Physician Procedure Volume and Complications of Cardioverter-Defibrillator Implantation

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Background—The outcomes of procedures are often better when they are performed by more experienced physicians. We assessed whether the rate of complications after implantable cardioverter-defibrillator (ICD) placement varied with the volume of procedures a physician performed.

Methods and Results—We studied 356 515 initial ICD implantations in the National Cardiovascular Data Registry–ICD Registry, performed by 4011 physicians in 1463 hospitals. We examined the relationship between physician annual ICD implantation volume and in-hospital complications, using hierarchical logistic regression to adjust for patient characteristics, implanting physician certification, hospital characteristics, hospital annual procedure volume, and the clustering of patients within hospitals and by physician. We repeated this analysis for ICD subtypes: single chamber, dual chamber, and biventricular. There were 10 994 patients (3.1%) with a complication after ICD implantation, and 1375 died (0.39%). The complication rate decreased with increasing physician procedure volume from 4.6% in the lowest quartile to 2.9% in the highest quartile ($P<0.0001$), and the mortality rate decreased from 0.72% to 0.36% ($P<0.0001$). The inverse relationship between physician procedure volume and complications remained significant after adjusting for patient, physician, and hospital characteristics (OR 1.55 for complications in lowest-volume quartile compared with highest; 95% confidence interval, 1.34–1.79; $P<0.0001$). This inverse relationship was independent of physician specialty and of hospital volume, was consistent across ICD subtypes, and was also evident for in-hospital mortality.

Conclusion—Physicians who implant more ICDs have lower rates of procedural complications and in-hospital mortality, independent of hospital procedure volume, physician specialty, and ICD type. **(*Circulation*. 2012;125:57-64.)**

Key Words: defibrillation ■ epidemiology ■ morbidity ■ mortality

Physicians who perform more procedures generally have fewer complications and better clinical outcomes. Among cardiovascular procedures, the inverse relationship between procedural volume and outcomes has been most consistently shown for coronary artery bypass surgery and percutaneous coronary interventions.[1–16] Several studies have shown that higher physician volume of pacemaker implantations is associated with improved outcomes,[17–21] which suggests that a similar relationship may exist for implantable cardioverter-defibrillators (ICDs). The only prior study of this question analyzed Medicare claims of 9854 patients who received an initial ICD between 1999 and 2001 and showed that higher physician procedure volume was associated with fewer mechanical complications and infections, but not with death, within 90 days after ICD implantation.[22] However, that study was based on a relatively early experience with ICD implantation and may not apply to contemporary practice, which has included the increased use of biventricular ICDs since 2002.[23] Implantation of biventricular ICDs, which now constitutes almost 40% of all ICDs, is more complex, and procedural complications may be particularly dependent on the experience of the implanting physician. In addition, this earlier study did not control for the effect of hospital volume of ICD implantation, which we recently demonstrated is inversely associated with procedural complications.[24] Finally, because this earlier study was in Medicare beneficiaries, it did not include younger patients and was based on administrative data, which do not have the strict data quality standards of large clinical registries and do not capture the full range of procedural complications.

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We therefore analyzed the most recent experience of the National Cardiovascular Data Registry (NCDR) ICD Registry to examine the relationship between physician procedure volume and in-hospital complications and death in a large contemporary population controlling for confounding factors such as patient clinical characteristics, hospital volume, and

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physician specialty. We further evaluated whether the relationship between physician volume and outcome was consistent in all ICD subtypes, including single-chamber, dual-chamber, and biventricular ICDs.

Methods

The NCDR ICD Registry was initiated in 2006. Although hospitals are required to submit data only on ICD implantations for primary prevention among Medicare patients, 80% of hospitals submit data on all ICD implantations performed, irrespective of the payor or clinical indication. As described in detail elsewhere,[25–27] clinical, demographic, and procedural data are recorded using a standardized format based on established data definitions. Data on any in-hospital adverse events related to the procedure are recorded in the ICD Registry; long-term follow-up data are not available currently.

For the purposes of this study, we examined all patients who had an ICD implanted between April 2006 and March 2010. Participating hospitals met the data quality standards established by the NCDR of 95% completeness of specific core data elements and participation in the site auditing program (annual on-site chart review and data abstraction for at least 5% of participating sites).[27] A priori, we excluded patients who had a previous ICD or who required epicardial lead placement because the complications of these procedures were likely to differ from those of initial ICD implantations and were more likely than initial implantations to be performed by specialty physicians. The primary outcome for this study was any adverse event that occurred during the implantation or preceding hospital discharge. Major adverse events were defined a priori as cardiac arrest, cardiac perforation, valve injury, coronary venous dissection, hemothorax, pneumothorax, deep vein thrombosis, transient ischemic attack, stroke, myocardial infarction, pericardial tamponade, and arteriovenous fistula. Any adverse event included these major adverse events, as well as drug reaction, conduction block, hematoma, lead dislodgement, peripheral embolus, superficial phlebitis, peripheral nerve injury, and device-related infection.

We identified physicians who implanted ICDs by their National Provider Identifier number. We used the hospital and physician National Provider Identifier database created by the Centers for Medicare and Medicaid Services[28] to verify identifiers by cross-referencing them with the Unique Physician Identifier Number and physician names. We collected data on physician certification by searching the databases of the American Board of Internal Medicine, the Society for Thoracic Surgery, and the American College of Surgery.[26] We categorized physicians as electrophysiologists, non-electrophysiologist cardiologists ("cardiologists"), thoracic surgeons ("surgeons"), physicians who met the training standards for ICD implantation promulgated by the Heart Rhythm Society,[29,30] or none of the above. We annualized physician procedure volume by dividing the total number of ICD implantations a physician performed by the number of years the physician contributed data to the NCDR ICD Registry. We ranked physicians by their annualized ICD implantation volume and divided them into quartiles of increasing procedure volume for analysis.

Statistical Methods

We evaluated the baseline patient clinical characteristics, implanting physician certification, and hospital characteristics among quartiles of physician annual procedure volume using ANOVA for continuous variables and the χ^2 test for categorical variables. We compared the crude rate of adverse events stratified by quartiles of physician annual ICD volume. We used the Cochran-Armitage test to assess the trend across quartiles for the overall quartiles and then stratified by subtype of ICD. In the primary analysis, we used hierarchical logistic regression to test for a declining rate of adverse events with increasing physician procedure volume for the overall cohort, unadjusted for other characteristics. We repeated this analysis sequentially adjusting for patient characteristics (demographics, medical history, diagnostics), physician certification (electrophysiology board certified, electrophysiology fellowship, surgery board certified, Heart Rhythm Society guidelines, none), hospital characteristics (number of beds, teaching status, urban location), and finally hospital annual procedure volume and patient clustering by hospital and physician. In a secondary analysis, we performed the same fully adjusted hierarchical logistical regression for each of the ICD subtypes (single chamber, dual chamber, and biventricular) to evaluate the consistency of the relationship between physician volume and outcome according to the type of ICD implanted.

To evaluate whether the relationship between physician ICD procedure volume and adverse events was independent of physician training and hospital volume, we evaluated the rate of complications stratified by quartiles of physician annual procedure volume and then stratified by categories of physician training and hospital volume. To further separate the effect of physician factors from hospital factors on the rate of adverse events, we compared the rate of adverse events for ICD implantations that were performed by the same physician at different hospitals. We identified the 2 hospitals in which each physician performed the most ICD implantations and designated the hospital with the greater number of ICD implantations as the higher-volume hospital (mean hospital volume, 97) and the second hospital as the lower-volume hospital (mean hospital volume, 23). The Human Investigation Committee of the Yale University School of Medicine approved the use of data from the ICD Registry for research purposes.

Results

Between April 2006 and March 2010, 4375 physicians performed 510 835 ICD implantations for 498 379 patients at 1 of the 1473 hospitals participating in the ICD Registry. After exclusion of 8258 patients who had epicardial leads implanted, 133 363 patients who had previously undergone ICD implantation and 243 patients with an ICD implantation by a physician who could not be identified, the study population consisted of 4011 physicians who performed 356 515 initial ICD implantations at 1 of 1463 hospitals.

Physician annualized ICD procedure volume varied widely, with a median of 16 implantations per year (interquartile range 4–37). Clinical characteristics of patients varied somewhat by physician ICD procedure volume (Table 1). Patients who had an ICD implanted by a physician in the highest quartile of volume were slightly older, more likely to have a diagnosis of congestive heart failure, and more likely to have more severe heart failure symptoms (New York Heart Association functional class III–IV). Other clinical differences were small in absolute terms (<2%) yet were statistically significant because of the large sample size in the study. More of the high-volume physicians were board-certified cardiac electrophysiologists. In addition, implantations performed by high-volume physicians were more likely to be done at hospitals that were teaching institutions located in urban areas that had more patient beds.

Overall, 10 994 patients (3.1%) had an in-hospital adverse event after ICD implantation, 4170 (1.2%) experienced a major adverse event, and 1375 died (0.4%). The rate of adverse events was lower among patients who received a single-chamber ICD (1.9%) than among patients who received a dual-chamber ICD (2.9%) or a biventricular ICD (4.1%). The most common adverse events (Table 2) were lead dislodgement (1.0%), hematoma (0.9%), pneumothorax (0.4%), and cardiac arrest (0.3%).

The unadjusted rate of any adverse event declined significantly (P-trend <0.0001) with increasing physician procedure volume (Table 3 and the Figure). The inverse relationship between physician procedure volume and clinical

Table 1. Baseline Characteristics Stratified by Quartiles of Physician Annual ICD Volume

Baseline Characteristic Description	Overall (N=356 515)	Quartile of Physician Annual ICD Volume Q1 (≤4) (N=4973)	Q2 (4–15.5) (N=28 613)	Q3 ((15.5–37.25) (N=88 127)	Q4 (>37.25) (N=234 802)	*P*
Patient demographics						
Age, mean, y	67.3	66.8	67.6	67.3	67.3	<0.0001
Gender, female	27.3	26.1	27.0	27.2	27.3	0.16
Nonwhite race	18.9	19.6	19.9	19.0	18.7	<0.0001
<Hispanic ethnicity	5.4	9.3	6.5	6.9	4.6	<0.0001
Insurance payor						<0.0001
Medicare	64.9	68.1	68.5	66.0	63.9	
Medicaid	5.1	6.3	5.5	5.1	5.0	
Commercial	18.7	14.6	16.3	17.6	19.5	
Health maintenance organization	7.0	6.7	5.7	7.2	7.1	
Patient history and risk factors						
Syncope	19.2	19.1	18.2	19.2	19.4	0.0001
Congestive heart failure	77.4	71.7	75.4	76.1	78.3	<0.0001
NYHA class, current status						<0.0001
Class I	12.5	15.9	13.1	13.6	12.0	
Class II	35.9	36.3	36.5	36.0	35.7	
Class III	47.5	41.1	44.9	45.9	48.6	
Class IV	4.1	6.7	5.4	4.5	3.7	
Atrial fibrillation/atrial flutter	31.4	30.5	31.2	30.8	31.6	0.0001
Nonischemic dilated cardiomyopathy	33.0	30.0	31.9	32.5	33.3	<0.0001
Ischemic heart disease	63.9	63.7	63.6	63.2	64.3	<0.0001
Previous myocardial infarction	52.1	51.2	50.9	51.2	52.6	<0.0001
Previous revascularization	32.9	33.6	32.8	32.1	33.2	<0.0001
Previous pacemaker	10.7	10.1	10.7	10.5	10.7	0.10
Cerebrovascular disease	14.5	15.1	15.1	14.0	14.6	<0.0001
Chronic lung disease	23.0	24.1	23.5	22.5	23.1	0.0001
Diabetes mellitus	37.4	35.7	37.3	37.0	37.6	0.0005
Hypertension	76.5	75.6	76.0	75.2	77.1	<0.0001
Renal failure-dialysis	4.1	4.4	4.6	4.2	4.0	0.0001
Patient diagnostic and ICD data						
Ejection fraction, mean	27.9	28.1	27.8	28.1	27.8	<0.0001
Electrophysiology study done	13.9	8.7	8.5	11.5	15.5	<0.0001
QRS duration categories						<0.0001
QRS <120 ms	50.5	57.1	52.6	50.4	50.2	
QRS ≥120 to QRS <140 ms	16.3	16.0	16.1	16.4	16.3	
QRS ≥140 ms	33.2	26.9	31.3	33.2	33.5	
Creatinine level, mean, mg/dL	1.37	1.39	1.40	1.38	1.37	0.0003
ICD indication: primary prevention	82.4	80.7	83.3	82.5	82.3	<0.0001
ICD type						<0.0001
Single chamber	23.3	30.3	27.1	24.9	22.2	
Dual chamber	41.7	51.2	46.4	42.8	40.5	
Biventricular	34.8	18.4	26.3	32.2	37.2	

(*Continued*)

Table 1. Continued

Baseline Characteristic Description	Overall (N=356 515)	Quartile of Physician Annual ICD Volume Q1 (≤4) (N=4973)	Q2 (4–15.5) (N=28 613)	Q3 ((15.5–37.25) (N=88 127)	Q4 (>37.25) (N=234 802)	P
Implanting physician certification						
Physician certification						<0.0001
EP board certified	76.8	20.8	34.1	68.2	86.4	
EP fellowship only	5.8	3.5	4.5	7.1	5.5	
Surgery board certified	1.8	26.3	9.3	1.9	0.3	
HRS guideline trained	9.6	24.1	32.0	16.0	4.2	
None of the above	6.0	24.6	20.0	6.6	3.6	
Hospital characteristics						
Ownership						<0.0001
Government	1.6	3.6	2.7	2.3	1.2	
Private/community	84.6	87.2	83.3	79.0	86.8	
University	13.8	9.1	14.0	18.7	12.0	
Location						<0.0001
Rural	10.1	16.1	17.7	12.2	8.3	
Suburban	27.9	27.5	25.0	26.6	28.8	
Urban	61.9	56.4	57.4	61.2	62.9	
Patient beds, mean	478	406	427	475	487	<0.0001
Teaching Hospital	54.9	40.9	45.4	54.3	56.6	<0.0001

ICD indicates implantable cardioverter-defibrillator; Q, quartile; NYHA, New York Heart Association; EP, electrophysiology; HRS, Heart Rhythm Society.

outcomes was also evident when the analysis was restricted to major adverse events (*P*-trend <0.0001, Table 3) and to mortality (*P*-trend <0.0001, Table 3). The overall inverse relationship between physician ICD volume and any adverse event remained statistically significant after successive adjustments for patient characteristics, implanting physician characteristics, hospital characteristics, and hospital procedure volume (Table 4). The inverse relationship between physician ICD volume and periprocedural mortality also remained significant ($P<0.05$) after full adjustment.

We repeated the analysis of physician procedure volume and outcomes using different specifications for volume. The inverse relationship between physician procedure volume and any adverse event remained significant ($P<0.0001$) when volume was analyzed as a continuous variable and also when physician procedure volume was classified using alternative volume categories (≤30; >30 and ≤51; >51 and ≤75; and >75) with roughly equal numbers of procedures in each category. These results remained significant ($P<0.0001$) even after adjustment for patient characteristics, implanting physician characteristics, hospital characteristics, and hospital volume.

Physician Specialty and Adverse Events

Because physician specialty has been previously shown to affect adverse events after ICD implantation,[26] we examined the relationship between ICD procedure volume and outcomes among physicians with different types of training (Table 5). An inverse relationship between procedure volume and adverse events was evident for all types of physician training except for surgeons, a group with a relatively small sample size (404 total, with only 4 surgeons in the highest volume quartile) (Table 5). There was no significant interaction between physician procedure volume and physician

Table 2. Most Common Adverse Events (per 100 Patients), Overall and by ICD Type

Type of Complication	Overall	Single Chamber	Dual Chamber	Biventricular
All complications (N=10 994)	3.08	1.88	2.89	4.13
Lead dislodgement (N=3634)	1.02	0.47	0.90	1.53
Hematoma (N=3056)	0.86	0.58	0.77	1.15
Pneumothorax (N=1579)	0.44	0.34	0.46	0.49
Cardiac arrest (N=1042)	0.29	0.23	0.29	0.34
Coronary venous dissection (N=432)	0.12	0.01	0.10	0.22
No. of Patients*	356 515	83 191	148 723	124 108

ICD indicates implantable cardioverter-defibrillator.
*Data on ICD type missing in 493 patients.

Table 3. Rate of Adverse Events (per 100 Patients) by Physician ICD Volume and ICD Type

Type Of Device and Adverse Event	Overall	Quartile of Physician Annual ICD Volume				
		Q1 (≤4)	Q2 ((4–15.5)	Q3 (15.5–37.25)	Q4 (>37.25)	*P*-Trend
All ICD Types						
Any complications (N=10 994)	3.08	4.60	3.74	3.39	2.86	<0.0001
Major complications (N=4170)	1.17	1.81	1.56	1.29	1.07	<0.0001
In-hospital death (N=1375)	0.39	0.72	0.51	0.38	0.36	<0.0001
No. of Patients*	356 515	4973	28 613	88 127	234 802	—
Single-chamber ICD						
Any complications (N=1566)	1.88	2.66	2.40	2.12	1.68	<0.0001
Major complications (N=640)	0.77	1.20	1.18	0.81	0.68	<0.0001
In-hospital death (N=230)	0.28	0.53	0.48	0.20	0.27	0.03
No. of Patients*	83 191	1506	7764	21 912	52 009	—
Dual-chamber ICD						
Any complications (N=4293)	2.89	5.10	3.75	3.36	2.52	<0.0001
Major complications (N=1731)	1.16	2.12	1.54	1.39	1.00	<0.0001
In-hospital death (N=590)	0.40	0.71	0.52	0.46	0.35	<0.0001
No. of Patients*	148 723	2548	13 267	37 698	95 210	—
Biventricular ICD						
Any complications (N=5123)	4.13	6.33	5.12	4.41	3.93	<0.0001
Major complications (N=1795)	1.45	1.97	1.96	1.52	1.37	<0.0001
In-hospital death (N=553)	0.45	1.09	0.52	0.43	0.44	0.009
No. of Patients*	124 108	916	7539	28 398	87 255	—

ICD indicates implantable cardioverter-defibrillator; Q, quartile.
*Data on ICD type missing in 493 patients.

specialty (*P*-interaction =0.32) and the occurrence of any adverse event.

Hospital Volume and Adverse Events

Because hospital volume of ICD implantations has been previously shown to affect the rate of adverse procedural events,[22,24] we sought to separate the effect of physician volume from that of hospital volume. This inverse relationship between physician ICD procedure volume and outcome was evident for implantations performed at higher-volume and lower-volume hospitals (Table 5).

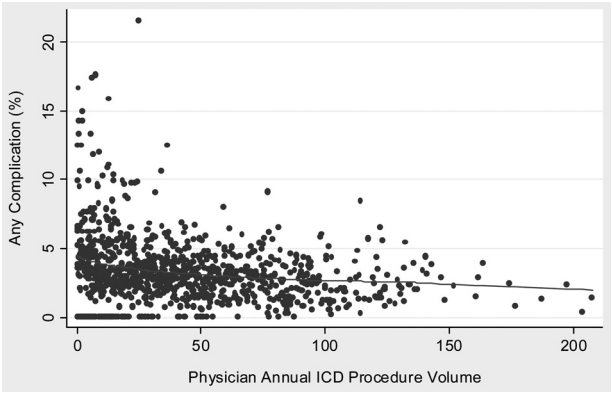

Figure. Unadjusted rate of any complication (vertical axis) by physician annual ICD procedure volume (horizontal axis). The solid line indicates the locally smoothed relationship between physician annual ICD volume and any complication. The unadjusted rate of any complication decreased steadily with increasing physician annual ICD procedure volume, without evidence of nonlinearity or a volume threshold. ICD indicates implantable cardioverter-defibrillator.

Many physicians implanted ICDs at >1 hospital: A total of 1042 physicians (26%) performed ICD implantations at 2 hospitals, 447 physicians (11%) at 3 hospitals, and 384 physicians (10%) at ≥4 hospitals. The rate of any adverse event did not differ statistically (*P*=0.26) when the same physicians performed ICD implantations in the higher-volume hospitals (3.02%) or in lower-volume hospitals (3.12%). The rate of major adverse events (1.10% versus 1.19%, *P*=0.10) and the rate of death (0.38% in 0.37%, *P*=0.67) also did not differ for implantations done in higher-volume versus lower-volume hospitals by the same physicians.

ICD Subtypes and Adverse Events

The inverse relationship between physician procedure volume and in-hospital adverse events was evident for each ICD subtype, including single-chamber (*P*<0.0001), dual-chamber (*P*<0.0001), and biventricular devices (*P*<0.0001). The fully adjusted odds of any adverse event after ICD implantation for the lowest-volume quartile compared with the highest-volume quartile of physicians were similar (interaction *P*=0.16) for dual-chamber ICDs (odds ratio 1.73, confidence interval 1.42 to 2.11), biventricular ICDs (odds ratio 1.42, confidence interval 1.07–1.87), and single-chamber ICDs (odds ratio 1.29, confidence interval 0.93–

Table 4. Odds Ratios of Any Complication Comparing the Lowest 3 Quartiles of Physician Annual ICD Volume With the Highest Volume Quartile*

	Quartile of Physician Annual ICD Volume			
Adjustment Level	Q1 (≤4)	Q2 (4–15.5)	Q3 (15.5–37.25)	*P*-Trend
None	1.59 (1.39–1.82)	1.27 (1.18–1.37)	1.16 (1.10–1.23)	<0.0001
Demographics (1)	1.60 (1.40–1.84)	1.27 (1.18–1.37)	1.16 (1.11–1.23)	<0.0001
+Clinical history (2)	1.60 (1.40–1.84)	1.28 (1.19–1.38)	1.18 (1.12–1.24)	<0.0001
+Test report (3)	1.72 (1.50–1.97)	1.33 (1.24–1.43)	1.20 (1.14–1.26)	<0.0001
+Physician characteristics (4)	1.55 (1.34–1.79)	1.25 (1.15–1.35)	1.17 (1.11–1.23)	<0.0001
+Hospital characteristics (5)	1.56 (1.34–1.80)	1.25 (1.15–1.35)	1.16 (1.10–1.23)	<0.0001
+Hospital volume (6)	1.54 (1.34–1.79)	1.24 (1.14–1.35)	1.16 (1.10–1.22)	<0.0001

*Reference is fourth quartile (≥37.25).

ICD indicates implantable cardioverter-defibrillator; Q, quartile.

(1): Demographics (age, gender, race, and payor status).

(2): Patient history and risk factors (congestive heart failure, New York Heart Association class, cardiac arrest, atrial fibrillation/atrial flutter, ventricular tachycardia, non-ischemic dilated cardiomyopathy, ischemic heart disease, previous myocardial infarction, previous revascularization, previous valvular surgery, cerebrovascular disease, chronic lung disease, diabetes mellitus, hypertension, and renal failure requiring dialysis).

(3): Diagnostic data (left ventricular ejection fraction, QRS duration, blood urea nitrogen, and ICD type).

(4): Implanting physician certification (electrophysiology board certified, surgery boards, pediatric cardiology boards, Heart Rhythm Society guidelines, or none of the above).

(5): Hospital characteristics (geographic location, profit type, community, patient beds, and teaching status).

(6): Hospital annual ICD implantation volume.

1.80). However, the absolute difference in the rate of any complication between the highest and lowest quartiles of procedure volume was larger for biventricular (3.9% versus 6.3%) and dual-chamber devices (2.5% versus 5.1%) than for single-chamber devices (1.7% versus 2.7%).

Discussion

This study demonstrates that the patients treated by physicians who implant ICDs more frequently are less likely to have an in-hospital complication or die as a result of the procedure. This effect was independent of physician specialty training and hospital ICD procedure volume, and the relationship remained significant even after adjusting for patient, physician, and hospital characteristics, as well as for clustering of patients within hospitals and physicians. Furthermore, the inverse relationship between physician volume and outcome was evident for all subtypes of ICDs, including single-chamber, dual-chamber, and biventricular ICDs.

Al-Khatib and associates[22] found physician volume of ICD procedures to be inversely proportional to the risk of mechanical complications and infections at 90 days among 9854 Medicare beneficiaries between 1999 and 2001; however, that study may not apply to contemporary experience with ICD implantation because it was conducted early on the learning curve for ICD implantation: In 2009, there were over twice as many ICDs implanted in the United States than in 2000.[23] In addition, implantation of biventricular ICDs was infrequent before 2002, and these devices now constitute nearly 40% of ICD implantations in the United States. Biventricular ICDs require cannulation of the coronary sinus and placement of an additional lead and as a consequence have a 2-fold higher complication rate than single-chamber

Table 5. Rate of Adverse Events (per 100 patients) Stratified by Physician ICD Volume, Specialty Certification, and Hospital Annual Volume

		Quartile of Physician Annual ICD Volume				
Stratification	Overall	Q1 (≤4)	Q2 (4–15.5)	Q3 (15.5–37.25)	Q4 (>37.25)	*P*-Trend
Specialty Certification						
EP board certified (N=1951)	2.94	3.75	3.59	3.19	2.84	<0.0001
EP fellowship only (N=227)	2.93	6.79	3.35	3.09	2.76	0.01
Surgery board certified (N=404)	4.96	5.18	4.76	4.67	6.11	0.66
HRS guideline trained (N=720)	3.71	5.29	3.87	3.92	3.07	0.0001
None of the above (N=511)	3.41	3.75	3.53	4.08	2.82	0.01
Hospital annual volume						
Median and above	3.02	4.19	3.79	3.35	2.83	<0.0001
Below median	3.57	5.21	3.66	3.58	3.23	0.0003

ICD indicates implantable cardioverter-defibrillator; EP, electrophysiology; and HRS, Heart Rhythm Society.

ICDs. We also examined a full range of patient ages and a much more comprehensive set of complications based on the high-quality clinical data contained in the NCDR ICD Registry.

Our study shows that the inverse relationship between physician volume and in-hospital complications and death is independent of hospital volume, which we have previously shown to be associated with outcomes (Tables 4 and 5).[24] The relationship between physician procedure volume and outcome has been difficult to disentangle from that of hospital volume, in part because physicians may perform procedures at several hospitals, and several different physicians may perform procedures in the same hospital. Birkmeyer and associates examined the relative contribution of surgeon volume and hospital volume to operative mortality among Medicare beneficiaries and showed that surgeon volume accounted for roughly half of the effect of hospital volume on the outcomes of coronary artery bypass grafting and abdominal aneurysm repair.[31,32] The outcomes of patients undergoing major surgery or being treated for a life-threatening illness, such as acute myocardial infarction, may be particularly dependent on hospital-level factors, as they require the care of multidisciplinary teams over extended hospitalizations, and therefore coordination and attention to processes of care ought to have a substantial effect on outcome. By contrast, outcomes of elective procedures such as ICD implantations that are performed under local anesthesia and require relatively brief postprocedure monitoring may depend more on the skills of the individual physician who performs the procedure.

A physician's level of training and type of board certification are also potential markers of procedural skills and have previously been shown to affect the risk of an adverse procedure event after ICD implantation.[26] It may be difficult to separate the effect of training per se from that of greater practical experience in performing the procedure because physicians with more specific training tend to perform the procedure more often. We found that the inverse volume–outcome relationship was present even among electrophysiologists, suggesting that maintenance of procedural skills by performing a sufficient volume of procedures continues to be important even among physicians trained specifically in ICD implantation.

The inverse relationship between procedure volume and adverse events for a variety of procedures has led to proposals for minimum volume standards for hospitals, physicians, or both.[33] Such proposals are particularly attractive when the empirical data show a nonlinear relationship between volume and outcome and there is a clear volume threshold below which the rate of adverse events increases sharply. However, when the relationship is smooth and continuous, as it is in the case of ICDs (Figure), there is no natural point at which to set a minimum standard for procedure volume. In addition, setting a minimum volume standard may have unintended consequences, such as increasing use of inappropriate or borderline procedures by physicians seeking to increase their case volumes, or limiting access to procedures for patients from more sparsely populated regions where procedure volumes are necessarily low. Nevertheless, our data suggest that if the 33 585 patients who had an ICD implanted by a physician in the lower 2 quartiles of procedure volume instead had had their ICD implantation performed by a physician in the higher 2 volume quartiles, there might have been 292 fewer complications and 58 fewer deaths. Consequently, the volume of ICD procedures performed by a physician is pertinent information that might be useful to patients or health plans when choosing providers. Moreover, because our data show larger absolute differences in complication rates between high- and low-volume physicians implanting biventricular and dual-chamber ICDs, physician procedure volume may be a particularly important consideration for these more complex devices than for single-chamber ICDs.

Our study has a number of limitations that should be considered in interpreting its results. First, we were only able to measure the volume of procedures captured in the ICD Registry between 2006 and 2010. Accordingly, we could not evaluate the influence on outcome of a physician's cumulative experience in implanting ICDs or implanting related cardiac devices such as pacemakers. Second, we have data only on adverse events that were evident within the same hospital admission and cannot evaluate longer-term adverse effects that might be attributable to the initial procedure, such as lead dislodgement, late perforation, or infection. Third, we have no data on the appropriateness of the decision to implant an ICD or the balance between the risk of the procedure and the future clinical benefits of having the device in place. Finally, a small number of hospitals participating in the ICD Registry only submitted data for Medicare patients, and a small number of ICD procedures were excluded because the submitted data did not meet the quality standards of the NCDR, which may have biased our results.

In conclusion, physicians who perform ICD implantations more often tend to have fewer adverse events from the procedure and lower periprocedural mortality. This effect was consistent for all subtypes of ICDs, including single-chamber, dual-chamber, and biventricular ICDs. Concentrating ICD implantation in the hands of fewer physicians may improve the clinical outcomes of this increasingly common procedure.

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CLINICAL PERSPECTIVE

The outcomes of procedures are often better when they are performed by more experienced physicians and in hospitals with higher procedure volumes. This study examined the relationship between physician procedure volume and in-hospital complications and death after implantation of an implantable cardioverter-defibrillator using data from a national clinical registry of implantable cardioverter-defibrillator procedures. A significant inverse relationship between physician procedure volume and the rate of implantable cardioverter-defibrillator procedural complications was demonstrated, which was not explained by physician specialty, hospital volume, or patient characteristics. These data suggest that concentrating implantable cardioverter-defibrillator implantation in the hands of more experienced physicians may reduce procedural complications.

Physician Procedure Volume and Complications of Cardioverter-Defibrillator Implantation

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