61, 568.81, 569.3, 578.0, 578.1, 578.9, 599.70, 599.71, 623.8, 626.8, 719.10, 719.11, 719.12, 719.13, 719.14, 719.15, 719.16, 719.17, 719.18, 719.19, 729.92, 784.7, 784.8, 786.30, 786.39, 784.7, 998.11, 998.12			
Myocardial infarction	ICD-9-CM Dx	410.10, 410.11, 410.12, 410.20, 410.21, 410.22, 410.30, 410.31, 410.32, 410.40, 410.41, 410.42, 410.50, 410.51, 410.52, 410.60, 410.61, 410.62, 410.70, 410.71, 410.72, 410.80, 410.81, 410.82, 410.90, 410.91, 410.92		Principal Dx	Principal Dx
Heart failure	ICD-9-CM Dx	398.91, 402.01, 402.11, 402.91, 404.01, 404.11, 404.91, 404.03, 404.13, 404.93, 428.0, 428.1, 428.20, 428.21, 428.22, 428.23, 428.30, 428.31, 428.32, 428.33, 428.40, 428.41, 428.42, 428.43, 428.9		Principal Dx	Principal Dx
Revascularization					
CABG	ICD-9-CM Px	36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19		Any Px	
Coronary PCI	ICD-9-CM Px	00.66, 36.06, 36.07, 36.09		Any Px	
	CPT	92920, 92921, 92924, 92925, 92928, 92929, 92933, 92934, 92937, 92938, 92941, 92943, 92944			Any CPT

AF, atrial fibrillation; *ICD-9-CM*, International Classification of Diseases, Ninth Revision-Clinical Modification; *Dx*, diagnosis; *AFL*, atrial flutter; *AT*, atrial tachycardia; *Px*, procedure; *CPT*, Current Procedure Terminology; *TIA*, transient ischemic attack; *POA*, present on admission; *CIED*, cardiovascular implantable electronic device; *PM*, pacemaker; *ICD*, implantable cardiac defibrillator; *CRT-P*, cardiac resynchronization device-pacemaker only; *CRT-D*, cardiac resynchronization device with defibrillator; *CABG*, coronary artery bypass grafting surgery; *PCI*, percutaneous coronary intervention.