Supplementary Online Content

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This supplementary material has been provided by the authors to give readers additional information about their work.

eMethods

National Inpatient Sample (NIS) redesign, 2012

Between 1998 and 2011, the NIS database sampling methodology remained largely unchanged. During this period, the database was constructed after including 100% of all inpatient discharges from a random 20% sample of hospitals in the United States. The number of states participating in NIS increased from 8 states in 1988 to 46 states in 2011, the latter drawing from a pool of 97% of all national discharges. Given the expansion, the NIS was redesigned in 2012 with the goal of improving national estimates.[1] Starting in 2012, there were three major changes to the NIS.[1] First, the sampling methodology was modified to include 20% of discharges from all of the reporting hospitals in the NIS (over 4500 hospitals in 2012) using a self-weighting systematic design. Second, hospitals were now identified using the state-inpatient database (SID) instead of the American Hospital Association (AHA) survey, and long term acute care (LTAC) hospitals were excluded from the hospital universe. Third, the states reporting to Healthcare Cost and Utilization Project (HCUP) and hospital sampled to the 2012 dataset were de-identified.

The redesign of the sampling methodology was the most significant change in the NIS in 2012, with improvement in precision and stability of national estimates by 42 to 48% (NIS redesign report, page ii).[1] The systematic sampling used in 2012 is a form of simple random sampling performed at the stratum level. For each stratum, all discharges were organized by hospital number and within hospitals by their Diagnosis-related group (DRG) and month of admission. Sampling of discharges was performed from this sorted list of hospitals such that the every x^{th} discharge was included, and on an average across all strata, x was equal to 5, such that every 5^{th} discharge was sampled and a 20% sample was generated. The sorting and sampling were performed within strata defined by hospital, census division, ownership, urban-rural

location, teaching status, bed-size catergory, diagnosis-related group (DRG) and admission month. While the overall sampling rate was 20%, the sampling rate varied across different strata due to missing discharges. (NIS redesign report, page 16).[1] The change in sampling methodology led a to 42% - 48% improvement in the precision of the estimates of in-hospital mortality, total charges and average length of stay.[1]

The replacement of discharge information from American Hospital Association (AHA) with SID and use of SID definition of acute-care hospitals, led to more reliable discharge volume information and improvement in classification of hospitals. Notably, using the SID discharge universe instead of the AHA led to a 3.6% drop in national estimates with an additional 0.7% drop with the exclusion of LTAC hospitals. To account for these changes and maintain uniformity in trends for years spanning 2012, new discharge-level weights, called 'trend weights' were calculated for patient level analysis for the year 1988 to 2011 by using the SID discharge universe, and were designed to be used instead of the originally supplied discharge weights for these years.[2] The application of trend weight was associated with a one-time 4.3% drop in national estimates without any changes in their precision (i.e. confidence intervals).

Propensity matched analysis

We aimed to determine whether use of percutaneous ventricular assist device (PVAD) was associated with lower mortality compared to intra-aortic balloon pump (IABP). Patients who receive PVAD are significantly different from patients who receive IABP with regards to clinical characteristics and disease severity, and this difference may not only influence the choice of device (PVAD or IABP) but also risk of mortality (confounding by indication). Therefore, we used a matched propensity score design for survey data to explicitly account for indication bias.

For this analysis, we only included patients who received either a PVAD or IABP, and excluded patients who received both PVAD and IABP (n=552, un-weighted) during the same hospital stay as such patients are sicker compared to either PVAD or IABP group alone. Moreover, we also restricted our study cohort to only hospitals that had a PVAD program. This was done in order to minimize confounding due to between-hospital differences in patients who receive IABP at non-PVAD hospitals. Finally, a total of 1679 PVAD patients (un-weighted), and 21645 IABP patients (un-weighted) were included (eFigure 1).

Estimation of the propensity score model:

We constructed a non-parsimonious multivariable logistic regression model with receipt of PVAD or IABP as the dependent variable ('0'=IABP, and '1'= PVAD) to determine each patient's likelihood of receiving a PVAD based on his or her measured clinical characteristics. Variables used in our model included age, sex, race, discharge diagnoses (cardiogenic shock, acute myocardial infarction (AMI), cardiac arrest, coronary atherosclerosis, congestive heart failure (CHF), valvular heart disease, cardiac arrhythmias, peripheral arterial disease), co-morbidities (diabetes, hypertension, dyslipidemia, cancer, liver disease, chronic kidney disease, fluid-electrolyte disorder, chronic obstructive pulmonary disease, coagulopathy, substance-use disorder), procedures (percutaneous coronary intervention [PCI], coronary artery bypass graft surgery [CABG] or mechanical ventilation) and nature of admission (non-elective vs. elective). Furthermore, as is recommended for conducting propensity score analysis in survey data, we also included the NIS discharge weight as a covariate in the propensity score estimation model.[3] It has been shown that inclusion of sample weights in the propensity score model significantly reduces bias in the estimation of relative risk.[3] The c-statistic for our propensity score model was 0.81.

Matching algorithm:

We used an innovative algorithm to match each patient who received a PVAD (i.e., "cases") with up to 2 similar patients who received an IABP (i.e., "controls") using the propensity scores with a caliper width less than one-quarter of the standard deviation of the logit of the propensity score as well as the nearest available Mahalanobis metric.[4] The Mahalanobis metric is a multivariate distance between two observations based on a set of pre-specified characteristics. It is based on the mean, variance and the covariance of the pre-specified variables, and measures the degree of closeness between 2 observations with regards to the pre-specified variables.[4,5]

Our matching algorithm works iteratively to match each PVAD patient with up to 2 IABP patients whose propensity score was within the specified caliper width. If no candidate match existed, the PVAD patient was removed from analysis (this occurred for 233 PVAD patients). If 1 or 2 candidate matches were available based on propensity score, then that patient was selected and the match was considered final. If more than 2 candidate matches existed, the Mahalanobis distance between the case patient and the candidate matches was calculated based on the propensity score and the following additional patient characteristics: age, cardiogenic shock, AMI, and PCI. Only 2 control patients with the smallest distance to the case patient were selected as the final match. These control patients were then removed from the possible pool of candidate matches for subsequent patients. The matching process was repeated iteratively for all patients. The final sample included 1446 PVAD patients matched to 2888 IABP patients.

Previous studies have showed that the above matching algorithm was superior to nearest neighbor propensity matching in terms of achieving covariate balance.[4,5] To perform these analyses, we used a SAS macro created by Feng et al for running the above matching algorithm.[4]

Standardized Difference:

To ensure that our matching algorithm was successful in achieving balance between PVAD and IABP patients on measured covariates, we calculated standardized differences for all covariates using the formulae below.

For categorical variables

$$d = 100x[(p_{PVAD} - p_{IABP})/(SQRT\ ((p_{PVAD}\ (1 - p_{PVAD})\ + p_{IABP}(1 - p_{IABP}))/2)]$$

d=standardized difference;

p_{PVAD} *= prevalence of the covariate in the PVAD group*

p_{IABP} *= prevalence of the covariate in the IABP group;*

SQRT = square root

For continuous variables

$$d = 100x[(X_{PVAD} - X_{IABP})/(SQRT\ ((S^2_{PVAD} + S^2_{IABP})/2))]$$

d=standardized difference;

X_{PVAD} *= mean of the covariate in the PVAD group*

X_{IABP} *= mean of the covariate in the IABP group;*

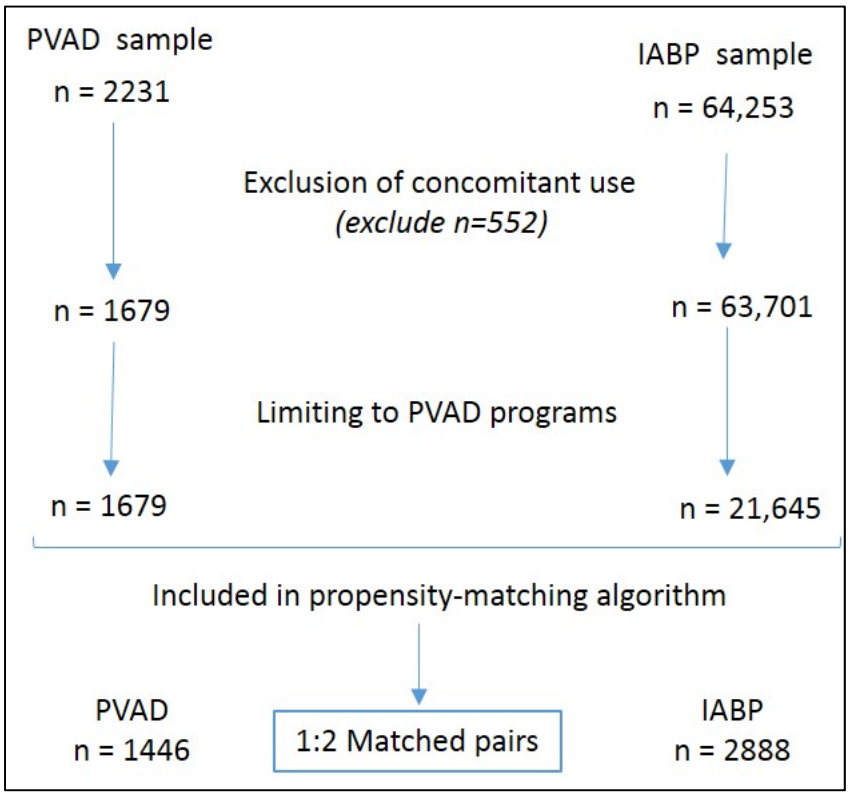
S^2_{PVAD} *= Standard deviation of the covariate in the PVAD group*

S^2_{IABP} *= Standard deviation of the covariate in the IABP group*

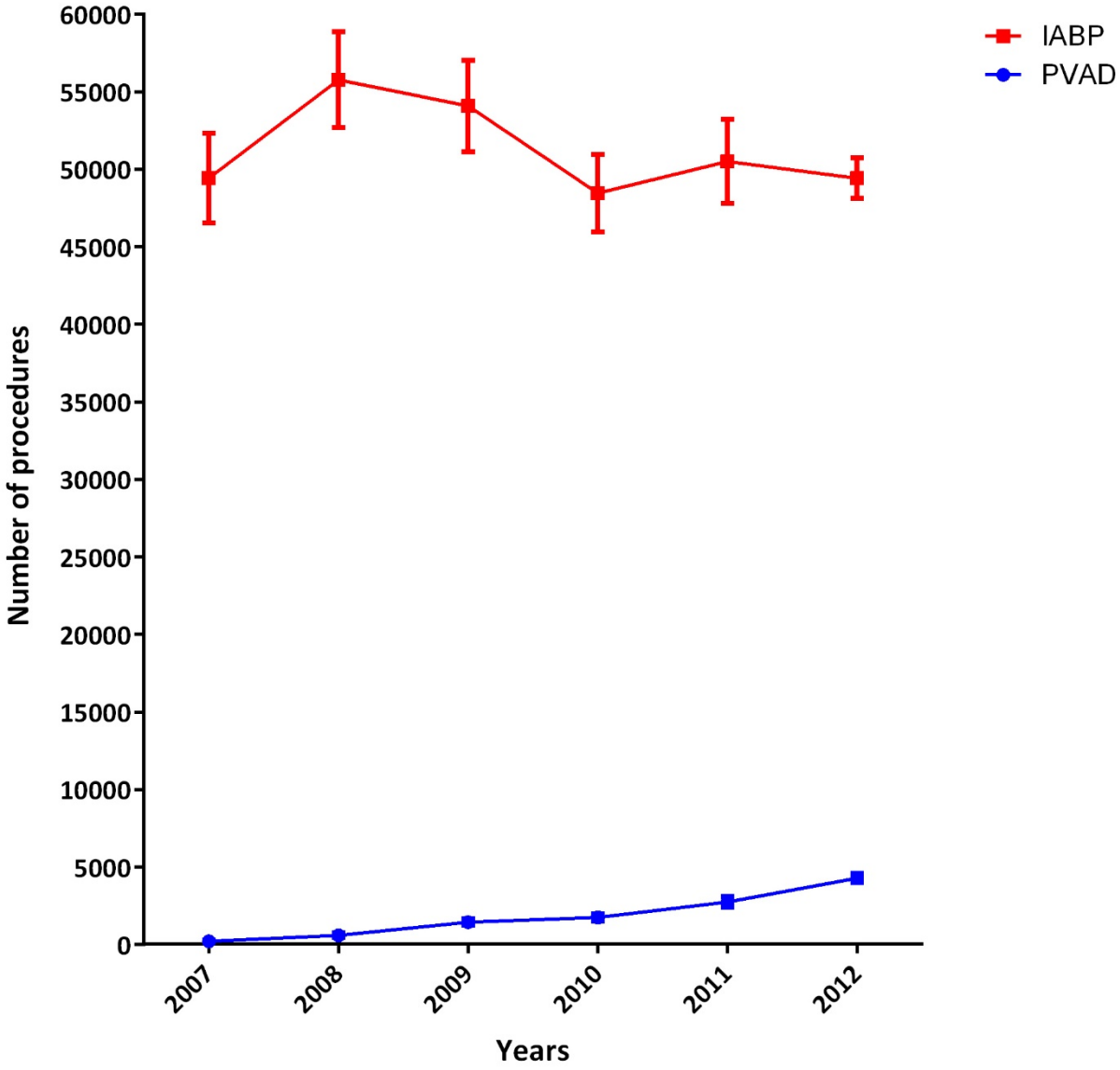
SQRT = square root

Matching is considered to be successful, if standardized differences for all covariates are < 10%, which was achieved in our study (Figure 3).[6]

eFigure 1. Derivation of the PVAD and IABP Cohort for Propensity Matched Analysis



eFigure 2. Calendar-Year Trends in the Volume of PVAD Implantation in the United States



During 2007-2012, annual PVAD volume increased significantly from 167 in 2007 to 4245 in 2012, P for trend < 0.0001)

eTable 1. Predictors of In-Hospital Mortality in PVAD Recipients (c-statistic - 0.83)

Covariates	Odds ratio	95% confidence interval		P value
		Lower limit	Upper limit	
Age	1.02	1.01	1.03	<0.0001
Year 2008 vs 2007	0.90	0.31	2.62	0.85
Year 2009 vs 2007	0.69	0.25	1.85	0.46
Year 2010 vs 2007	0.85	0.31	2.31	0.75
Year 2011 vs 2007	0.76	0.29	2.01	0.58
Year 2012 vs 2007	0.90	0.34	2.37	0.83
Sex, male vs female	1.08	0.81	1.45	0.59
Race, white vs non-white	0.76	0.60	0.97	0.02
Cardiogenic shock	2.26	1.66	3.07	<0.0001
AMI	1.63	1.21	2.19	0.0013
PCI	0.41	0.29	0.58	<0.0001
CHF	0.59	0.44	0.78	0.0002
Arrhythmia	0.98	0.74	1.30	0.9131
Diabetes	0.84	0.64	1.10	0.1982
Hypertension	1.02	0.79	1.33	0.87
CKD	0.88	0.65	1.19	0.4123
Fluid electrolyte disorder	1.86	1.45	2.39	<0.0001
Coagulopathy	1.07	0.79	1.45	0.682
Cardiac arrest	2.16	1.58	2.95	<0.0001
Mechanical ventilation	2.24	1.71	2.94	<0.0001
Liver disease	1.19	0.89	1.59	0.2507
COPD	0.91	0.67	1.24	0.5444
CAD	0.48	0.34	0.69	<0.0001
Cancer	1.15	0.75	1.76	0.5342
CABG	1.29	0.85	1.98	0.2368
Non- elective vs. elective admission	0.96	0.70	1.31	0.7862

Abbreviations: AMI – Acute myocardial infarction, PCI – Percutaneous coronary intervention, CHF – congestive heart failure, CKD – chronic kidney disease, COPD – chronic obstructive pulmonary disease, CAD – Coronary artery disease, CABG – coronary artery bypass grafting.

eTable 2. Characteristics of PVAD Recipients According to Clinical Subgroups

Characteristics*	Cardiogenic shock	AMI, no cardiogenic shock	PCI, no AMI or cardiogenic shock	Others	**P value**
Estimated number of PVAD recipients (weighted numbers ± SD)	4904 ± 334	2362 ± 176	2606 ± 200	921 ± 95	<0.0001
Proportion of all PVAD recipients (%)	45.4 (1.5)	21.9 (1.0)	24.1 (1.2)	8.5 (0.7)	<0.0001
Patient characteristics					
Mean Age (SEM)	61.3 (0.5)	69.4 (0.6)	69.5 (0.5)	61.0 (1.2)	<0.0001
Age ≥ 65 year (%)	44.0 (1.7)	67.0 (2.0)	65.9 (1.9)	45.9 (3.8)	<0.0001
Male Sex	72.6 (1.4)	71.5 (2.1)	77.1 (1.8)	76.6 (3.1)	0.13
Race					0.22
White	59.9 (2.2)	63.4 (2.7)	65.6 (2.5)	63.8 (4.1)	
Black	11.7 (1.4)	8.3 (1.6)	8.9 (1.4)	12.3 (2.5)	
Other	15.6 (1.5)	14.7 (1.7)	14.6 (2.0)	16.1 (3.0)	
Missing/Unknown	12.8 (2.0)	13.6 (2.6)	11.0 (2.1)	7.9 (2.3)	
Income quartiles†					0.17
0-25	28.8 (1.9)	31.9 (2.7)	31.4 (2.3)	25.1 (3.8)	
26 to 50	24.3 (1.6)	27.3 (2.2)	26.7 (2.0)	30.8 (3.3)	
51 to 75	25.7 (1.5)	22.2 (2.1)	19.6 (1.9)	20.9 (3.0)	
76 to 100	21.2 (1.6)	18.5 (2.6)	22.2 (2.4)	23.2 (3.2)	
Discharge diagnoses					
Cardiogenic shock	100	0	0	0	-
AMI	67.0 (1.7)	100	0	0	-
CHF	69.9 (1.6)	68.9 (2.3)	70.0 (2.2)	74.4 (3.3)	0.60
Coronary Artery Disease	73.1 (1.6)	90.3 (1.5)	98.9 (0.4)	65.0 (3.6)	<0.0001
Cardiac arrest	36.5 (1.6)	9.9 (1.3)	3.9 (0.8)	15.4 (2.6)	<0.0001
Peripheral Artery Disease	9.8 (1.0)	17.7 (1.8)	16.2 (1.6)	14.0 (2.5)	<0.0001
Arrhythmia	57.0 (1.7)	36.7 (2.4)	33.7 (2.2)	71.0 (3.5)	<0.0001
Comorbid Conditions					
Hypertension	49.7 (1.6)	68.6 (2.4)	73.8 (2.0)	59.0 (3.9)	<0.0001
Diabetes Mellitus	36.7 (1.6)	48.3 (2.2)	45.6 (2.3)	36.7 (3.6)	<0.0001
Cancer	6.1 (0.7)	10.8 (1.4)	9.9 (1.3)	7.4 (1.8)	0.004
Liver disease	31.2 (1.8)	7.6 (1.2)	4.4 (0.9)	17.3 (2.9)	<0.0001
COPD	13.2 (1.2)	22.2 (1.8)	18.0 (1.9)	16.7 (2.7)	0.0004
Dyslipidemia	37.0 (1.7)	56.5 (2.6)	61.5 (2.2)	39.6 (4.0)	<0.0001
Chronic kidney disease	21.8 (1.4)	30.0 (2.0)	36.4 (1.9)	36.0 (3.8)	<0.0001
Fluid/electrolyte disorder	58.4 (1.8)	32.0 (2.3)	13.8 (1.6)	44.3 (3.9)	<0.0001
Coagulation disorder	31.1 (1.7)	12.5 (1.3)	5.4 (1.1)	22.1 (3.4)	<0.0001
Substance-abuse	2.5 (0.5)	1.3 (0.5)	1.3 (0.5)	1.9 (1.0)	0.25
Procedures					
PCI	52.1 (1.9)	87.4 (1.6)	100	0	-

CABG	13.0 (1.1)	7.7 (1.2)	0.6 (0.4)	18.0 (3.1)	<0.0001
Mechanical ventilation	54.6 (1.8)	14.0 (1.5)	4.0 (0.9)	22.8 (3.0)	<0.0001
Administrative/ financial details					
Payment source					<0.0001
Medicare	45.5 (1.7)	67.5 (2.2)	67.7 (2.1)	59.1 (3.6)	
Medicaid	10.3 (1.1)	7.2 (1.1)	6.3 (1.1)	8.3 (1.9)	
Private insurance	33.9 (1.7)	18.7 (1.8)	22.3 (2.0)	28.7 (3.3)	
Others	10.4 (1.0)	6.6 (1.2)	3.7 (0.8)	3.9 (1.4)	
Elective admission	15.5 (1.4)	12.7 (1.8)	48.5 (2.6)	37.8 (4.0)	<0.0001
Disposition					<0.0001
Home or self-care	15.8 (1.4)	44.4 (2.3)	73.6 (2.1)	38.5 (3.8)	
Short term hospital	8.0 (1.0)	1.9 (0.6)	0.4 (0.3)	2.8 (1.2)	
Skilled care facility	18.8 (1.5)	20.4 (2.0)	10.1 (1.4)	14.9 (2.7)	
Home health care	9.9 (1.0)	16.3 (1.9)	12.6 (1.6)	12.5 (2.6)	
Died	47.5 (1.7)	17.1 (1.8)	3.3 (0.8)	31.4 (3.6)	
Length of stay (days – mean ± SEM)	15.7 (0.9)	10.1 (0.5)	5.8 (0.3)	15.4 (1.4)	<0.0001[#]
In-hospital mortality	47.5 (1.7)	17.0 (1.8)	3.3 (0.8)	31.4 (3.6)	<0.0001
Risk-adjusted odds ratio (95% C.I.) - Mortality	1	0.42 (0.30 – 0.60)	0.10 (0.05 - 0.18)	0.8 (0.52 - 1.24)	<0.0001

Abbreviations: SD – standard deviation, SEM – standard error of mean
All numbers in table represent percentages (standard errors), unless otherwise specified
[§]Median household income
[†]Median household income quartiles for patient zip code
#for differences in geometric means of length of stay

eTable 3. Propensity Score Estimation Model

Covariates	Odds ratio	95% confidence interval		P - value
		Lower limit	Upper limit	
Age	1.005	1.000	1.009	0.0315
Male sex vs females	1.239	1.096	1.400	0.0006
Race, white vs non-white	1.004	0.881	1.144	0.25
Cardiogenic shock	0.565	0.498	0.642	<0.0001
AMI	0.318	0.278	0.364	<0.0001
CHF	2.170	1.920	2.452	<0.0001
CAD	1.385	1.173	1.635	0.0001
Arrhythmia	0.934	0.836	1.045	0.23
Diabetes	1.246	1.112	1.397	0.0002
Hypertension	0.917	0.809	1.038	0.17
Chronic kidney disease	1.268	1.112	1.447	0.0004
Fluid-electrolyte disorder	1.027	0.908	1.161	0.68
Coagulopathy	1.014	0.872	1.179	0.86
Cardiac arrest	1.014	0.875	1.176	0.85
Mechanical ventilation	0.807	0.703	0.927	0.0024
Liver disease	1.847	1.572	2.169	<0.0001
COPD	1.212	1.050	1.399	0.0087
Dyslipidemia	1.008	0.895	1.134	0.90
Substance abuse	1.053	0.718	1.543	0.79
Valvular heart disease	0.746	0.651	0.856	<0.0001
Peripheral artery disease	1.448	1.231	1.702	<0.0001
Cancer	0.970	0.798	1.179	0.76
PCI	3.712	3.179	4.334	<0.0001
CABG	0.133	0.106	0.166	<0.0001
Admission, non-elective vs elective	0.706	0.618	0.806	<0.0001
Patient-level weight	1.113	0.997	1.243	0.06

Abbreviations: AMI – Acute myocardial infarction, CHF – congestive heart failure, CAD – Coronary artery disease, COPD – chronic obstructive pulmonary disease PCI – Percutaneous coronary intervention, CABG – coronary artery bypass grafting.

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