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Influence of Age on Perioperative Complications Among Patients Undergoing Implantable Cardioverter-Defibrillators for Primary Prevention in the United States

Vivian Tsai, MD; Mary K. Goldstein, MD; Henry H. Hsia, MD; Yongfei Wang, MS;
Jeptha Curtis, MD; Paul A. Heidenreich, MD; on behalf of the National Cardiovascular Data's ICD Registry

Background—The majority of current implantable cardioverter-defibrillator (ICD) recipients are significantly older than those in the ICD trials. Data on periprocedural complications among the elderly are insufficient. We evaluated the influence of age on perioperative complications among primary prevention ICD recipients in the United States.

Methods and Results—Using the National Cardiovascular Data's ICD Registry, we identified 150 264 primary prevention patients who received ICDs from January 2006 to December 2008. The primary end point was any adverse event or in-hospital mortality. Secondary end points included major adverse events, minor adverse events, and length of stay. Of 150 264 patients, 61% (n=91 863) were 65 years and older. A higher proportion of patients ≥65 years had diabetes, congestive heart failure, atrial fibrillation, renal disease, and coronary artery disease. Approximately 3.4% of the entire cohort had any complication, including death, after ICD implant. Any adverse event or death occurred in 2.8% of patients under 65 years old; 3.1% of 65- to 69-year-olds; 3.5% of 70- to 74-year-olds; 3.9% of 75- to 79-year-olds, 4.5% of 80- to 84-year-olds; and 4.5% of patients 85 years and older. After adjustment for clinical covariates, multivariate analysis found an increased odds of any adverse event or death among 75- to 79-year-olds (1.14 [95% confidence interval, 1.03 to 1.25], 80-to 84-year-olds (1.22 [95% confidence interval, 1.10 to 1.36], and patients 85 years and older (1.15 [95% confidence interval, 1.01 to 1.32], compared with patients under 65 years old.

Conclusions—Older patients had a modestly increased—but acceptably safe—risk of periprocedural complications and in-hospital mortality, driven mostly by increased comorbidity. (***Circ Cardiovasc Qual Outcomes***. 2011;4:549-556.)

Key Words: aging ■ implantable cardioverter-defibrillator ■ complications ■ registries

Although prior studies were mixed about the benefits of implantable cardioverter-defibrillator (ICD) therapy among the elderly,[1–4] recent studies have found that ICDs are effective in reducing total mortality in all age groups.[5–7] With the number of US individuals over age 65 projected to reach 72 million by 2030,[8,9] the number of elderly patients eligible for ICD therapy will increase severalfold over the next 2 decades. Already, the average age of the ICD recipient is 68 years,[10–11] with approximately 40% of recipients being 70 years and older at implant.[12]

Data on complication rates are needed to help older patients make an informed decision about the risks and benefits with ICD implantation. However, few studies have adequately examined the question. Patients of advanced age were underrepresented in the large primary prevention ICD trials (mean age, 60 to 65 years),[4,13–15] and cohort studies of elderly recipients have been limited to single centers,[16–21] outdated databases,[7,16–18,20–22] or patients outside of the United States.[16–19] With the advent of newer and smaller ICDs,[23] the complication rates associated with ICD implantation reported from the older databases[7,16–18] may be inaccurate. In addition, the influence of age on implantation complications may be continuous across the age groups. Past studies used only one age cut-off to define elderly patients,[7,16–18,24] even though sexagenarians may have complication rates different from those of septuagenarians or octogenarians.

To determine the current rates of ICD complications among advanced-age ICD recipients in different decades of life across different communities in the United States, we describe the influence of age on ICD implantation-related complications and mortality using a national registry of patients undergoing ICD implant for primary prevention.

Methods

We obtained the data from the National Cardiovascular Data Registry's (NCDR) ICD Registry. Initiated in 2006, the registry was

formed in response to a mandate from the Centers of Medicare and Medicaid Services (CMS) with the purpose of characterizing primary prevention ICD recipients. Although implanting institutions are required to enter data only from Medicare beneficiaries, the majority of institutions register all ICD recipients, regardless of indication or insurance status.[25] Institutions use a standardized questionnaire to submit clinical information, such as baseline patient clinical characteristics, device used, and in-hospital outcomes on a quarterly basis. Only hospitals achieving >95% completeness of specific data elements were included in the data analysis. The rate of missing values was <1% for all variables except left ventricular ejection fraction (LVEF). The data are subject to quality-control checks of missing or improperly coded items.[26]

WHAT IS KNOWN

- Although approximately 40% of recipients are 70 years or older at implant, implantable cardioverter-defibrillator complication rates among advanced-aged patients are unknown.

WHAT THE STUDY ADDS

- Differences in complication rates among older patients were found.
- In unadjusted analyses, the occurrence of any adverse event or in-hospital death increased from 2.8% in the youngest age group (under 65 years of age) to 4.5% in the oldest age groups (80 years and older).
- After multivariate adjustment, advanced age was associated with only a modestly increased risk of periprocedural complications and in-hospital death.
- Comorbid conditions were as important, of even more so, than age in determining complication risks.

Study Population

All patients within the NCDR-ICD Registry who had undergone ICD implantation between January 2006 to December 2008 were included if they received an ICD implantation for primary prevention. This study excluded patients who had received ICDs for secondary prevention (history of syncope, cardiac arrest, or sustained ventricular tachycardia) to avoid potential underreporting by institutions, or had received a prior ICD.

Independent Variables

The primary independent variable was age, categorized into 5 groups: <65, 65 to 69, 70 to 74, 75 to 79, 80 to 84, and at least 85 years old. We categorized age because it was not linearly associated with outcomes. We also examined the following clinical variables in the multivariate model: (1) clinical data (sex, diabetes, hypertension, atrial fibrillation, renal failure, ischemic versus nonischemic cardiomyopathy, New York Heart Association (NYHA) class heart failure, LVEF at the time of ICD implant, QRS duration, atrioventricular (AV) block, bundle-branch block, timing of myocardial infarction (MI) to ICD implant (implant ≤40 days versus >40 days after MI), and reason for admission); (2) device data (type of ICD implanted); and (3) physician and hospital characteristics (including physician certification, community versus university versus government hospitals, hospital size, and geographic location).

Dependent Variables

The occurrence of any adverse event (major or minor adverse event) or death was considered the primary end point. Secondary end points included major adverse events, minor adverse events, and length of hospital stay. Adverse events were reported by implanting centers using standard definitions (online-only Supplement Appendix) and were defined as any major or minor event that occurred during or after ICD implant up until the time of discharge. Major adverse events were defined as cardiac arrest, cardiac perforation, cardiac valve injury, coronary venous dissection, hemothorax, pneumothorax, deep phlebitis, transient ischemic attack, stroke, MI, pericardial tamponade, lead dislodgment, and arterial-venous fistula. Minor adverse events were defined as drug reaction, conduction block, hematoma, peripheral embolus, superficial phlebitis, peripheral nerve injury, and infection related to device.

Statistical Analysis

To identify significant patient, physician, and hospital factors associated with our primary and secondary end points, we used hierarchical logistic regression models or multilevel models—which adjust for patient clustering within hospitals—to evaluate the relationship between age and any adverse event or death. Our initial analysis was unadjusted for other characteristics. We repeated the analysis after sequentially adjusting for patient clinical characteristics, physician certification, and hospital characteristics. Confounding factors included in the model were demographic, clinical, procedure, and physician characteristics listed in Tables 1 and 2. We used Markov chain Monte Carlo multiple imputation procedure[27] to impute missing values with assumptions that the data were missing at random, and the parameters of the data model and of the missing data indicators were distinct. The statistical level of 0.05 was used for significance. All analyses were performed using the SAS statistical package version 9.2 (SAS Institute, Cary, NC). All analyses were approved by the Yale University Human Investigation Committee.

Results

Study Population

We identified 333 993 patients who underwent ICD implantation from January 2006 to December 2008. We excluded 32 767 patients who had received a prior ICD; 119 435 patients who had received ICDs for secondary prevention; and 31 527 patients from hospitals that had submitted data only on Medicare beneficiaries. The final study group consisted of 150 264 patients.

Clinical Characteristics of the Study Group

Figure 1 illustrates the distribution of ICD implantations among the age groups. Of 150 264 patients, 61% (n=91 863) were 65 years and older. The average age of the cohort was 67±13 years. Among patients 65 years and older, patients 70 to 79 years made up the largest age subgroups (15.1%, 70 to 74 years and 15.4%, 75 to 79 years); 65- to 69-year-old patients represented 14.5% of the total ICD population, 80- to 84-year-olds represented 11.3%, and ≥85-year-olds represented 4.8%.

Table 1 describes the characteristics of the ICD recipients. As expected, the proportion of patients with more advanced NYHA heart failure class and ischemic cardiomyopathy increased with age. Patients ≥65 years old had a higher frequency of diabetes, atrial fibrillation, and renal disease. Approximately one-quarter (27%) of recipients were women, a proportion that only modestly changed with age. The majority of patients were hospitalized electively for device implantation, whereas the remainder of patients received ICDs after being hospitalized for other cardiac or noncardiac issues; the latter occurred more frequently with age.

Otherwise, only clinically modest differences were observed among the age groups in measures of timing of MI to

Table 1. Characteristics of ICD Recipients

Clinical Characteristics	Total (n=150 264)	Age Groups, Years					
		<65 (n=58 401)	65–69 (n=21 805)	70–74 (n=22 680)	75–79 (n=23 132)	80–84 (n=16 937)	≥85 (n=7309)
Female, %	27	28	26	27	27	27	25
White, %	80	71	82	84	87	90	91
NYHA class, %							
I	8	10	8	7	7	5	5
II	36	39	37	36	32	30	28
III	52	47	51	53	57	60	61
IV	4	4	4	4	4	5	6
LVEF, mean, % (SD)	25 (8)	25 (9)	25 (8)	26 (8)	26 (7)	26 (7)	26 (8)
QRS duration, mean (SD)	127 (34)	118 (32)	127 (33)	130 (34)	135 (35)	138 (35)	141 (36)
AV block, %							
1st-Degree	16	12	16	18	19	20	21
2nd/3rd-Degree	3	2	3	3	4	5	6
Left bundle-branch block, %	28	23	29	31	33	34	35
Other medical conditions, %							
Hypertension	75	70	78	79	79	78	79
Diabetes	38	36	44	42	38	34	28
Renal disease*	41	25	42	48	54	60	64
Myocardial infarction							
≤40 d	4	4	4	4	4	4	5
>40 d	45	39	49	50	50	50	48
Coronary disease	65	52	69	71	74	75	75
Atrial fibrillation	30	19	28	34	40	45	48
Reason for hospitalization							
Elective†	71	71	73	73	71	69	65
Cardiac	14	14	13	13	14	16	18
Noncardiac	13	13	12	12	12	13	14
ICD type, %							
Single	25	33	24	21	18	16	15
Dual	35	37	37	35	33	31	30
Biventricular	40	30	39	44	49	53	55

ICD indicates implantable cardioverter-defibrillator; NYHA, New York Heart Association; LVEF, left ventricular ejection fraction; and AV, atrioventricular.

*Glomerular filtration rate <60 mL/min per 1.73 m^2.

†Elective admission for ICD implantation.

ICD implant, QRS duration, type of physician performing the ICD implant, hospital type, and geographic location. Tables 1 and 2 summarize the clinical, physician, and hospital characteristics of the study population by age group.

Perioperative Complications

Figure 2 shows the crude adverse event and mortality rates for each age group; 5068 patients (3.4%) had any adverse event or death. Of the total events (n=5359), minor events comprised 61% (n=3244). The rates of any adverse or death varied across the age groups. Patients under 65 years old had the lowest rates of any events, including death, (2.8%), followed by 65- to 69-year-olds (3.1%), then 70- to 74-year-olds (3.5%), and then 75- to 79-year-olds (3.9%). Once patients reached 80 years of age, the rate of any events, including mortality, reached a plateau (4.5%, 80- to 84-years and 4.5%, ≥85 years). In-hospital mortality rates only modestly increased with age.

Exclusive of death, the frequencies of major and minor adverse events varied with age, with minor events comprising the majority of events. Among all the complications, hematoma was the most common. A higher frequency of pneumothorax, MI, pericardial tamponade, hemothorax, and hematoma were observed with age. Otherwise, the rates of drug reaction, cardiac valve injury, lead dislodgment, peripheral nerve injury, peripheral embolus, transient ischemic attack, stroke, AV fistula, and device-related infections appeared similar across ages. Table 3 describes the adverse event rates in each age group.

Using patients under 65 years old as the reference group, in the hierarchical model, which adjusted only for clustering and

Table 2. Physician and Hospital Characteristics by Age Group

Clinical Characteristics	Total (n=150 264)	Age Groups, Years					
		<65 (n=58 401)	65–69 (n=21 805)	70–74 (n=22 680)	75–79 (n=23 132)	80–84 (n=16 937)	≥85 (n=7309)
Operator, %							
EP	81	81	81	82	81	81	81
Surgeon	2	2	2	2	2	2	2
Non-EP	10	10	11	11	11	11	11
Other specialist	7	7	7	6	6	6	6
Geographic location, %							
Northeast	17	16	16	17	19	20	20
West	12	12	12	13	12	13	15
Midwest	27	27	27	27	28	28	27
South	44	45	44	44	40	38	38
Hospital type, %							
Private	86	83	86	87	88	89	90
University	13	16	12	11	11	10	9
Government	1	1	1	1	1	1	2
Hospital beds, mean (SD)	478 (249)	493 (248)	473 (246)	470 (246)	470 (248)	463 (247)	454 (245)

EP indicates electrophysiologist; surgeon, thoracic surgeon; non-EP, nonelectrophysiologist cardiologist who has met credentialing for ICD implants, per Heart Rhythm Society Guidelines; other specialist, no formal training (electrophysiology fellowship, cardiac thoracic surgery training, or completion of HRS credentialing.

no other characteristics, the odds ratios for the combined outcome of any adverse event or mortality were 1.12 (95% confidence interval [CI], 1.03 to 1.22) for 65- to 69-year-olds, 1.27 (95% CI, 1.17 to 1.38) for 70- to 74-year-olds, 1.42 (95% CI, 1.31 to 1.54) for 75- to 79-year-olds, 1.63 (95% CI, 1.49 to 1.77) for 80- to 84-year olds, and 1.61 (95% CI, 1.43 to 1.81) for patients 85 years and older.

After adjustment for clinical characteristics (including comorbidities and type of ICD implanted), physician certification, and hospital characteristics, multivariate analysis found an increased odds of any adverse event or death among 75- to 79-year-olds (1.14 [95% CI, 1.03 to 1–25], 80-to 84-year-olds (1.22 [95% CI, 1.10 to 1.36], and patients 85 years and older (1.15 [95% CI, 1.01 to 1.32], compared with patients under 65 years old. However, age was a weaker predictor of complications, compared with sex, renal failure, stage IV heart failure, 2nd- or 3rd-degree AV block, atrial fibrillation, biventricular ICD place-

ment, hospitalizations not primarily for device implant, and physician certification. Besides device type, the strongest predictor for periprocedural complications was ICD implantation by a thoracic surgeon (odds ratio, 1.49 [95% CI 1.24 to 1.79]), compared with board-certified electrophysiologists. Table 4 describes the predictors of any adverse events or death after ICD implantation.

Impact on Length of Hospital Stay
The overall median length of stay was 1 [1, 4] days. Although median length of stay was different among the age groups, clinically significant differences were modest (Table 3). Among patients electively admitted for device implantation, the median length of stay was 1 [1, 4] days for patients under 65 years of age, 1 [1, 3] 65 to 69 years of age, 1 [1, 4] 70 to 74 years of age, 1 [1, 4] 75 to 79 years of age, 1 [1, 5] 80 to 84 years of age, and 1 [1, 6] for patients 85 years and older.
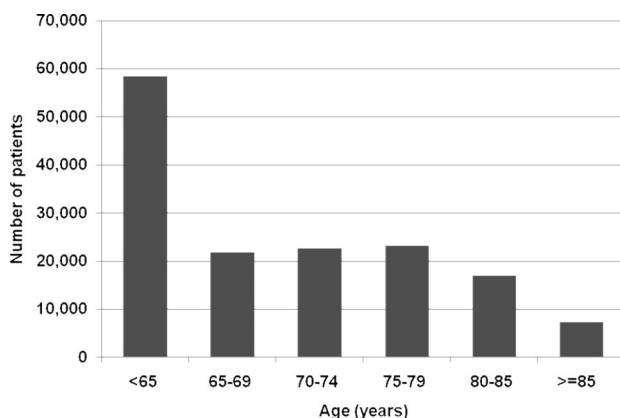
Figure 1. Distribution of ICD recipients by age group.
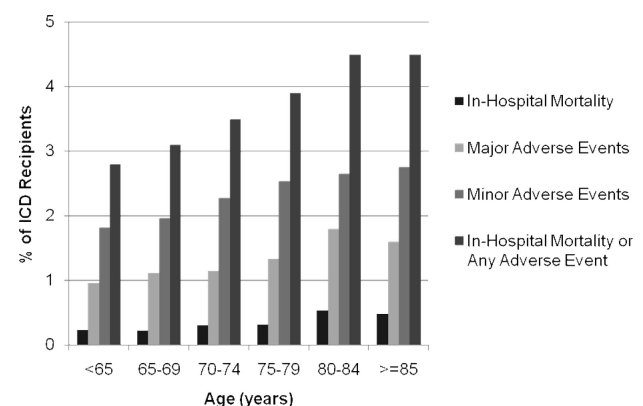
Figure 2. In-hospital adverse events and mortality by age group.

Table 3. Select Perioperative Adverse Events and Length of Stay by Age Group

		Age Groups, Years					
Adverse Events	Total (n=150 264)	<65 (n=58 401)	65–69 (n=21 805)	70–74 (n=22 680)	75–79 (n=23 132)	80–84 (n=16 937)	≥85 (n=7309)
Major adverse events, n (%)							
Cardiac arrest	393 (0.26)	165 (0.28)	50 (0.23)	48 (0.21)	47 (0.20)	65 (0.38)	18 (0.25)
Cardiac perforation	110 (0.07)	23 (0.04)	18 (0.08)	17 (0.07)	29 (0.13)	19 (0.11)	4 (0.05)
Hemothorax	142 (0.09)	38 (0.07)	20 (0.09)	19 (0.08)	28 (0.12)	26 (0.15)	11 (0.15)
Pneumothorax	676 (0.45)	186 (0.32)	91 (0.42)	104 (0.46)	127 (0.55)	116 (0.68)	52 (0.71)
TIA	38 (0.03)	9 (0.02)	4 (0.02)	11 (0.05)	7 (0.03)	6 (0.04)	1 (0.01)
Stroke	75 (0.05)	24 (0.04)	7 (0.03)	10 (0.04)	12 (0.05)	15 (0.09)	7 (0.10)
MI	39 (0.03)	6 (0.01)	4 (0.02)	5 (0.02)	12 (0.05)	8 (0.05)	4 (0.05)
Tamponade	149 (0.10)	39 (0.07)	22 (0.10)	28 (0.12)	21 (0.09)	27 (0.16)	12 (0.16)
AV fistula	3 (0.00)	1 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.01)	0 (0.00)
Minor adverse events, n (%)							
Conduction block	65 (0.04)	22 (0.04)	9 (0.04)	5 (0.02)	9 (0.04)	15 (0.09)	5 (0.07)
Hematoma	1410 (0.94)	369 (0.63)	170 (0.78)	243 (1.07)	288 (1.25)	229 (1.35)	111 (1.52)
Any major or minor adverse event	4897 (3.26)	1575 (2.70)	658 (3.02)	758 (3.34)	871 (3.77)	725 (4.28)	310 (4.24)
Any adverse event (major or minor) or death	5068 (3.37)	1614 (2.76)	671 (3.08)	792 (3.49)	904 (3.91)	756 (4.46)	331 (4.53)
In-hospital mortality	462 (0.31)	141 (0.24)	48 (0.22)	71 (0.31)	75 (0.32)	91 (0.54)	36 (0.49)
Overall length of stay, median d*	1 [1, 4]	1 [1, 4]	1 [1, 3]	1 [1, 4]	1 [1, 4]	1 [1, 5]	1 [1, 6]
LOS, elective admissions, median d*	1 [1, 1]	1 [1, 1]	1 [1, 1]	1 [1, 1]	1 [1, 1]	1 [1, 1]	1 [1, 1]
LOS, urgent admissions, cardiac, median d*	7 [4, 10]	7 [4, 10]	7 [4, 11]	7 [4, 10]	7 [4, 11]	7 [4, 11]	7 [5, 11]
LOS, urgent admissions, noncardiac, median d*	6 [3, 9]	5 [3, 9]	5 [3, 9]	5 [3, 9]	6 [3, 10]	6 [3, 9]	6 [3, 9]

TIA indicates transient ischemic attack; MI, myocardial infarction; AV, atrioventricular; and LOS, length of stay.
*Median days [1st quartile, 3rd quartile].

Similarly, for urgent cardiac and noncardiac admissions, despite variations in length of stay with age, clinically significant differences were modest.

Discussion

We evaluated the rate of ICD implantation-related complications, using a national registry of the largest population of older patients to date, and found differences in complication rates among older patients. In analyses without adjustment for clinical characteristics, the occurrence of any adverse event or in-hospital death increased from 2.8% in the youngest age group (under 65 years of age) to 4.5% in the oldest age groups (80 years and older). After multivariate adjustment, advanced age was associated with only a modestly increased risk of periprocedural complications and in-hospital death. Comorbid conditions were as important, or even more so, than age in determining complication risks.

With the aging population, it is not surprising that the average age of the current ICD recipient is above 65 years of age.[11,12] However, other comorbidities may also increase with age and predispose patients to procedural complications. Prior studies have reported ICD complication rates as high as 10% to 40%,[7,16–18,22] making some physicians weary of referring their elderly patients for ICD implant.[28] In our study, we found low complication rates—fewer than 5%— even for individuals older than 80 years of age. Despite the older average age of these patients (age, 67 years), and their multiple risk variables, these patients performed similarly to

patients in the ICD trials,[4,13,29] who were on average 5 to 10 years younger, and had fewer comorbidities. The patients probably benefitted from having received ICDs in recent years[30]—when operators had already gained significant experience with ICD implantation and that the majority of these patients were implanted by electrophysiologists.[30]

Notably, despite trends in underreferral of older patients for ICD implantation,[31–32] we still found that a significant proportion of current ICD recipients were older. Almost half (46%) of the patients were 70 years and older, and more than 15% were 80 years and older, confirming the rapidly expanding demographic of elderly ICD recipients. Such observations are consistent with reports from the ACT Registry,[12] a national registry of patients with St Jude devices. Our study extends the observations from the ACT study by including all current ICD recipients in the US and providing a real-world evaluation in a large cohort. The numbers of elderly ICD recipients will only to continue to grow in the coming years,[9,33] and they probably will require more biventricular devices than the standard ICDs. Given the technical challenge associated with biventricular devices, the trend of decreasing ICD complications[30] is unlikely to continue.

We observed that for all age groups, the majority of complications were minor. These minor complications did not appear to meaningfully impact length of stay, or significantly increase in-hospital mortality. However, the effect on quality of life could not be measured in our study and perhaps can be addressed in future studies.

Table 4. Adjusted Multivariate Analysis of Predictors of Any Adverse Events or Death Related to ICD Implantation

Predictor	OR	95% CI	P Value
Age, y			
65–69	1.02	0.92–1.12	0.76
70–74	1.08	0.98–1.19	0.11
75–79	1.14	1.03–1.25	<0.05
80–84	1.22	1.10–1.36	<0.001
≥85	1.15	1.01–1.32	<0.05
Women	1.31	1.24–1.39	<0.001
Black	1.14	1.05–1.24	<0.01
Congestive heart failure			
NYHA class II vs I	0.92	0.81–1.05	0.23
NYHA class III vs I	1.15	1.01–1.31	<0.05
NYHA class IV vs I	1.38	1.17–1.63	<0.001
Atrial fibrillation or flutter	1.20	1.13–1.27	<0.001
Cerebrovascular disease	1.14	1.06–1.23	<0.001
Chronic lung disease	1.20	1.13–1.28	<0.001
QRS duration	1.02	1.01–1.03	<0.001
2nd- or 3rd-Degree AV block	1.27	1.12–1.44	<0.001
End-stage renal disease on hemodialysis	1.50	1.33–1.70	<0.001
Type of ICD			
Dual chamber vs single chamber	1.57	1.43–1.72	<0.001
Biventricular vs single chamber	1.96	1.78–2.16	<0.001
Physician certification			
Surgeon vs board-certified electrophysiologist	1.49	1.24–1.79	<0.001
Nonelectrophysiologist cardiologist vs board-certified electrophysiologist	1.20	1.08–1.34	<0.001
Other specialist vs board-certified electrophysiologist	1.18	1.03–1.35	<0.05
In-hospital for cardiac reason vs device implantation	1.33	1.22–1.44	<0.001
In-hospital for noncardiac reason vs device implantation	1.27	1.17–1.38	<0.001

OR indicates odds ratio; CI, confidence interval; NYHA, New York Heart Association; AV, atrioventricular; and ICD, implantable cardioverter-defibrillator.

One important finding of our study was the identification of multiple cardiac and noncardiac conditions, besides age, that increase perioperative complications. Consistent with prior investigations,[11,30,34,35] we found that female sex, those who received ICDs with cardiac resynchronization therapy, and device implantation by nonelectrophysiologists were associated with higher perioperative complications, and were even stronger predictors of complications than advance age. Comorbidities, including end-stage renal disease, stage IV heart failure, atrial fibrillation, and advanced heart block, were also stronger predictors of complications than advanced age. Consistent with clinical experience, we found that patients who received ICDs in the latter portion of a hospitalization precipitated by cardiac and noncardiac reasons were more likely to have complications than patients hospitalized primarily for device implant, an observation reflecting the higher morbidity of the former group of patients. These

findings confirm clinical experience that patients should not be excluded from ICD consideration, based on age alone. Clinicians must weigh the number and severity of comorbid conditions—both observed here and perhaps, some not captured in our dataset—even more so than age when deciding the potential complication risks in older patients.

Interestingly, although women tend to live longer and their risk of coronary heart disease increases with age,[36] the proportion of female ICD recipients did not increase with age. This observation appears to support observations of ICD underutilization among women[37] and probably are multifactorial. Potential explanations include more stringent application of ICD guidelines to women,[38] higher complication rates among women,[30,34] or presentation of women with coronary disease at an older age (and with more comorbidities), leading to a higher threshold for referral.

Finally, few data are available on the impact of age on length of stay after ICD implant. Similar to other types of procedures,[39] we found that age was associated with a longer length of stay. However, the differences were clinically modest. Among patients electively hospitalized for device implantation—which was a more meaningful representation of device-related morbidity—these differences were clinically insignificant. The lack of clinically meaningful variations in hospital stay likely reflected the low rates of major events and deaths overall, and in each of the age groups.

Our study had several limitations. First, the data were obtained from a national database that required mandatory enrollment only of Medicare beneficiaries. Therefore, to generate a study cohort representative of the community, we confined analysis to hospitals who submitted data on both Medicare and non-Medicare beneficiaries. Second, we examined only in-hospital complications and mortality. We were unable to capture complications, such as infection or lead failure, which develop after hospital discharge. However, evaluating this early time window allowed us to evaluate complication rates related to implantation, which are important for decision-making. Third, we did not include lead complications (except lead dislodgment), given the short follow-up, but instead a comprehensive list of other implantation-related adverse events was evaluated. Finally, our database consisted only of patients who had received ICD implants. Potentially, not all the preselection factors may have been captured by the covariates in the dataset. Complication rates depend on patient case selection, and we cannot exclude the possibility that complication rates were decreased in practice because ICD use was restricted to seemingly healthier, older adults. Nevertheless, our dataset has broad representativeness for actual ICD use in older adults. It includes near-complete data on the large number of ICD recipients over age 65 nationally, and rates are probably up to date and accurate, since these rates are not publicly reported and centers had little incentive to underreport adverse events.

Conclusions
Our study offers a real-world evaluation of ICD implantation-related complications among the US elderly. After adjusting for various clinical, device-related, and operator characteristics, patients 75 years and older have an increased, but

acceptably safe, risk of periprocedural complications, including in-hospital mortality, some of which is explained by observed comorbidity and some perhaps by unobserved comorbidity. Nevertheless, these results should not preclude elderly patients from receiving ICDs, but provide much needed information for elderly patients who are eligible for ICD therapy, so that an individualized decision can be reached.

References

1. Curtis LH, Al-Khatib SM, Shea AM, Hammill BG, Hernandez AF, Schulman KA. Sex differences in the use of implantable cardioverter-defibrillators for primary and secondary prevention of sudden cardiac death. *JAMA*. 2007;298:1517–1524.
2. Lee DS, Tu JV, Austin PC, Dorian P, Yee R, Chong A, Alter DA, Laupacis A. Effect of cardiac and noncardiac conditions on survival after defibrillator implantation. *J Am Coll Cardiol*. 2007;49:2408–2415.
3. Sweeney MO, Hellkamp AS, Ellenbogen KA, Lamas GA. Reduced ejection fraction, sudden cardiac death, and heart failure death in the mode selection trial (most): implications for device selection in elderly patients with sinus node disease. *J Cardiovasc Electrophysiol*. 2008;19:1160–1166.
4. Bardy GH, Lee KL, Mark DB, Poole JE, Packer DL, Boineau R, Domanski M, Troutman C, Anderson J, Johnson G, McNulty SE, Clapp-Channing N, Davidson-Ray LD, Fraulo ES, Fishbein DP, Luceri RM, Ip JH. Amiodarone or an implantable cardioverter-defibrillator for congestive heart failure. *N Engl J Med*. 2005;352:225–237.
5. Chan PS, Nallamothu BK, Spertus JA, Masoudi FA, Bartone C, Kereiakes DJ, Chow T. Impact of age and medical comorbidity on the effectiveness of implantable cardioverter-defibrillators for primary prevention. *Circ Cardiovasc Qual Outcomes*. 2009;2:16–24.
6. Huang DT, Sesselberg HW, McNitt S, Noyes K, Andrews ML, Hall WJ, Dick A, Daubert JP, Zareba W, Moss AJ. Improved survival associated with prophylactic implantable defibrillators in elderly patients with prior myocardial infarction and depressed ventricular function: A MADIT-II substudy. *J Cardiovasc Electrophysiol*. 2007;18:833–838.
7. Groeneveld PW, Farmer SA, Suh JJ, Matta MA, Yang F. Outcomes and costs of implantable cardioverter-defibrillators for primary prevention of sudden cardiac death among the elderly. *Heart Rhythm*. 2008;5:646–653.
8. Day JC. Population projections of the united states by age, sex, race, and Hispanic origin: 1995 to 2050. *Curr Population Rep*. 1996:25–1130.
9. Federal Interagency Forum on Aging-Related Statistics. Older Americans 2008: Key indicators of well-being. Federal Interagency Forum on Aging-Related Statistics. 2008:1–149.
10. Kurtz SM, Ochoa JA, Lau E, Shkolnikov Y, Pavri BB, Frisch D, Greenspon AJ. Implantation trends and patient profiles for pacemakers and implantable cardioverter defibrillators in the united states: 1993–2006. *Pacing Clin Electrophysiol*. 2010;33:705–711.
11. Curtis JP, Luebbert JJ, Wang Y, Rathore SS, Chen J, Heidenreich PA, Hammill SC, Lampert RI, Krumholz HM. Association of physician certification and outcomes among patients receiving an implantable cardioverter-defibrillator. *JAMA*. 2009;301:1661–1670.
12. Epstein AE, Kay GN, Plumb VJ, McElderry HT, Doppalapudi H, Yamada T, Shafiroff J, Syed ZA, Shkurovich S. Implantable cardioverter-defibrillator prescription in the elderly. *Heart Rhythm*. 2009;6:1136–1143.
13. Moss AJ, Zareba W, Hall WJ, Klein H, Wilber DJ, Cannom DS, Daubert JP, Higgins SL, Brown MW, Andrews ML. Prophylactic implantation of a defibrillator in patients with myocardial infarction and reduced ejection fraction. *N Engl J Med*. 2002;346:877–883.
14. Buxton AE, Lee KL, DiCarlo L, Gold MR, Greer GS, Prystowsky EN, O'Toole MF, Tang A, Fisher JD, Coromilas J, Talajic M, Hafley G. Electrophysiologic testing to identify patients with coronary artery disease who are at risk for sudden death: Multicenter Unsustained Tachycardia Trial Investigators. *N Engl J Med*. 2000;342:1937–1945.
15. Moss AJ, Hall WJ, Cannom DS, Daubert JP, Higgins SL, Klein H, Levine JH, Saksena S, Waldo AL, Wilber D, Brown MW, Heo M. Improved survival with an implanted defibrillator in patients with coronary disease at high risk for ventricular arrhythmia. Multicenter automatic defibrillator implantation trial investigators. *N Engl J Med*. 1996;335:1933–1940.
16. Grimm W, Stula A, Sharkova J, Alter P, Maisch B. Outcomes of elderly recipients of implantable cardioverter defibrillators. *Pacing Clin Electrophysiol*. 2007;30(Suppl 1):S134–S138.
17. Duray G, Richter S, Manegold J, Israel CW, Gronefeld G, Hohnloser SH. Efficacy and safety of ICD therapy in a population of elderly patients treated with optimal background medication. *J Interv Card Electrophysiol*. 2005;14:169–173.
18. Noseworthy PA, Lashevsky I, Dorian P, Greene M, Cvitkovic S, Newman D. Feasibility of implantable cardioverter defibrillator use in elderly patients: a case series of octogenarians. *Pacing Clin Electrophysiol*. 2004;27:373–378.
19. Ermis C, Zhu AX, Vanheel L, Sakaguchi RN, Lurie KG, Lu F, Benditt DG. Comparison of ventricular arrhythmia burden, therapeutic interventions, and survival, in patients <75 and patients ≥75 years of age treated with implantable cardioverter defibrillators. *Europace*. 2007;9:270–274.
20. Pellegrini CN, Lee K, Olgin JE, Turakhia MP, Tseng ZH, Lee R, Badhwar N, Lee B, Varosy PD. Impact of advanced age on survival in patients with implantable cardioverter defibrillators. *Europace*. 2008;10:1296–1301.
21. Panotopoulos PT, Axtell K, Anderson AJ, Sra J, Blanck Z, Deshpande S, Biehl M, Keelan ET, Jazayeri MR, Akhtar M, Dhala A. Efficacy of the implantable cardioverter-defibrillator in the elderly. *J Am Coll Cardiol*. 1997;29:556–560.
22. Reynolds MR, Cohen DJ, Kugelmass AD, Brown PP, Becker ER, Culler SD, Simon AW. The frequency and incremental cost of major complications among Medicare beneficiaries receiving implantable cardioverter-defibrillators. *J Am Coll Cardiol*. 2006;47:2493–2497.
23. Haqqani HM, Mond HG. The implantable cardioverter-defibrillator lead: principles, progress, and promises. *Pacing Clin Electrophysiol*. 2009;32:1336–1353.
24. Swindle JP, Rich MW, McCann P, Burroughs TE, Hauptman PJ. Implantable cardiac device procedures in older patients: use and in-hospital outcomes. *Arch Intern Med*. 2010;170:631–637.
25. Hammill SC, Stevenson LW, Kadish AH, Kremers MS, Heidenreich P, Lindsay BD, Mirro MJ, Radford MJ, Wang Y, Lang CM, Harder JC, Brindis RG. Review of the registry's first year, data collected, and future plans. *Heart Rhythm*. 2007;4:1260–1263.
26. Anderson HV, Shaw RE, Brindis RG, Hewitt K, Krone RJ, Block PC, McKay CR, Weintraub WS. A contemporary overview of percutaneous coronary interventions: the American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR). *J Am Coll Cardiol*. 2002;39:1096–1103.
27. Schafer JL. Multiple imputation: A primer. *Stat Methods Med Res*. 1999;8:3–15.
28. Yarnoz MJ, Curtis AB. Why cardioverter-defibrillator implantation might not be the best idea for your elderly patient. *Am J Geriatr Cardiol*. 2006;15:367–371.
29. Kadish A, Dyer A, Daubert JP, Quigg R, Estes NA, Anderson KP, Calkins H, Hoch D, Goldberger J, Shalaby A, Sanders WE, Schaechter A, Levine JH. Prophylactic defibrillator implantation in patients with nonischemic dilated cardiomyopathy. *N Engl J Med*. 2004;350:2151–2158.
30. Al-Khatib SM, Greiner MA, Peterson ED, Hernandez AF, Schulman KA, Curtis LH. Patient and implanting physician factors associated with mortality and complications after implantable cardioverter-defibrillator implantation, 2002–2005. *Circ Arrhythm Electrophysiol*. 2008;1:240–249.

31. Chae SH, Koelling TM. Patient and physician determinants of implantable cardioverter defibrillator use in the heart failure population. *Congest Heart Fail*. 2010;16:141–146.

32. Voigt A, Ezzeddine R, Barrington W, Obiaha-Ngwu O, Ganz LI, London B, Saba S. Utilization of implantable cardioverter-defibrillators in survivors of cardiac arrest in the united states from 1996 to 2001. *J Am Coll Cardiol*. 2004;44:855–858.

33. Day J. Population projections of the United States, by age, sex, race, and Hispanic origin: 1993 to 2050. Washington, DC: U.S. Government Printing Office; 1993:1104.

34. Peterson PN, Daugherty SL, Wang Y, Vidaillet HJ, Heidenreich PA, Curtis JP, Masoudi FA. Gender differences in procedure-related adverse events in patients receiving implantable cardioverter-defibrillator therapy. *Circulation*. 2009;119:1078–1084.

35. Lee D, Krahn AD, Healey JS, Birnie D, Crystal E, Dorian P, Simpson C, Khaykin Y, Cameron D, Janmohamed A, Yee J, Austin PC, Chen Z, Hardy J, Tu JV. Evaluation of early complications related to de novo cardioverte defibrillator implantation: insights from the Ontario ICD Database. *J Am Coll Cardiol*. 2010;55:774–782.

36. Lloyd-Jones D, Adams R, Carnethon M, De Simone G, Ferguson TB, Flegal K, Ford E, Furie K, Go A, Greenlund K, Haase N, Hailpern S, Ho M, Howard V, Kissela B, Kittner S, Lackland D, Lisabeth L, Marelli A, McDermott M, Meigs J, Mozaffarian D, Nichol G, O'Donnell C, Roger V, Rosamond W, Sacco R, Sorlie P, Stafford R, Steinberger J, Thom T, Wasserthiel-Smoller S, Wong N, Wylie-Rosett J, Hong Y. Heart disease and stroke statistics: 2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. *Circulation*. 2009;119:480–486.

37. Gauri AJ, Davis A, Hong T, Burke MC, Knight BP. Disparities in the use of primary prevention and defibrillator therapy among blacks and women. *Am J Med*. 2006;119:167 e117–e121.

38. Daugherty SL, Peterson PN, Wang Y, Curtis JP, Heidenreich PA, Lindenfeld J, Vidaillet HJ, Masoudi FA. Use of implantable cardioverter defibrillators for primary prevention in the community: do women and men equally meet trial enrollment criteria? *Am Heart J*. 2009;158:224–229.

39. Polanczyk CA, Marcantonio E, Goldman L, Rohde LE, Orav J, Mangione CM, Lee TH. Impact of age on perioperative complications and length of stay in patients undergoing noncardiac surgery. *Ann Intern Med*. 2001; 134:637–643.

Appendix – Definitions of Adverse Events

ICD Registry™

Cardiac Arrest: Sudden cessation of cardiac activity so that the patient became unresponsive, with no normal breathing and no signs of circulation.

Drug Reaction: Anaphylaxis, rash, etc.

Cardiac Perforation: Migration of pacing or defibrillator lead to epicardial surface, resulting in pain, pericardial effusion, failure to capture, capture of diaphragm, phrenic nerve, or intercostals muscle of sufficient magnitude to require repositioning.

Cardiac Valve Injury: Manipulation of pacing or defibrillating leads that may tear a valve leaflet or chordae tendinae (usually manifests as a new regurgitant murmur appearing after the procedure).

Conduction Block: Injury parts of the specialized cardiac conducting system from manipulation of pacing or defibrillating leads. (Usually manifest as a new RBBB or new on set of complete heart block in a person with preexisting LBBB).

Coronary Venous Dissection: Manipulation of pacing or defibrillating leads in the coronary sinus (CS) leading to tear of the CS endothelium, with dissection into the CS wall. Occasionally result in perforation of the CS.

Hematoma: Hematoma resulting in re-operation or transfusion.

Lead Dislodgement: Movement of lead sufficient to require repositioning.

Hemothorax: As documented by accumulation of blood in thorax.

Pneumothorax: Air in thorax sufficient to require chest tube.

Peripheral Nerve Injury: Sensory or motor loss of peripheral nerve function. This may result from external nerve compression as a result of positioning during an implantation procedure, internal compression (e.g. secondary to hematoma formation) or direct nerve injury.

Peripheral Embolus: Acute occlusion of an artery resulting from embolization of a cardiac or proximal arterial thrombus.

Phlebitis – Superficial: As documented by signs of superficial venous inflammation, such as local erythema, tenderness or swelling.

Phlebitis – Deep: As documented by occlusion of deep vein resulting in extremity swelling, plus or minus signs of inflammation.

TIA: Loss of neurological function that was abrupt in onset but with complete return of function within 24 hours.

CVA/Stroke: Central neurologic deficit persisting > 72 hours after onset.

Pericardial Tamponade: Fluid in the pericardial space compromising cardiac filling, and requiring intervention as documented by either: 1) Echo showing pericardial fluid and signs of tamponade such as right heart compromise, or 2) Systemic hypotension due to pericardial fluid compromising cardiac function.

AV Fistula: A connection between the access artery and the accompanying vein that is demonstrated by arteriography or ultrasound and often characterized by a continuous bruit.

Infection Related to Device: Infection related to the device.

MI: MI during the EP lab visit or after lab visit until discharge (or before any subsequent lab visits) as documented by:

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NON ST ELEVATION MYOCARDIAL INFARCTION (NSTEMI)

AT LEAST ONE OF THE FOLLOWING BIOCHEMICAL INDICATORS for detecting

myocardial necrosis must be present:

1) Troponin T or I: Maximal concentration of troponin T or I > the MI decision limit on at least one occasion during the first 24 hours after the index clinical event.

2) CK-MB: Maximal value of CK-MB > 2 x the upper limit of normal on one occasion during the first hours after the index clinical event. OR Maximal value of CK-MB, preferable CK-MB mass, > upper limit of normal on two successive samples.

3) Total CK: In the absence of availability of a troponin or CK-MB assay, total CK > 2 x the upper limit of normal, or the B fraction of CK may be employed, but these last two biomarkers are considerably less satisfactory than CK-MB.

AND ONE OF THE FOLLOWING:

1) Either ST segment depression or T wave abnormalities; or

2) Ischemic symptoms in the presence or absence of chest discomfort. Ischemic symptoms

may include:

    a) unexplained nausea and vomiting; or

    b) persistent shortness of breath secondary to left ventricular failure; or

    c) unexplained weakness, dizziness, lightheadedness, or syncope.

ST ELEVATION MYOCARDIAL INFARCTION (STEMI)

AT LEAST ONE OF THE FOLLOWING BIOCHEMICAL INDICATORS for detecting

myocardial necrosis must be present (Reference Control Limits as above):

1) Troponin T or I

2) CK-MB

3) Total CK

3

AND ONE OF THE FOLLOWING ECG CHANGES:

1) ST-segment elevation: New or presumed new ST segment elevation at the J point in two

or more contiguous leads with the cut-off points >=0.2 mV in leads V1, V2, or V3, or >=0.1

mV in other leads; OR

2) Development of any Q wave in leads V1 through V3, or the development of a Q-wave > or

= to 30 ms (0.03s) in leads I, II, aVL, aVF, V4, V5, or V6. (Q wave changes must be

present in any two contiguous leads, and be > or = to 1mm in depth.)

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