ORIGINAL RESEARCH

Geographic and Temporal Variation in Cardiac Implanted Electric Devices to Treat Heart Failure

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Background—Cardiac implantable electric devices are commonly used to treat heart failure. Little is known about temporal and geographic variation in use of cardiac resynchronization therapy (CRT) devices in usual care settings.

Methods and Results—We identified new CRT with pacemaker (CRT-P) or defibrillator generators (CRT-D) implanted between 2008 and 2013 in the United States from a commercial claims database. For each implant, we characterized prior medication use, comorbidities, and geography. Among 17 780 patients with CRT devices (median age 69, 31% women), CRT-Ps were a small and increasing share of CRT devices, growing from 12% to 20% in this study period. Compared to CRT-D recipients, CRT-P recipients were older (median age 76 versus 67), and more likely to be female (40% versus 30%). Pre-implant use of β-blockers and angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers was low in both CRT-D (46%) and CRT-P (31%) patients. The fraction of CRT-P devices among all new implants varied widely across states. Compared to the increasing national trend, the share of CRT-P implants was relatively increasing in Kansas and relatively decreasing in Minnesota and Oregon.

Conclusions—In this large, contemporary heart failure population, CRT-D use dwarfed CRT-P, though the latter nearly doubled over 6 years. Practice patterns vary substantially across states and over time. Medical therapy appears suboptimal in real-world practice. **(*J Am Heart Assoc*. 2016;5:e003532 doi: 10.1161/JAHA.116.003532)**

Key Words: defibrillation • heart failure • pacing • population • variation

Several device-based therapies are used to supplement pharmaceutical treatment for systolic heart failure, primarily cardiac resynchronization therapy (CRT), either alone (CRT-P) or in combination with defibrillator back-up (CRT-D). These devices are increasingly common in the United States, with estimated implant rates in patients with heart failure diagnoses or hospitalizations for sudden cardiac arrest ranging from 24% to 38%.[1–3] For patients potentially eligible for CRT, CRT-D devices appear to be the "default" device in the United States.[4,5] In a US national registry, patients who met trial eligibility for CRT (ie, left ventricular ejection fraction <35%, QRS width >120 ms, and New York Heart Association class III/IV), the overwhelming proportion (80%) received a combined CRT-D device. A re-analysis of the 74 patients randomized to CRT-P in the REVERSE trial (compared to 345 with CRT-D) found lower long-term mortality in CRT-D patients.[6] While some argue that any patient treated with CRT should also receive defibrillator backup,[7] others counsel restraint in adding additional device functions.[8,9] A recent cohort study adjudicated cause of death for patients with CRT-P versus CRT-D and found that the vast majority of excess mortality in CRT-P patients was non-sudden death, weakening the argument for default defibrillator backup.[10] Preventing sudden cardiac death with an implantable cardioverter-defibrillator (ICD) is distinct from improving heart failure symptoms, and not every patient views these as necessarily linked.[11] Only the COMPANION trial has directly compared the relative effectiveness of CRT-D versus CRT-P; it found lower risk of cardiac death for CRT-D versus CRT-P, but the trial was powered to compare each device to medical therapy alone, not to compare the 2 devices.[12] CRT-D devices are nearly 3 times more costly and require more frequent battery replacements compared with CRT-P[13]; accordingly,

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Accompanying Tables S1 through S4 and Figure S1 are available at http://jaha.ahajournals.org/content/5/8/e003532/DC1/embed/inline-supplementary-material-1.pdf

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cost-effectiveness analyses have suggested that the incremental benefit of CRT-D over CRT-P may not justify the large cost difference.[14,15]

Few studies have evaluated real-world practice patterns of CRT implantation. Previous studies of geographic variation in treatment and spending have focused on traditional fee-for-service Medicare populations, but the Institute of Medicine has called for more understanding of variation in commercially insured populations, including Medicare Advantage.[16] One recent study used the National Inpatient Sample to characterize CRT-D versus CRT-P and found significant variation among hospitals.[17] We build on these efforts, examining both inpatient and outpatient procedures. Thus, we sought to evaluate patients treated with implantable cardiac devices as measured in a large national commercial claims database, focusing on the overall, temporal, and geographic variation in the United States between 2008 and 2013.

Methods

Data Source

Eligible patients were drawn from 2 Truven MarketScan databases: Commercial Claims & Encounters and Medicare Supplemental & Coordination of Benefits. Large self-insured employers, health plans, hospitals, and Medicare contribute claims data to these databases. The full population includes ≈26 million people annually in the commercial data and 4 million people annually in the Medicare claims. The data include inpatient, outpatient, and medication claims. The Medicare population includes people 65 and older with employer-sponsored comprehensive HMO coverage through Medicare Advantage or supplemental coverage through Medigap plans. MarketScan data are widely used in health services research to characterize patterns of care.[18–21] Compared to the whole US population, the MarketScan population is generally younger, more likely to be employed, and thus wealthier. Previous comparisons have shown that MarketScan represents the under-65, noncapitated population well.[22] This study was deemed not human subjects research by the Health Care Policy Compliance Office, in accordance with the Office of Human Research Administration, Harvard Longwood Medical Area policy, and federal regulations [45 CFR 46.102(f)].

Study Cohort

We matched inpatient and outpatient claims using dates of service to form episodes of care that included any International Classification of Disease, 9th Revision—Clinical Modification (ICD-9-CM) procedure codes or Current Procedural Terminology codes related to the 3 devices of interest. Though we focused primarily on CRT-P and CRT-D implants, we identified ICD implants to provide context according to overall device utilization. We limited the sample to adults (≥18 years old) receiving new implants between 2008 and 2013 by excluding episodes with codes that indicated removals, revisions, and generator changes, and then classified each new implant as ICD, CRT-D, or CRT-P (Figure 1). Tables S1 and S2 list the specific codes used to select new implants and classify devices. We required 6 months of continuous enrollment prior to implant in order to measure comorbidities and medications.

Variables

Demographic characteristics of enrollees included age, sex, and state of residence. We measured characteristics of patients' heart failure using claims in the 6 months prior to implant. Two of these (arrhythmias and congestive heart failure) use codes from the 2013 Centers for Medicare and Medicaid Services' Hierarchical Condition Categories.[23] The other 3 (atrial fibrillation/flutter, cardiac failure, and conduction disorders) use small subsets of diagnosis codes, listed in Table S3. We also measured Charlson index comorbidities in the 6 months prior to implant: cerebrovascular disease, coronary disease, dementia, diabetes mellitus, HIV/AIDS, kidney disease, liver disease, paralysis, peripheral vascular disease, pulmonary disease, rheumatoid arthritis, and stomach ulcers. We used the Deyo adaptation with several codes that reflect the Romano adaptation; specific ICD-9-CM diagnosis codes are found in Table S3.[24–26] We defined medication use as at least 90 days of medication supply in the 6 months prior to implant. We measured drugs in the following categories: β-blockers, angiotensin-converting enzyme inhibitors, and angiotensin receptor blockers. This 90-day window prior to implant is consistent with the lower bound of a 3- to 6-month course recommended in the 2010 Comprehensive Heart Failure Practice Guideline[27] and used in previous studies.[28] Specific drug names are found in Table S4. We defined optimal medical therapy as use of any β-blocker combined with any angiotensin-converting enzyme inhibitor or angiotensin receptor blocker. Some individuals in the database lack claims for prescription drugs (either because they do not have prescription drug coverage or their employer/insurer does not contribute these claims to the data). Thus, we restrict our measures of medication use to people with *any* drug claim in the period (75% of all patients), a conservative definition of the subpopulation with both prescription drug coverage and available claims.

Statistical Analysis

We summarized patient characteristics by device type using counts and percentages for binary variables, and median,

25th, and 75th percentiles for continuous variables. We computed standardized mean differences in binary patient characteristics for all pairwise combinations of the 3 devices. We computed unadjusted implant rates using the entire MarketScan population. In our main analyses, we combine the commercial and Medicare Advantage populations. To highlight the differences in clinical characteristics and medications among patients receiving each device, we plot standardized mean differences (with 95% CIs) in Figure 2. These are considered substantial when they exceed 0.10 in absolute value.[29]

To evaluate changes over time and geography in the relative proportions of each device type among new CRT implants, we modeled device receipt using year, age quintiles, sex, and all 2- and 3-way interactions among them (ie, a saturated model). For the 3-way comparison of each device type among all implants, we fit a multinomial model; for CRT-P receipt versus CRT-D, we used a logistic model. These models produce fitted probabilities of receiving each device type adjusted for age, sex, and year. We fit a version of the logistic model that also included state fixed effects; for that model, we excluded 4 states (North Dakota, Puerto Rico, South Dakota, and Vermont) with no CRT-P implants. We present results as fitted device percentages (out of all new implants) in selected patient subgroups, rather than regression coefficients, for ease of interpretation.

Results

Patient Characteristics

We identified a cohort of 55 044 patients implanted with new CRT or ICD devices over 6 years (Figure 1). The majority (68%) were implanted with an ICD, 27% with a CRT-D, and 5%

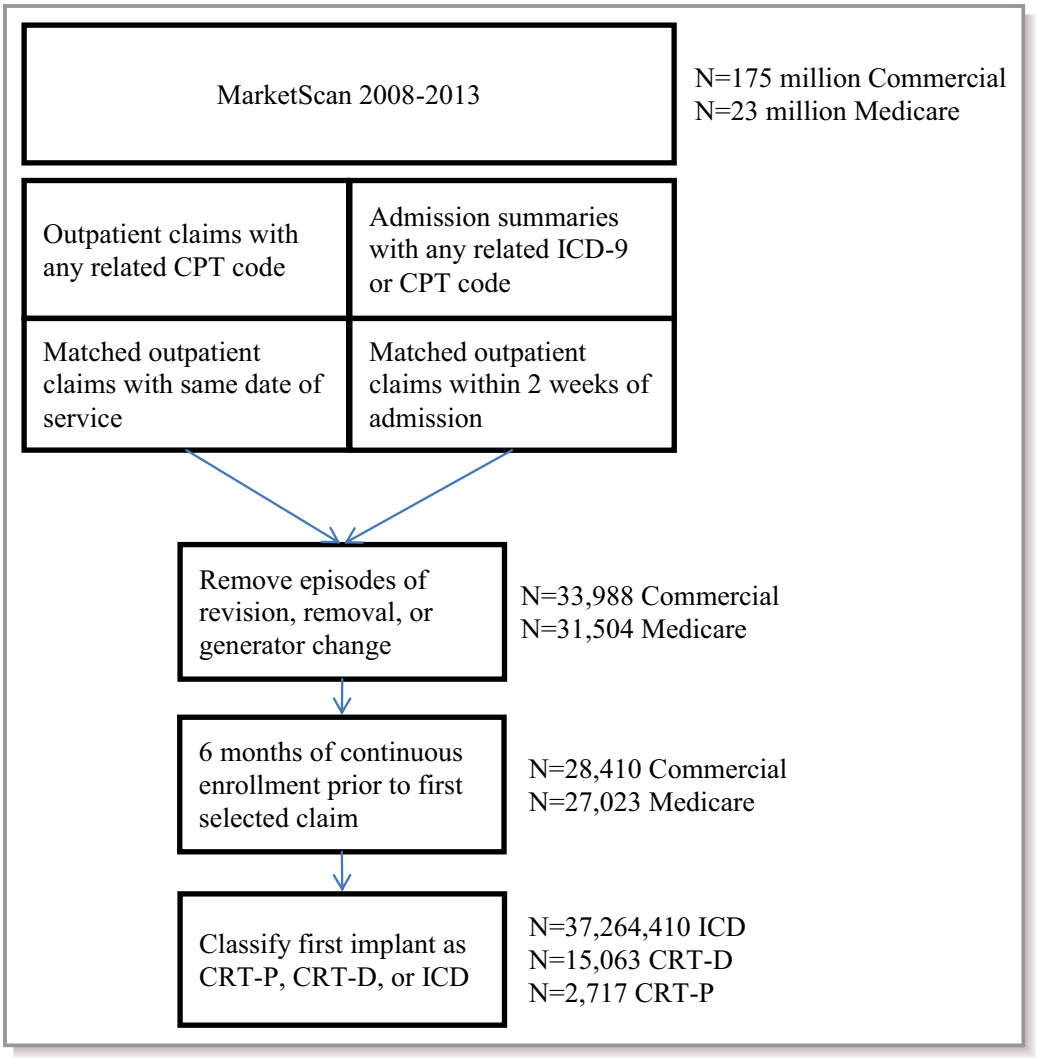

Figure 1. Cohort selection method. CPT indicates Current Procedural Terminology; CRT-D, CRT with ICD backup; CRT-P, cardiac resynchronization therapy pacemaker; ICD, implantable cardioverter defibrillator; ICD-9, International Classification of Disease, 9th Revision.

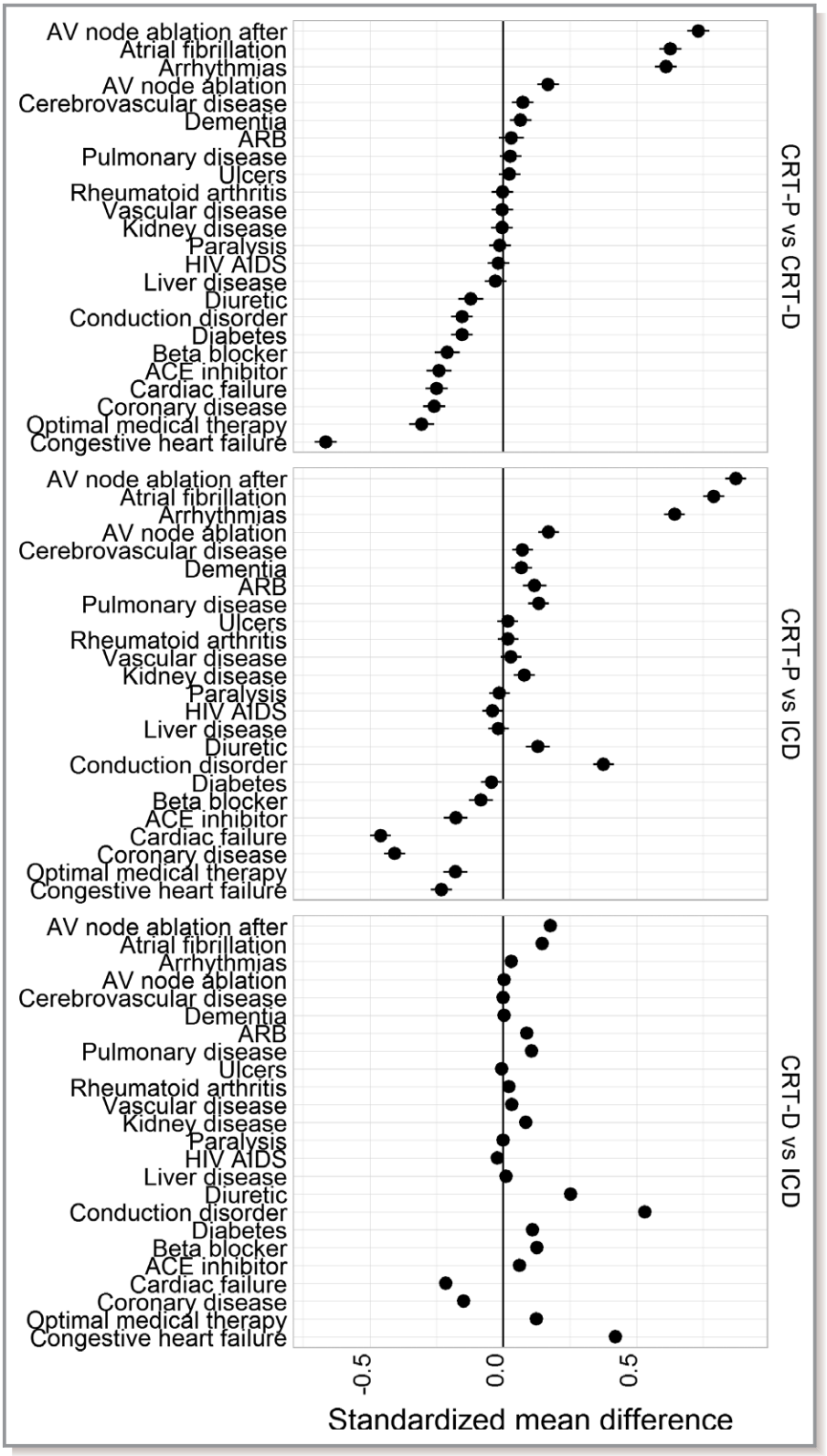

Figure 2. Clinical differences between implant groups. Points (intervals) are standardized mean differences (95% CI) for each characteristic. Positive numbers indicate higher prevalence in the device listed first in each panel, measured using the 6 months of claims prior to implant. ACE indicates angiotensin-converting enzyme; ARB, angiotensin receptor blockers; AV, atrioventricular; CRT-D, CRT with ICD backup; CRT-P, cardiac resynchronization therapy pacemaker; ICD, implantable cardioverter defibrillator.

with a CRT-P. Among CRT devices, CRT-D were the vast majority (85%).

Table shows the differences in demographics, heart failure characteristics, comorbidities, and medication use across the 3 device types. Implants of CRT-P devices were most likely to be implanted in the outpatient setting (55%), followed by CRT-D (53%), and ICD (48%). The CRT-P group had the highest proportion of women (40%), followed by CRT-D (30%), and ICD (26%). Patients receiving CRT-P devices were older at implant (median 76 years) than those receiving CRT-Ds (67 years) and ICDs (62 years).

The most common cardiovascular diagnosis was congestive heart failure, found in the majority of patients (CRT-P 55%, CRT-D 84%, ICD 66%). We also found high proportions with atrial fibrillation/flutter (CRT-P 59%, CRT-D 29%, ICD 23%). Cardiac conduction disorders were common only among patients with CRT-P (21%) and CRT-D devices (27%), but not those with ICD devices (8%). Among the significant comorbidities, diabetes mellitus and chronic pulmonary disease were highly prevalent. The proportion of patients receiving both β-blockers and angiotensin-converting enzyme inhibitors or angiotensin receptor blockers prior to implant appeared low: only 31% of CRT-P, 46% of CRT-D, and 40% of ICD patients. These proportions did not change appreciably when limited to the population with a diagnosis of congestive heart failure.

The biggest distinctions between patients who received CRT-P (compared to CRT-D) were higher prevalence of atrial fibrillation/flutter and arrhythmias, and much lower prevalence of congestive heart failure and cardiac failure (Figure 2).

Table. Baseline Characteristics of Patients With New Implants

	CRT-P	CRT-D	ICD
Total	2717	15 063	37 264
Outpatient, %	55	53	48
Median age, y	76	67	62
Women, %	40	30	26
Arrhythmias, %	68	39	37
Atrial fibrillation, %	59	29	23
Congestive heart failure, %	55	84	66
Conduction disorder, %	21	27	8
Cardiac failure, %	5	12	20
Diabetes mellitus, %	31	38	33
Pulmonary disease, %	24	23	18
Cerebrovascular disease, %	15	12	12
Kidney disease, %	13	13	11
Coronary disease, %	8	17	23
Vascular disease, %	8	8	8
Rheumatoid arthritis, %	2	2	2
Dementia, %	1	1	1
Ulcers, %	1	1	1
HIV AIDS, %	<1	<1	<1
Liver disease, %	<1	1	1
Paralysis, %	<1	1	1
β-Blocker, %	52	62	56
ACE inhibitor, %	31	43	40
ARB, %	20	19	15
Optimal medical therapy, %	31	46	40
Diuretic, %	47	53	41

ACE indicates angiotensin-converting enzyme; ARB, angiotensin receptor blocker; CRT-D, cardiac resynchronization therapy with ICD backup; CRT-P, cardiac resynchronization therapy pacemaker; ICD, implantable cardioverter defibrillator; optimal medical therapy, β-blocker and ACE inhibitor or ARB.

Proportional Device Utilization

Figure 3 displays the percentage of people who received new implants out of the entire MarketScan population in each year. Medicare Advantage enrollees, who are older than commercial enrollees, had higher proportions of all implant types. In 2013, for every 100 000 Medicare enrollees, there were 11 CRT-P recipients, 33.8 CRT-D recipients, and 58 ICD recipients. In the commercial population, these numbers were 0.4, 2.9, and 10.6, respectively. For the remaining results, we combined the commercial and Medicare populations.

Among new implants, ICDs dominated but decreased slightly over the study period, from a high of 72% of all implants in 2008 to 66% in 2013. CRTs represented 32% of new implants overall, of which the fraction of CRT-P devices grew from 12% to 20% over the study period. Figure S1 contains the results from a multinomial model for receipt of each device out of all new implants.

The results from the binomial model for CRT-P receipt (out of new CRT implants) from a model with year, age (in quintiles), sex, and all interactions are shown in Figure 4. All 3 predictors are influential. For example, among people in the middle-age quintile (ages 61–68) in 2010, women were 2.2 times as likely as men to receive CRT-P (18% versus 8% of new CRT implants). In that same year, men in the oldest-age quintile (77 and older) were 2.9 times more likely to receive CRT-P than the youngest (age 18–54): 23% versus 8% of new implants. The trend in increasing CRT-P implants over the study period was stronger at older ages and among women. For example, CRT-P proportion among men ages 18 to 54 remained essentially constant at 8% between 2008 and 2013. Among men 77 years and older, the CRT-P percentage increased from 18% to 27%. Among women, the CRT-P share in women 18 to 45 years also remained nearly constant at

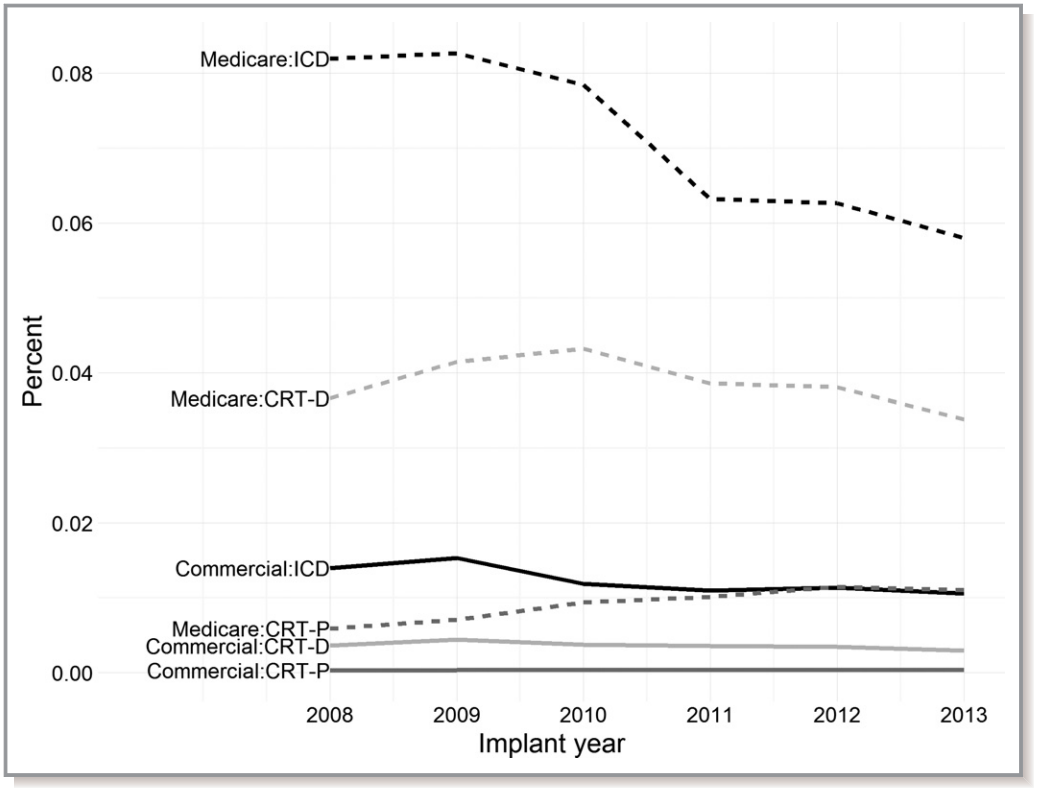

Figure 3. Annual device implant proportions in MarketScan. Each line represents the number of patients receiving each new implant type divided by the total number of enrollees in each year. CRT-D indicates CRT with ICD backup; CRT-P, cardiac resynchronization therapy pacemaker; ICD, implantable cardioverter defibrillator.

10%, while the share in those 77 and older increased from 25% to 43% of new implants.

Temporal and Geographic Trends in Device Use

Adding state to this model allowed us to examine patterns across states, adjusted for age, sex, and year. The state fixed effects from a binomial model of CRT-P implants (out of all new CRT implants) illustrate the geographic variation (Figure 5). Among states with at least an average of 100 new implants per year, we identified particularly high CRT-P percentages in South Carolina and Wisconsin, and particularly low shares in New York and Indiana. These state differences are sufficient to change the fitted proportions substantially. For example, the fitted percentage of CRT-P (out of all new CRT implants) among women age 62 to 68 in 2013 is 26% in South Carolina versus 12% in New York.

In addition, we examined how residuals from the binomial model with state effects changed over time. Figure 6 shows the difference between the modeled and observed patterns of CRT-P proportions (out of all new CRT implants) for women age 62 to 68 in 2013, limited to results for states with an average of at least 100 annual total implants. The trends are largely flat or symmetric around zero, with a few exceptions. Kansas appears to be increasing relative to national trends, while Minnesota and Oregon are decreasing.

Discussion

This study characterizes cardiac implantable electric device use in a large, nationwide sample of cardiac patients. We found that CRT-P devices comprise a growing minority of new CRT implants (12–20% from 2008 to 2013), with significant variation across states. While the fraction of each implant type in the entire MarketScan population does not reflect trends in the eligible populations, our study is among the largest samples of real-world inpatient and outpatient CRT implants in the United States. In addition, our finding of relatively low rates of appropriate neurohormonal blockade among device recipients raises questions about effective application of optimal medical therapy in these patients prior to device implantation.

The overwhelming preference for CRT-D devices among all CRT recipients in our study contrasts sharply with the application of CRT in other countries, particularly in Europe. A large multinational comparison of CRT-D and CRT-P implant rates reveal that among the 10 countries with the highest per

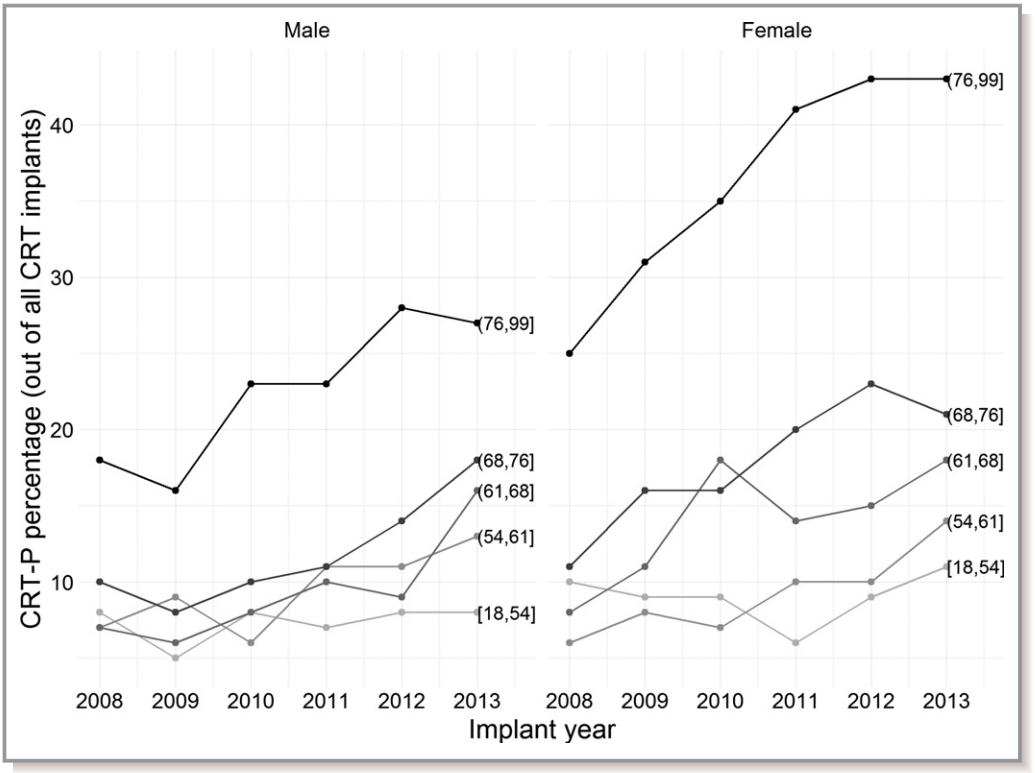

Figure 4. Modeled device proportions by age, sex, and year. Each line shows the modeled probability of receiving CRT-P (conditional on receiving a CRT device) by year (*x* axis), age (quintile, each line is a different quintile), sex (men in the top row, women in the bottom row) from a saturated logistic regression model. Dots are the observed device proportions for each year-age-sex combination. CRT-D indicates CRT with ICD backup; CRT-P, cardiac resynchronization therapy pacemaker; ICD, implantable cardioverter defibrillator.

capita rates of CRT implantation, CRT-P devices range from 17% (Italy) to 49% (Hungary) of CRT devices.[30] In the Swedish heart failure registry,[31] 63% of patients receiving CRT were implanted with CRT-P.[32] Our data accord with a smaller, single-center study from the Cleveland Clinic, which demonstrated that among Class III/IV heart failure patients receiving CRT, 95% received CRT-D versus CRT-P.[33] Even among patients aged >80, 86% received CRT-D.[34] What drives these striking national differences in device selection is not clear. American and European guidelines for CRT are generally similar, including guidance indicating insufficient evidence that CRT-D is superior to CRT-P.[35]

Some believe that older or frailer patients are better candidates for CRT-P rather than CRT-D or ICD.[36] Our study finds that while CRT-P recipients were older, they were otherwise not more likely to have identified comorbidities compared to CRT-D recipients. In practice, patients receiving CRT-P devices have worse survival than those receiving ICD or CRT-D.[37] Although older patients experience more in-hospital mortality and complications of device implants,[38] and may realize diminished survival benefit from ICDs,[39] the existing evidence provides little guidance on how to select CRT-P versus CRT-D devices for individual patients.[40] Even the existing clinical trial data characterizes outcomes for patients younger than those found in registries and in our sample, with trial populations having a mean age of 69.4 years and only 6.4% of studied patients aged 85 or older.[41] There are few data characterizing the differences between those who receive CRT (of either type) and those who are apparently eligible but either decline or are never offered CRT. Identifying such patients may help elucidate the rationale for device selection, if in fact patient characteristics guide these decisions. Studies currently under way are evaluating how patients assess their options for device-based therapy and whether decision support tools can streamline that process.[42]

Several possible mechanisms may explain the increasing proportion of CRT-P devices among CRT implants over the study period. For example, changes in patient and provider preferences, population demographics, and evidence in favor of "ablate and pace" strategies may contribute. In our sample, 32% of CRT-P recipients had AV node ablation on the day of implant or in the 3 months after. Because providers and patients appear to favor CRT-P at older ages, demographic changes are relevant. The US population aged 75 and older grew by ≈600k from 2008 to 2013. Early signs of CRT benefit in patients with atrial fibrillation began to appear in the

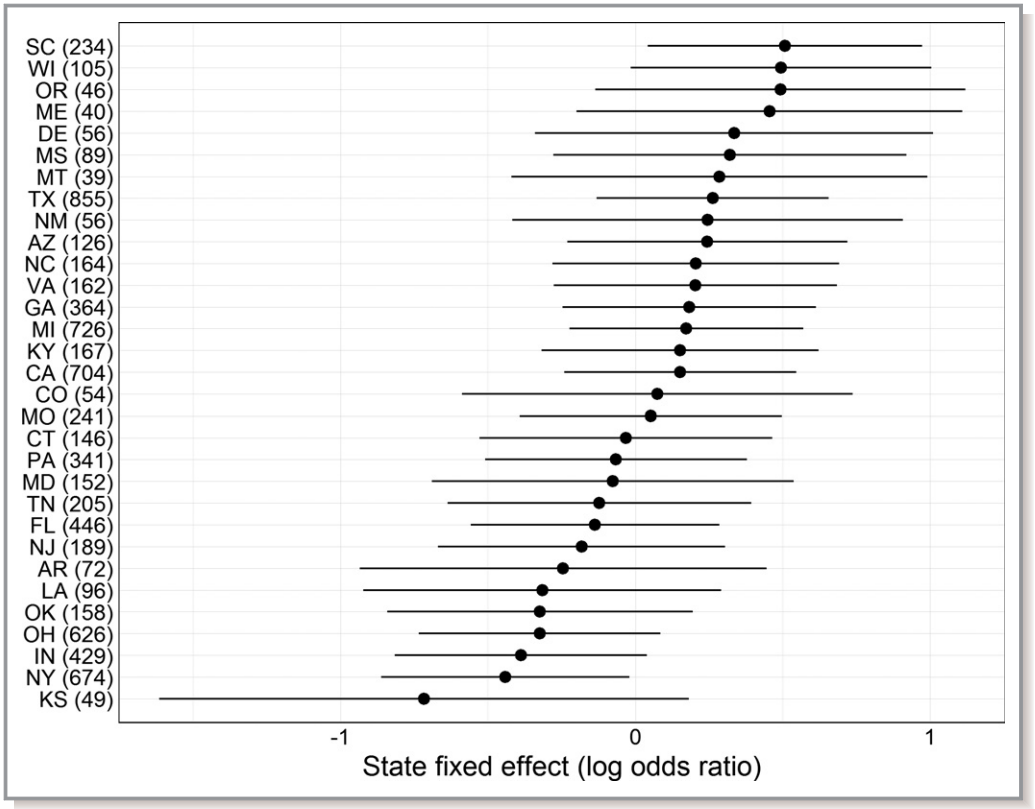

Figure 5. Variation across states in CRT-P proportions. Each point shows the state fixed effect from a binomial model for cardiac resynchronization therapy pacemaker (CRT-P) devices out of all new CRT implants with segments extending 2 SE on either side of the estimate. Numbers in parentheses give the average total annual implants in each state; we display only results for states with at least 20 CRT-P implants.

literature[43,44] before they were established by the BLOCK-HF trial in 2013.[45] In addition, there is increasing recognition of pacing-related cardiomyopathy, which generally responds well to upgrade to CRT-P.[46] Although our sample was restricted to de novo implants, increasing recognition of risk factors for likely future pacing-related deterioration may create a pool of patients who become eligible for CRT-P implant but likely not CRT-D. Finally, federal audits of ICD implants were launched in 2012 to investigate ICD implants in patients excluded in the 40 days after acute myocardial infarction and 3 months following percutaneous coronary intervention. The period of inquiry extended back to 2003 and "Although ICDs were the subject of this initial inquiry, dual-chamber pacemaker indications are also being actively scrutinized, and PCI is likely to receive similar attention."[47] Increased scrutiny on these implants may have encouraged providers to adopt more conservative device-based therapies.

We hypothesized that there would be geographic variation in CRT-P versus CRT-D utilization, as significant variability in practice patterns have been identified for other cardiac interventions. Previous studies have found wide variation in ICD implant rates by patient, hospital, and region.[48–51] Otherwise eligible patients who are older, African American, and admitted to smaller hospitals are less likely to receive an ICD, while larger, academic hospitals with the capability to perform other cardiac interventions are more likely to implant ICD devices. In keeping with these results, our study found substantial variation in implant rates by geography, computed as the fraction of each device type out of the total share of devices. The patterns of differences across states—adjusted for age, sex, and national time trends—were not changing appreciably over time in all but a handful of states. Thus, how CRT decisions are made locally and what drives this regional variability requires further investigation.

Optimal medical therapy reported in registry studies is much higher than what we find here.[52,53] One study found 70% of patients without contraindications were prescribed a β-blocker and angiotensin-converting enzyme inhibitors/angiotensin receptor blockers following implantation with a CRT-D device. Back calculating from the study, we can see that in their cohort of 45 392 patients receiving a CRT-D implant, 96% to 99% of patients had no contraindication. These studies both used reported "discharge on" optimal medical therapy from the National Cardiovascular Data Registry ICD Registry. A more recent study examined guideline-recommended medical therapy prior to primary prevention ICD implant

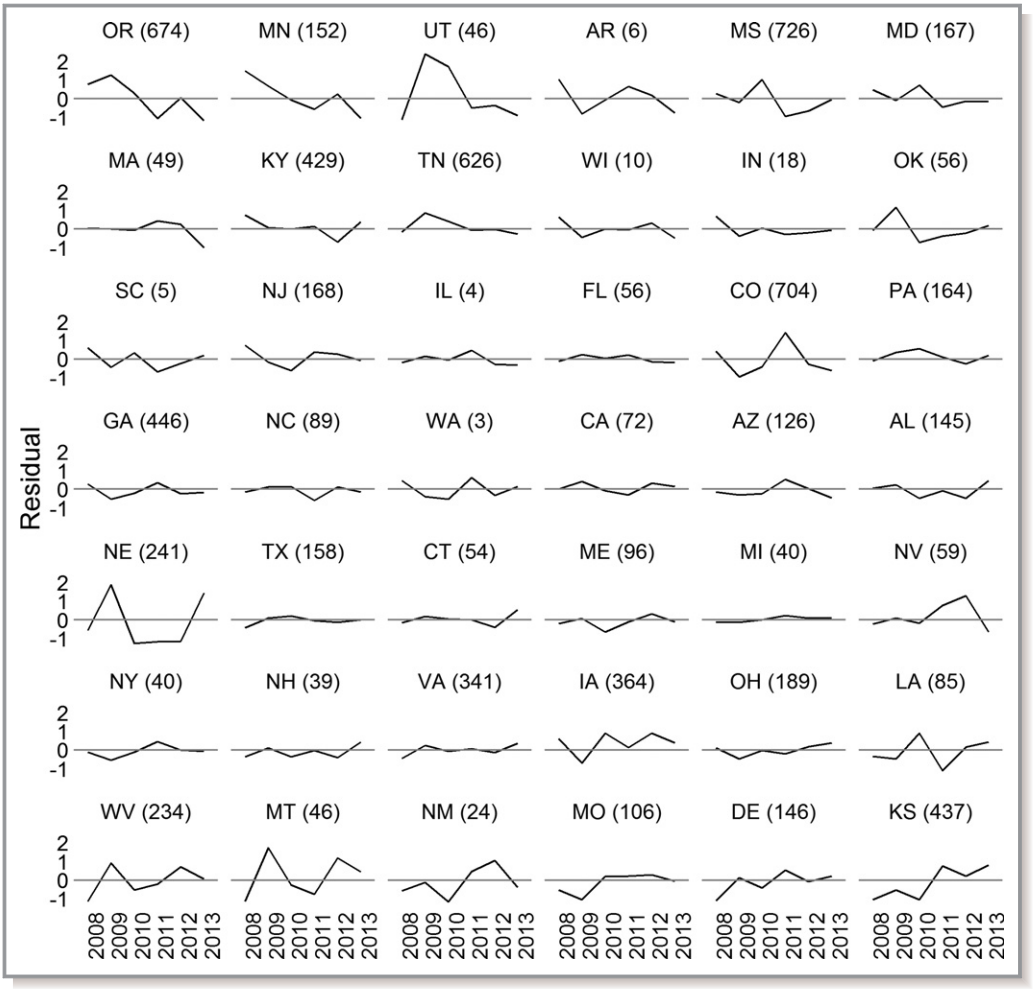

Figure 6. Residual CRT-P implant proportions over time. Lines connect the difference between each state's annual cardiac resynchronization therapy pacemaker (CRT-P) percentage (out of all new CRT implants) and the fit from a multinomial model that includes age, sex, year, and state. Positive numbers indicate more CRT-P implants than the model predicts. Numbers in parentheses give the average total annual implants in each state. The states are arranged in order of the overall trend of the residuals from most negative (top left) to most positive (bottom right).

using Part D claims linked to the National Cardiovascular Data Registry ICD Registry.[28] Like that study, our claims-based analysis reflects prescription fills rather than prescriptions, and therefore may reflect actual medication use. The Roth et al study distinguished between any claim for guideline-directed therapy (61% of patients) and an "adequate supply" (28% of patients), which they defined as 80% coverage of the 90 days leading up to implant. Our definition of drug use requires 90 days' supply in the 6 months prior to implant, which is somewhere between these 2 definitions. Further work to reconcile these apparent differences will be important for characterizing whether, in fact, these patients are receiving guideline-based care prior to and concurrent with their device therapy.

Our study has several potential limitations, arising in part from our methodological strengths, including the broadly representative population of commercially insured and Medicare enrollees. The ICD Registry does not include CRT-P devices, so we are uniquely positioned to study CRT-P, CRT-D, and ICD devices. However, in this data source, diagnosis and procedure codes may not accurately reflect a patient's clinical characteristics. In particular, our inability to measure left ventricular ejection fraction and QRS morphology and duration are significant limitations of our claims-based analysis. Our 6-month lookback period may not adequately capture all relevant diagnosis codes. Registry-based studies contain much more comprehensive information about each patient and device implant, but lack follow-up information about outcomes and subsequent healthcare use. We are also limited in our ability to adjust for additional patient characteristics, such as comorbidities, in models for geographic and temporal variation. Even in such a large database as this, the total number of patients implanted with CRT-P devices was quite small. For example, in a medium-sized state like

Maryland (153 average annual total implants), there are only 1 or 2 CRT-P implants in each sex-age group each year, sometimes none. Finally, indications for CRT pacing have recently changed. Following publication of the BLOCK-HF trial in 2013,[45] it is reasonable to expect increasing use of CRT-P devices for patients with AV block who do not have indications for ICD therapy. Our study period precedes publication of this trial, but we have no left ventricular ejection fraction measurements or data beyond 2013, so we cannot directly address the question of changing practice in response to BLOCK-HF.

Although large randomized trials comparing CRT-P and CRT-D devices are unlikely, research to identify variation in patient responses to CRT therapy can leverage geographic variation in practice to perform quasi-experimental analyses and identify subgroups of patients most likely to benefit from CRT-P devices. Furthermore, recent developments in behavioral economics provide examples of effective means to improve adherence with guideline-recommended practice, such as a sufficient course of optimal medical therapy prior to device implant. For example, a recent study found that inappropriate antibiotic prescribing could be reduced by regular emails to physicians describing their performance as "top performing" or not.[54] Electronic health records could facilitate these interventions by enabling automatic report generation for physicians and patients.

In sum, our large, national study of cardiac implantable electric device use in a commercially insured population demonstrates that, among CRT recipients, CRT-D is overwhelmingly selected, though a small increase in CRT-P use has been seen in recent years, especially among older patients and women. In future work, we will describe outcomes of device therapy that are measurable in claims, particularly subsequent hospital-based healthcare use and the frequency with which each device type is upgraded, downgraded, or removed (for example, ICD downgrades to pacemakers).[55] In ongoing work, we are studying trends in CRT-P use among the fee-for-service Medicare population. The longitudinal dynamic treatment regimens for patients with implanted devices have not been previously studied. We also plan to fit and validate a model of eligibility in a rich data source such as a registry and apply it to the claims data using observables and statistical methods for incorporating external data.[56] This will clarify the treatment selection patterns within the larger population of potentially eligible recipients.

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Disclosures

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Supplemental Material

Geographic and temporal variation in cardiac implanted electric devices to treat heart failure

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Table S1 Device-related codes

Description	**ICD-9 Procedure Code**
CRT-P	00.50
CRT-D	00.51
ICD	37.94
Revision or removal	00.52, 00.53, 00.54, 37.70-37.78, 37.80-37.89, 37.95 37.96, 37.97, 37.98
Description	**CPT Code**
Pacing generator	33207, 33208
LV lead	33225
Defibrillator generator	33249, G0299, G0300
Revision or removal	G0297, G0298, 33212, 33213, 33214, 33216, 33217, 33218, 33220, 33221, 33224, 33227, 33228, 33229, 33230, 33231, 33233, 33234, 33235, 33240, 33241, 33244, 33262, 33263, 33264

Table S2 New implant codes and classification method

ICD-9-CM procedure codes

37.94	00.50	00.51	Classification	Notes
No	No	No	Ambiguous	Go to CPT codes
Yes	No	No	ICD	
No	Yes	No	CRT-P	
No	No	Yes	CRT-D	
Yes	Yes	No	Error	Two systems
No	Yes	Yes	Error	Two systems
Yes	No	Yes	Error	Two systems
Yes	Yes	Yes	Error	Three systems

CPT Codes

33207/8	33249	33225	Classification	Notes
No	No	No	None	
Yes	No	No	None	Pacemaker not a device of interest
No	Yes	No	ICD	
No	No	Yes	Ambiguous	No generator
Yes	Yes	No	Error	Two generator codes
No	Yes	Yes	CRT-D	
Yes	No	Yes	CRT-P	
Yes	Yes	Yes	Error	Two generator codes

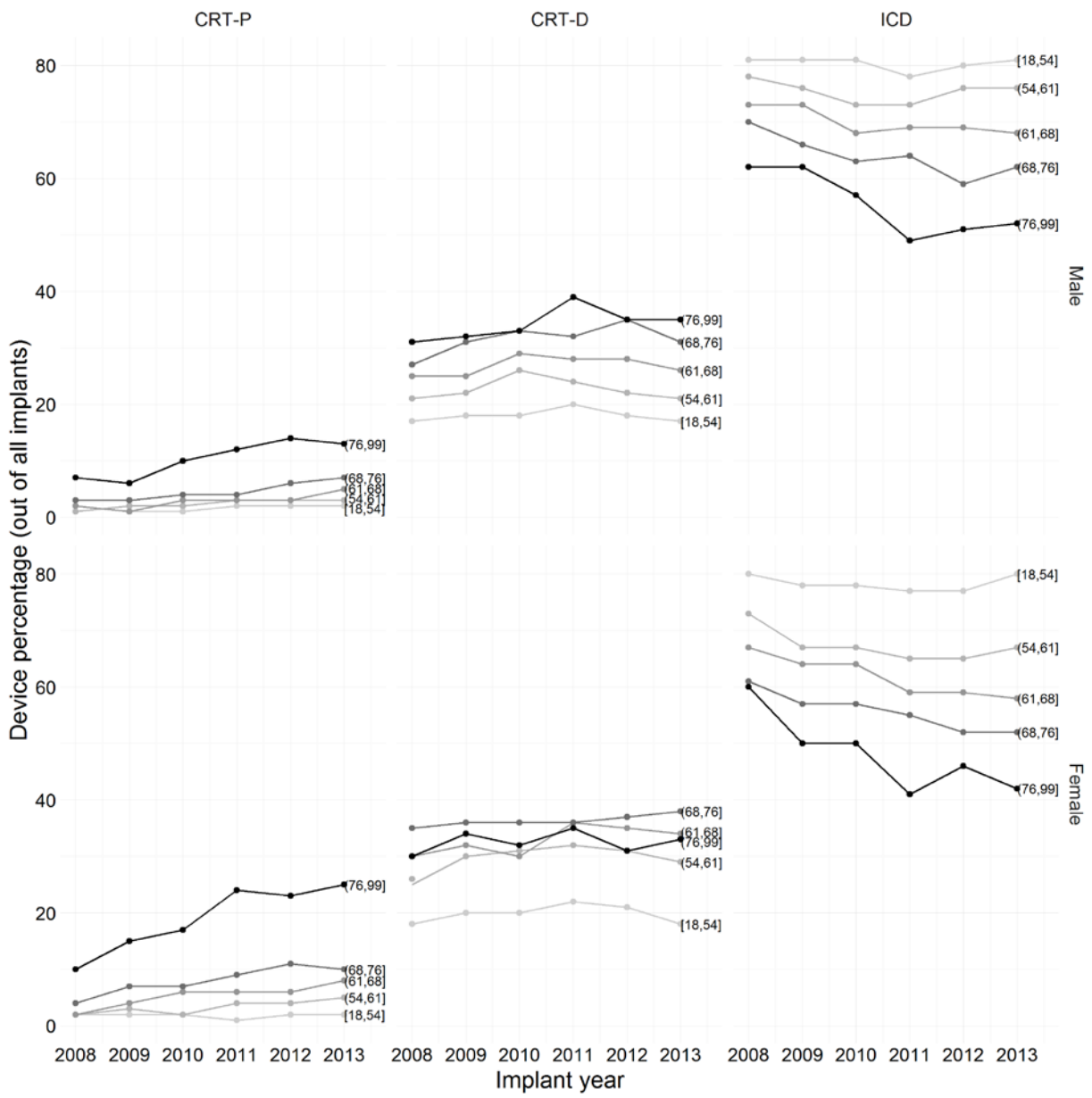
Table S3 Cardiovascular and comorbidity characteristic billing codes

Description	**ICD-9-CM codes**
Heart Failure Characteristics	
Atrial fibrillation/flutter	4273x
Arrhythmias	4260, 4270, 4271, 4272, 42731 42732, 42781
Cardiac failure	4271, 42741, 42742, 4275
Congestive heart failure	4150, 4160, 4161, 4168, 4169, 4170, 4171, 4178, 4179, 4250, 4252, 4253, 4254, 4255, 4257, 4258, 4259, 4280, 4281, 4289, 4290, 4291, 40201, 40211, 40291, 40401, 40403, 40411, 40413, 40491, 40493, 42511, 42518, 42820, 42821, 42822, 42823, 42830, 42831, 42832, 42833, 42840, 42841, 42842, 42843
Conduction disorders	42610-42613, 4262, 4263, 4264, 42650-42654, 42682
Charlson Comorbidities	
Coronary disease	410-4109, 412
Cerebrovascular disease	430x-437x, 438
Kidney disease	582x, 583x, 585, 586x, 588x
Pulmonary disease	490x-496x, 500x-505x
Dementia	290x
Diabetes	250x
HIV/AIDS	042x-044x
Liver disease	4560-4561, 4562, 45621, 5712, 5714, 5715, 5716, 5722-5728
Paralysis	342x, 3441
Vascular disease	441x, 4439, 7854, V434
Rheumatoid arthritis	7100, 7101, 7104, 7140-7412, 71481, 725x
Stomach ulcers	5310-5313, 5319, 5320-5323, 5329, 5330-5333, 5339, 5340-5343, 5349

Table S4 Medical therapies

Drug Class	**Specific Drug Names**
Beta blocker	acebutolol, atenolol, betaxolol, bisoprolol, carteolol , carvedilol, esmolol, labetalol, metoprolol, nadolol, nebivolol, penbutalol, pindolol, propranolol, sotalol, timolol
ACE inhibitor	benazepril, captopril, enalapril, fosinopril, Lisinopril, moexipril, (monopril), perindopril, quinapril, ramipiril, trandolapril
ARB	azilsartan, candesartan, eprosartan, irbesartan, losartan, olmesartan, telmisartan, valsartan
Diuretics	furosemide, bumetanide, torsemide, hydrochlorothiazide, metolazone, spironolactone

Figure S1. Fitted device probabilities from model for all new implants



Each line shows the modeled probability of receiving a particular device (conditional on receiving any new implant) by year (x axis), age (quintile, each line is a different quintile), sex (men in the top row, women in the bottom row) from a saturated multinomial regression model. Dots are the observed device proportions for each year-age-sex combination. CRT-P = cardiac resynchronization therapy pacemaker, ICD = implantable cardioverter defibrillator, CRT-D = CRT with ICD backup