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Clinical Investigation

Does the Type of Chronic Heart Failure Impact In-Hospital Outcomes for Aortic Valve Replacement Procedures?

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Abstract

Background: This study assessed in-hospital outcomes of patients with chronic systolic, diastolic, or mixed heart failure (HF) undergoing transcatheter aortic valve replacement (TAVR) or surgical aortic valve replacement (SAVR).

Methods: The Nationwide Inpatient Sample database was used to identify patients with aortic stenosis and chronic HF who underwent TAVR or SAVR between 2012 and 2015. Propensity score matching and multivariate logistic regression were used to determine outcome risk.

Results: A cohort of 9,879 patients with systolic (27.2%), diastolic (52.2%), and mixed (20.6%) chronic HF were included. No statistically significant differences in hospital mortality were noted. Overall, patients with diastolic HF had the shortest hospital stays and lowest costs. Compared with patients with diastolic HF, the risk of acute myocardial infarction (TAVR odds ratio [OR], 1.95; 95% CI, 1.20-3.19; $P = .008$; SAVR OR, 1.38; 95% CI, 0.98-1.95; $P = .067$) and cardiogenic shock (TAVR OR, 2.15; 95% CI, 1.43-3.23; $P < .001$; SAVR OR, 1.89; 95% CI, 1.42-2.53; $P \leq .001$) was higher in patients with systolic HF, whereas the risk of permanent pacemaker implantation (TAVR OR, 0.58; 95% CI, 0.45-0.76; $P < .001$; SAVR OR, 0.58; 95% CI, 0.40-0.84; $P = .004$) was lower following aortic valve procedures. In TAVR, the risk of acute deep vein thrombosis and kidney injury was higher, although not statistically significant, in patients with systolic HF than in those with diastolic HF.

Conclusion: These outcomes suggest that chronic HF types do not incur statistically significant hospital mortality risk in patients undergoing TAVR or SAVR.

Keywords: Heart failure; aortic valve; aortic stenosis

Introduction

Long-standing moderate to severe aortic stenosis (AS) can lead to chronic systolic, diastolic, or mixed heart failure (HF) presentation. With medical management alone, patients with symptomatic, severe AS have a very poor prognosis[1-3]; thus, valve replacement procedures are recommended. However, preexisting HF in patients with AS is an independent risk factor for increased mortality following aortic valve replacement.[4,5] Current guidelines recommend transcatheter aortic valve replacement (TAVR) as the procedure of choice for qualifying patients with severe, symptomatic AS who are at an intermediate to high risk for surgical aortic valve replacement (SAVR).[2,3,6-8]

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Recently, the use of TAVR in low-risk surgical populations has been evaluated, and favorable TAVR outcomes have been demonstrated.[9-11]

Recently, the authors' group conducted a retrospective analysis of the Nationwide Inpatient Sample (NIS) registry to compare the outcomes of patients with chronic heart failure (CHF) who underwent either TAVR or SAVR procedures.[12] The analysis identified a longer length of stay and higher costs associated with SAVR procedures, which is consistent with the results from previous studies.[3,6,10,13,14] Building on this knowledge, it was hypothesized that the type of CHF may be associated with in-hospital outcomes and might affect the risk profile for patients who undergo TAVR or SAVR procedures. Although studies on in-hospital outcomes following these procedures in patients with AS have been conducted, few have incorporated the type of CHF in the analysis. Because the NIS registry includes the diagnosis codes for chronic systolic, diastolic, and mixed HF, the aim was to determine their influence on the outcomes of TAVR and SAVR procedures.

Abbreviations and Acronyms

AS	aortic stenosis
CHF	chronic heart failure
HFbEF	heart failure with borderline ejection fraction
HFmrEF	heart failure with midrange ejection fraction
HFpEF	heart failure with preserved ejection fraction
HFrEF	heart failure with reduced ejection fraction
HIPAA	Health Insurance Portability and Accountability Act
ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
ICD-10	*International Classification of Diseases, Tenth Revision*
LVEF	left ventricular ejection fraction
MI	myocardial infarction
NIS	Nationwide Inpatient Sample
OR	odds ratio
SAVR	surgical aortic valve replacement
TAVR	transcatheter aortic valve replacement

Patients and Methods

Data Collection

This study used data from the NIS registry (Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality).[15] Data from January 2012 to September 2015 were screened for patients who underwent TAVR or SAVR procedures as identified by *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) procedure codes. Data were collected on patient demographic details, patient risk factors, and the Charlson Comorbidity Index (CCI).[16] Comorbidities were selected based on their established clinical significance in patients with CHF. The *ICD-9-CM* codes were also used to collect information on HF type (systolic, diastolic, or mixed). Collected hospital data included the geographic region, number of beds, location, and teaching status. The NIS database conforms to the limited data sets in which 16 direct identifiers have been removed; thus, it follows HIPAA (Health Insurance Portability and Accountability Act) regulations in compliance with human study guidelines. Under HIPAA, institutional review board approval is not required for use of limited data sets.

Study Cohort

The study cohort included individuals aged 18 years or older with a diagnosis of degenerative calcific or congenital AS and CHF (systolic, diastolic, or mixed) who underwent TAVR or SAVR. *International Classification of Diseases, Tenth Revision* (*ICD-10*) codes were used beginning in 2016. To avoid data complications, only *ICD-9-CM* codes (Table SI) were used, which limited the time frame to 2012 to 2015, as has been used in the literature.[12,17,18]

The study cohort excluded the following: (1) patients undergoing both TAVR and SAVR procedures during the same hospitalization, (2) patients undergoing concomitant percutaneous coronary intervention or coronary artery bypass surgery during aortic valve replacement, (3) patients with a history of nonaortic valvular surgeries and/or non-CHF, and (4) patients with diagnosed aortic or mitral insufficiency or mitral stenosis because of rheumatic disease, endocarditis, or an unspecified cause.

Primary and Secondary Outcomes

The primary outcome for this study was in-hospital mortality in patients with systolic, diastolic, or mixed CHF undergoing a TAVR or SAVR procedure for AS. Secondary outcomes were hospital length of stay, hospital cost, and in-hospital complications. The hospital cost for patients was calculated by multiplying the total hospital charges for each inpatient hospitalization by the Healthcare Cost and Utilization Project cost-to-charge ratios, as was previously described.[12]

Statistical Analysis

For categorical and continuous variables, χ^2 and Kruskal-Wallis test were used, respectively, to determine the primary (in-hospital mortality) and secondary (hospital length of stay, hospital cost, and in-hospital complications) outcomes. Categorical variables are noted as frequencies (percentages), and continuous variables are presented as medians (IQRs). Potential confounders that were clinically relevant or significantly different ($P < .05$) in TAVR and SAVR cohorts were included in the multivariate regression models. Odds ratios (ORs) were calculated from logistic regression models comparing the categorical primary and secondary outcomes among patients with systolic, diastolic, and mixed CHF who underwent TAVR or SAVR. To address the selection bias of retrospective analysis, patients in different CHF groups were matched by propensity score according to factors that may influence outcomes in patients with CHF, such as age, sex, race and ethnicity, median household income, and various comorbidities. Such covariates were further included in the multivariate logistic regression models as well. Moreover, hospital-level covariates, including hospital geographic location, number of beds, and hospital teaching status, were also adjusted for in the multivariate analysis. $P < .05$ was considered statistically significant. All statistical analyses were conducted with R, version 4.2.0 (http://www.R-project.org, The R Foundation).

Results

Patient and Hospital Characteristics

Among the cohort of 9,879 patients with AS and CHF, a majority had diastolic CHF (52.2%), followed by systolic (27.2%) and mixed (20.6%) CHF. A similar distribution of CHF was observed when patients were divided by the type of procedure (Table I). Figure 1 and

TABLE I. Distribution of Type of CHF in Patients Undergoing Aortic Valve Replacement Procedures

	Total No.	Systolic CHF, No. (%)	Diastolic CHF, No. (%)	Mixed CHF, No. (%)
TAVR	5,871	1,278 (22)	3,339 (57)	1,254 (21)
SAVR	4,008	1,406 (35)	1,820 (45)	782 (20)
Total	9,879	2,684 (27)	5,159 (52)	2,036 (21)

CHF, chronic heart failure; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

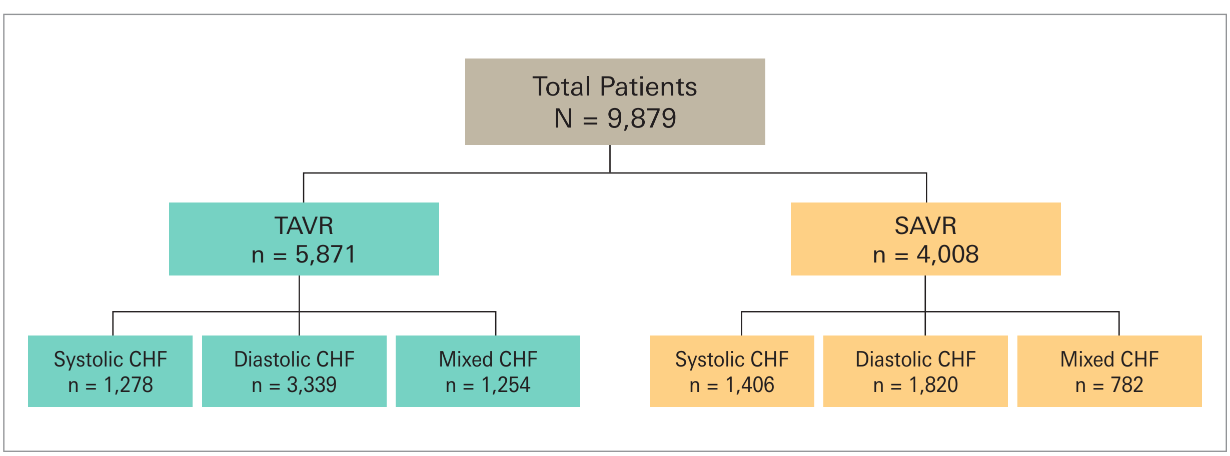

Fig. 1 Patient distribution with chronic heart failure types in TAVR and SAVR groups.

CHF, chronic heart failure; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

Table I depict the patient distribution with CHF types in the TAVR and SAVR groups.

In a comparison using a 2-sample *t* test, the mean age was not statistically different among CHF groups in the TAVR population, but a difference was found in the SAVR population (*P* = .0067). Patients with diastolic CHF were more likely to be female in the TAVR group (55.4%) and the SAVR group (51.6%); however, systolic and mixed CHF populations were more likely to be male regardless of procedure (Table II). A comparison of comorbidities revealed that patients with diastolic CHF, compared with systolic or mixed CHF, had a higher incidence of obesity, hypertension, and dyslipidemia and a lower incidence of prior myocardial infarction (MI), chronic obstructive pulmonary disease, and chronic kidney disease in both the TAVR and SAVR populations (Table II). Overall, patients with diastolic CHF had lower CCI scores than did patients with systolic and mixed CHF. No significant differences in race or ethnicity, income, hospital location, or hospital size were noted among CHF types for both procedures.

Outcomes in TAVR

The in-hospital outcomes of patients with systolic, diastolic, or mixed CHF who underwent TAVR are listed in Table III. The percentage of in-hospital mortality in patients with systolic, diastolic, or mixed CHF who underwent TAVR was statistically different (*P* = .026); the mixed-CHF group had the highest mortality rate (4.1%), and the diastolic group had the lowest (2.6%). Propensity score matching was used to compare in-hospital mortality among CHF groups (ie, systolic vs diastolic CHF and mixed vs diastolic CHF). There were no statistically significant differences in hospital mortality between the different CHF groups undergoing TAVR (Fig. 2, Fig. 3).

In the TAVR group, patients with diastolic or mixed CHF had the lowest median (IQR) hospital cost (diastolic, $40,580 [$10,391-$56,474]; mixed, $39,317 [$9,622-$56,945]), and patients with diastolic CHF had the shortest median (IQR) hospital length of stay, at 5 (3-8) days. Patients with systolic CHF had the highest median (IQR) cost ($43,240 [$12,456-$62,298]), and the longest median (IQR) hospital length of stay was similar among patients with systolic and mixed CHF (5 [3-9] days) (Table III).

In the TAVR group, patients with mixed CHF had a higher risk of acute MI (OR, 1.42; 95% CI, 0.87-2.32; *P* = .168), cardiac arrest (OR, 1.75; 95% CI, 1.14-2.68; *P* = .011), and cardiogenic shock (OR, 2.41; 95% CI, 1.54-3.78; *P* < .001) than did patients with diastolic CHF (Fig. 3). However, patients with mixed CHF had a significantly lower risk of acute hemorrhage (OR, 0.80; 95% CI, 0.66-0.95; *P* = .014) requiring a packed red blood cell transfusion (OR, 0.70; 95% CI, 0.53-0.93; *P* = .014) than did patients with diastolic CHF.

Figure 2 shows in-hospital complications between patients with systolic and diastolic CHF. In the TAVR group, patients with systolic CHF had a significantly higher risk of acute MI (OR, 1.95; 95% CI, 1.20-3.19; *P* = .008) and cardiogenic shock (OR, 2.15; 95% CI, 1.43-3.23; *P* < .001). A higher risk of permanent pacemaker implantation (OR, 0.58; 95% CI, 0.45-0.76; *P* < .001) was found in patients with diastolic CHF. Patients with systolic CHF in the TAVR group had an increased, although statistically nonsignificant, risk of acute deep vein thrombosis (OR, 2.17; 95% CI, 0.88-5.34] *P* = .095) and acute kidney injury (OR, 1.18; 95% CI, 0.96-1.45; *P* = .109); they also had a decreased risk of acute hemorrhage (OR, 0.84; 95% CI, 0.70-0.99; *P* = .045) compared with patients with diastolic CHF.

Outcomes in SAVR

There was no significant difference observed in the frequency of in-hospital mortality for CHF groups among the SAVR cohort (Table III). A multivariate logistic model showed no significant between-group differences in mortality among CHF types in the SAVR group (Fig. 2, Fig. 3).

Patients with diastolic CHF who underwent SAVR had the lowest median (IQR) hospital cost ($37,813 [$23,605-$53,456]) and shortest median (IQR) hospital length of stay (7 [5-12] days) (Table III). The mixed CHF group had the highest median (IQR) hospital cost ($44,477 [$28,483-$63,369]), and the longest median (IQR) hospital length of stay was similar among patients with systolic and mixed CHF (8 [5-14] days).

Compared with patients with diastolic CHF, those with mixed CHF had a higher risk of acute MI (OR, 1.63; 95% CI, 1.06-2.52; *P* = .028), cardiac arrest (OR, 1.54; 95% CI, 0.92-2.57; *P* = .101), and cardiogenic shock (OR, 1.80; 95% CI, 1.20-2.70; *P* = .004) (Fig. 3).

In a comparison of patients with systolic and diastolic CHF in the SAVR group, those with systolic CHF had a higher risk of acute MI (OR 1.38; 95% CI, 0.98-1.95; *P* = .067) and cardiogenic shock (OR, 1.89; 95% CI,

TABLE II. Baseline Inpatient and Hospital Characteristics for Patients Who Underwent TAVR or SAVR Procedures Between 2012 and 2015 in the United States

Variable[a]	TAVR				SAVR			
	Systolic CHF (n = 1,278)	Diastolic CHF (n = 3,339)	Mixed CHF (n = 1,254)	Total (N = 5,871)	Systolic CHF (n = 1,406)	Diastolic CHF (n = 1,820)	Mixed CHF (n = 782)	Total (N = 4,008)
Age, mean (SD) y[b]	71.9 (21.6)	70.7 (23.2)	70.1 (22.5)	70.9 (22.7)	65.8 (17.8)	67.8 (17.9)	66.7 (18.1)	66.9 (18.0)
Male[b,c]	749 (58.6)	1,488 (44.6)	698 (55.7)	2,935 (50.0)	893 (63.5)	881 (48.4)	484 (61.9)	2,258 (56.3)
Race and ethnicity[d]								
African American	97 (8.1)	281 (9.0)	106 (9.2)	484 (8.8)	137 (10.4)	177 (10.5)	61 (8.4)	375 (10.0)
Asian	15 (1.2)	45 (1.4)	22 (1.9)	82 (1.5)	15 (1.1)	10 (0.6)	12 (1.6)	37 (1.0)
Hispanic	63 (5.2)	163 (5.2)	50 (4.3)	276 (5.0)	81 (6.1)	111 (6.5)	54 (7.4)	246 (6.6)
Native	≤10	≤10	≤10	16 (0.3)	≤10	≤10	≤10	15 (0.4)
White	985 (81.8)	2,517 (80.3)	918 (79.3)	4,420 (80.4)	1,017 (77.1)	1,301 (77.0)	572 (78.4)	2,890 (77.2)
Other	42 (3.5)	122 (3.9)	55 (4.7)	219 (4.0)	64 (4.9)	84 (5.0)	28 (3.8)	176 (4.7)
CCI score[b,c]								
Mild (1-2)	388 (30.4)	1,241 (37.2)	382 (30.5)	2,011 (34.3)	725 (51.6)	987 (54.2)	366 (46.8)	2,078 (51.8)
Moderate (3-4)	562 (44.0)	1,399 (41.9)	569 (45.4)	2,530 (43.1)	492 (35.0)	585 (32.1)	293 (37.5)	1,370 (34.2)
Severe (≥5)	328 (25.7)	699 (20.9)	303 (24.1)	1,330 (22.7)	189 (13.4)	248 (13.6)	123 (15.7)	560 (14.0)
Income quartile[e]								
First (0-25th percentile)	299 (24.0)	801 (24.4)	323 (26.2)	1,423 (24.7)	348 (25.4)	428 (24.0)	193 (25.2)	969 (24.7)
Second (26th-50th percentile; median)	329 (26.4)	759 (23.1)	294 (23.9)	1,382 (24.0)	343 (25.1)	453 (25.3)	213 (27.8)	1,009 (25.7)
Third (51st-75th percentile)	303 (24.3)	837 (25.5)	323 (26.3)	1,463 (25.4)	352 (25.7)	431 (24.1)	180 (23.5)	963 (24.6)
Fourth (76th-100th percentile)	317 (25.3)	885 (27.0)	290 (23.6)	1,492 (25.9)	325 (23.8)	475 (26.6)	179 (23.4)	979 (25.0)
Hospital location and teaching status[b]								
Rural	46 (3.6)	133 (4.0)	61 (4.8)	240 (4.1)	35 (2.5)	78 (4.3)	24 (3.1)	137 (3.4)
Urban nonteaching	211 (16.5)	499 (14.9)	164 (13.1)	874 (14.9)	294 (20.9)	341 (18.7)	167 (21.3)	802 (20.0)
Urban teaching	1,021 (79.9)	2,707 (81.1)	1,029 (82.1)	4,757 (81.0)	1,077 (76.6)	1,401 (77.0)	591 (75.6)	3,069 (76.6)
Hospital geographic region[b,c]								
Northeast	342 (26.7)	1,076 (32.2)	355 (28.3)	1,773 (30.1)	372 (26.5)	577 (31.7)	171 (21.9)	1,120 (27.9)
Midwest	305 (23.9)	786 (23.5)	365 (29.1)	1,456 (24.8)	333 (23.7)	481 (26.4)	220 (28.1)	1,034 (25.8)
Hospital geographic region[b,c]								
South	486 (38.0)	1,084 (32.5)	410 (32.7)	1,980 (33.7)	522 (37.1)	547 (30.1)	241 (30.8)	1,310 (32.7)
West	145 (11.4)	393 (11.8)	124 (9.9)	662 (11.3)	179 (12.7)	215 (11.8)	150 (19.2)	544 (13.6)

Continued

TABLE II. Baseline Inpatient and Hospital Characteristics for Patients Who Underwent TAVR or SAVR Procedures Between 2012 and 2015 in the United States (continued)

	TAVR				SAVR			
Variable[a]	Systolic CHF (n = 1,278)	Diastolic CHF (n = 3,339)	Mixed CHF (n = 1,254)	Total (N = 5,871)	Systolic CHF (n = 1,406)	Diastolic CHF (n = 1,820)	Mixed CHF (n = 782)	Total (N = 4,008)
Hospital bed size								
Small	119 (9.3)	334 (10.0)	131 (10.5)	584 (9.9)	110 (7.8)	160 (8.8)	63 (8.0)	333 (8.3)
Medium	271 (21.2)	704 (21.1)	276 (22.0)	1,251 (21.3)	321 (22.8)	367 (20.2)	182 (23.3)	870 (21.7)
Large	888 (69.5)	2,301 (68.9)	847 (67.5)	4,036 (68.7)	975 (69.4)	1,293 (71.0)	537 (68.7)	2,805 (70.0)
Comorbidities								
Antiplatelet use	243 (19.0)	727 (21.8)	283 (22.6)	1,253 (21.3)	193 (13.7)	290 (15.9)	111 (14.2)	594 (14.8)
CAD[c]	755 (59.1)	1,722 (51.6)	708 (56.5)	3,185 (54.2)	570 (40.5)	787 (43.2)	327 (41.8)	1,684 (42.0)
Prior MI[b,c]	214 (16.7)	415 (12.4)	219 (17.5)	848 (14.4)	119 (8.5)	96 (5.3)	72 (9.2)	287 (7.2)
Obesity[b,c]	145 (11.4)	514 (15.4)	158 (12.6)	817 (13.9)	292 (20.8)	519 (28.5)	182 (23.3)	993 (24.8)
Hypertension[b,c]	468 (36.6)	1,554 (46.5)	470 (37.5)	2,492 (42.4)	733 (52.1)	997 (54.8)	357 (45.7)	2,087 (52.1)
DM with complications	406 (31.8)	991 (29.7)	381 (30.4)	359 (6.1)	375 (26.7)	510 (28.0)	196 (25.1)	288 (7.2)
DM without complications[c]	80 (6.3)	181 (5.4)	98 (7.8)	1,778 (30.3)	88 (6.3)	145 (8.0)	55 (7.0)	1081 (27.0)
Dyslipidemia[b]	811 (63.5)	2,216 (66.4)	798 (63.6)	3,825 (65.2)	756 (53.8)	1,153 (63.3)	430 (55.0)	2,339 (58.4)
COPD[b]	385 (30.1)	894 (26.8)	357 (28.5)	1,636 (27.9)	246 (17.5)	313 (17.2)	174 (22.3)	733 (18.3)
CKD[b,c]	608 (47.6)	1,360 (40.7)	594 (47.4)	2,562 (43.6)	379 (27.0)	484 (26.6)	256 (32.7)	1,119 (27.9)
Chronic nutritional anemia	349 (27.3)	874 (26.2)	336 (26.8)	1,484 (25.3)	273 (19.4)	377 (20.7)	171 (21.9)	791 (19.7)
GI angiodysplasia	18 (1.4)	25 (0.75)	15 (1.2)	31 (0.5)	15 (1.07)	19 (1.04)	≤10	18 (0.4)
LVAD implantation[b]	≤10	≤10	≤10	≤10	11 (0.78)	≤10	≤10	18 (0.4)
Malignancy	62 (4.9)	162 (4.9)	53 (4.2)	277 (4.7)	54 (3.8)	43 (2.4)	24 (3.1)	121 (3.0)
Opioid use disorder	≤10	≤10	≤10	≤10	≤10	≤10	≤10	22 (0.5)

CAD, coronary artery disease; CCI, Charlson Comorbidity Index; CHF, chronic heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; GI, gastrointestinal; LVAD, left ventricular assist device; MI, myocardial infarction; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

[a] Data are presented as No. (%), unless otherwise specified.
[b] $P < .05$ (systolic vs diastolic vs mixed CHF) in SAVR.
[c] $P < .05$ (systolic vs diastolic vs mixed CHF) in TAVR.
[d] Data collection was missing for 374 patients in the TAVR group and 269 patients in the SAVR group.
[e] Data collection was missing for 111 patients in the TAVR group and 88 patients in the SAVR group.

TABLE III. Unadjusted Outcomes of Patients With CHF Who Underwent TAVR or SAVR Between 2012 and 2015 in the United States

	TAVR (n = 5,871)				SAVR (n = 4,008)			
Outcomes	**Systolic CHF (n = 1,278)**	**Diastolic CHF (n = 3,339)**	**Mixed CHF (n = 1,254)**	***P* value**	**Systolic CHF (n = 1,406)**	**Diastolic CHF (n = 1,820)**	**Mixed CHF (n = 782)**	***P* value[a]**
In-hospital mortality, No. (%)	39 (3.1)	85 (2.6)	51 (4.1)	.026	35 (2.5)	41 (2.3)	22 (2.8)	.693
Hospital length of stay, median (IQR), d	5 (3-9)	5 (3-8)	5 (3-9)	<.001	8 (5-14)	7 (5-12)	8 (5-14)	<.001
Total costs, median (IQR), $	43,240 (12,456-62,298)	40,580 (10,391-56,474)	39,317 (9,622-56,945)	.004	40,715 (28,535-59,975)	37,813 (23,605-53,456)	44,477 (28,483-63,369)	<.001

CHF, chronic heart failure; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

[a] *P* < .05 was considered to be statistically significant.

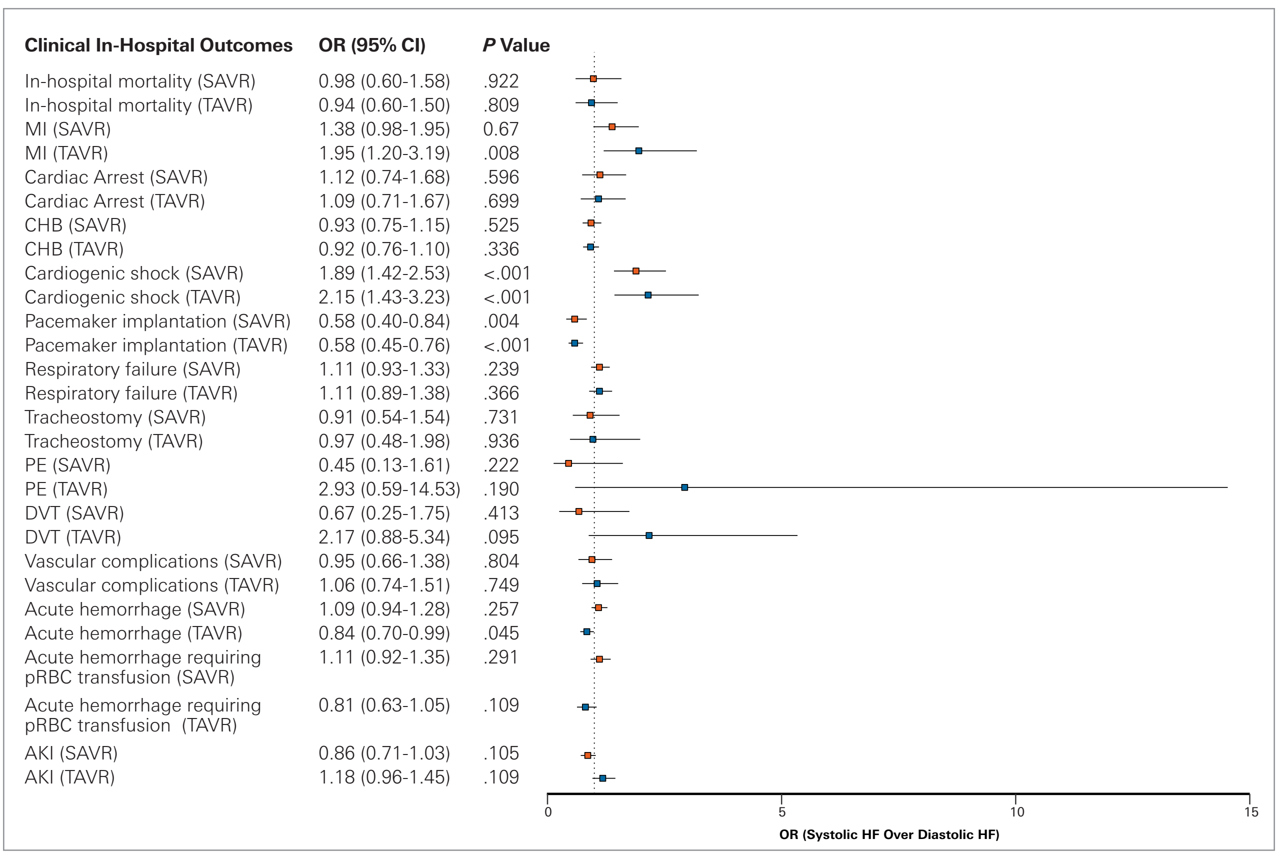

Fig. 2 Forest plot showing adjusted ORs of clinical in-hospital outcomes between TAVR and SAVR among patients with systolic chronic HF vs diastolic chronic HF. Red squares denote SAVR, and blue squares denote TAVR. *P* < .05 was considered statistically significant.

AKI, acute kidney injury; CHB, complete heart block; HF, heart failure; DVT, deep vein thrombosis; MI, myocardial infarction; OR, odds ratio; PE, pulmonary embolism; pRBC, packed red blood cells; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

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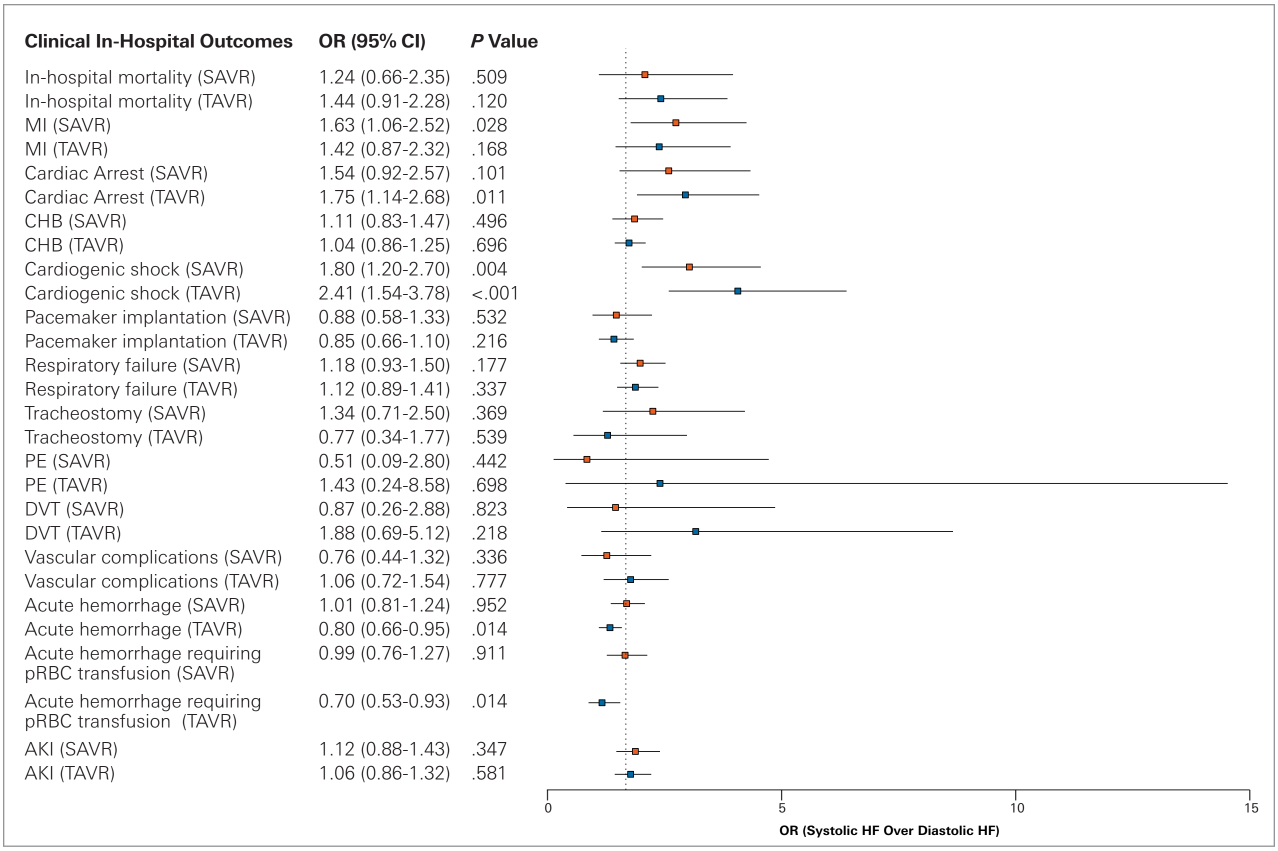

Fig. 3 Forest plot showing adjusted ORs of clinical in-hospital outcomes between TAVR and SAVR among patients with mixed chronic HF vs diastolic chronic HF. Red squares denote SAVR, and blue squares denote TAVR. $P < .05$ was considered statistically significant.

AKI, acute kidney injury; CHB, complete heart block; HF, heart failure; DVT, deep vein thrombosis; MI, myocardial infarction; OR, odds ratio; PE, pulmonary embolism; pRBC, packed red blood cells; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement.

1.42-2.53; *P* < .001) and a lower risk of permanent pacemaker implantation (OR, 0.58; 95% CI, 0.40-0.84; *P* = .004) (Fig. 2).

Discussion

This study found no statistically significant differences in hospital mortality between patients with CHF (ie, systolic vs diastolic CHF and mixed vs diastolic CHF) who underwent TAVR or SAVR. However, patients with diastolic CHF had shorter hospital stays and incurred lower hospital costs after TAVR and SAVR than did those with systolic and mixed CHF. Differences in complications following TAVR or SAVR are evident and may be related to the patient's underlying CHF pathology type.

In-Hospital Mortality

There is a considerably high level of evidence on mortality that supports TAVR as noninferior to SAVR in high-risk,[3,7] intermediate-risk,[6,8] and, more recently, low-risk[9-11] patients. A recent retrospective database analysis from this authors' group corroborates these results[12]; it was observed that postoperative cardiac, respiratory, and kidney complications were independent predictors of mortality in patients with CHF who underwent TAVR or SAVR.[12] Although no statistically significant association was found between type of HF and mortality in the TAVR and SAVR populations, a high risk of in-hospital mortality in patients with mixed CHF (vs diastolic CHF) who underwent TAVR was observed. A study by Steinberg et al[19] found a similar in-hospital mortality rate among hospitalized patients with nonsurgical HF across ejection fraction (EF) strata (HF

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with preserved ejection fraction [HFpEF] = 2.5%, HF with borderline ejection fraction [HFbEF] = 2.3%, HF with reduced ejection fraction [HFrEF] = 2.7%). This difference could be attributed to the large number of patients with high operative risk undergoing TAVR and the associated surgical complications. Moreover, because the NIS database does not report EF or severity of HF, the mixed-CHF cohort may contain a skewed patient population with low EFs. In addition, an overlap of systolic and diastolic cardiac failure pathophysiology resulting in morphological, neurohumoral, and hemodynamic changes may confer an increased risk of mortality in patients with AS with mixed CHF.[20]

In-Hospital Complications

In systolic HF, the left ventricle is dilated because of increased volumes, and decreased contractility leads to increased wall stress and reduced EF.[20] Over time, progressive ventricular remodeling and hemodynamic changes can lead to systolic CHF, which can increase the risk of a variety of surgical complications.[20] In diastolic HF, concentric hypertrophy of the left ventricular wall occurs most commonly because of long-standing or untreated hypertension.[20] Despite a normal EF, the presence of increased left ventricular wall stiffness and decreased compliance over time can worsen hemodynamics and symptoms of HF.[20]

In this cohort, patients with systolic and mixed CHF had higher rates of MI and cardiogenic shock in both the TAVR and SAVR populations, which may partially be attributable to a higher prevalence of coronary artery disease and prior MI. In addition, it was noted that patients with systolic CHF who underwent TAVR had a significantly greater OR for acute deep vein thrombosis and acute kidney injury. The acute kidney injury may be from problems with systemic circulation that result in decreased blood flow to the kidney (eg, prerenal azotemia). Circulation problems may be caused by the underlying systolic CHF and TAVR-specific insults, such as contrast use, or by hemodynamic instability resulting from rapid ventricular pacing.[21] Furthermore, reduced flow rates and venous blood stasis resulting from low cardiac output, older age, and decreased use of anticoagulation before TAVR procedures can all increase the risk of venous thromboembolism.[22]

Finally, it was observed that patients with diastolic CHF had a higher risk of permanent pacemaker implantation than did patients with systolic CHF in both populations. Although permanent pacemaker implantation and conduction abnormalities following TAVR are common,[23,24] the authors were unable to discern why the risk is higher in patients with diastolic CHF vs systolic CHF. It is suspected that for patients with systolic CHF or mixed CHF, the left ventricle is more dilated; thus, the left ventricular outflow tract could also be more open than in diastolic CHF. This dilation would result in less shear pressure on the left ventricular outflow tract (and conduction system) by the newly implanted valve and thus reduce the risk of pacemaker requirement.

Length of Hospitalization and Hospital Costs

A recent retrospective study[12] by the current author group showed that patients with CHF who underwent SAVR had increased hospital length of stay and hospital costs compared with those who underwent TAVR, which is consistent with results from previous trials.[3,6,10,13,14] Although procedural costs are higher initially in TAVR, shorter hospital and ICU stays and lower anesthesia-related services offset overall costs.[13] In this study, it was noted that for both procedures, patients with diastolic CHF had the shortest hospital length of stay and costs, followed by systolic CHF and mixed CHF. A possible explanation is that patients with dysfunction or failure of the systolic component (this would include the systolic CHF and the mixed CHF cohorts) have more cardiac in-hospital complications, which lead to a longer hospital stay and additional costs. Hence, to limit or prevent such complications, patients with systolic dysfunction or failure should be appropriately treated before surgery and cautiously treated perioperatively.

Study Limitations

Natural challenges and limitations can arise in outlining all confounders and specific indications in any retrospective study. By using the NIS database, it is recognized that coding errors can occur and could affect the analysis. In addition, the NIS database lacks quantitative data on HF, such as EF; thus, a certain correlation cannot be made with the terms systolic, diastolic, and mixed CHF with the modern terminologies of HF.

The 2013 guidelines from the American Heart Association/American College of Cardiology Foundation[25] and the 2016 guidelines from the European Society of Cardiology[26] define patients with symptoms and signs of HF and left ventricle ejection fraction (LVEF) of less than 40% as having HFrEF; those with LVEF of 50% or greater are defined as having HFpEF. In addition, both guidelines created an intermediate range of HF. Patients with LVEF between 41% and 49% are classified as having HFbEF or HF with midrange ejection fraction (HFmrEF).[25,26] HFrEF is characterized predominantly by systolic heart dysfunction, and HFpEF is characterized by diastolic heart dysfunction.[25] According to the European guidelines, patients with HFmrEF potentially have a combination of mild systolic and diastolic heart dysfunction,[26] which is defined as "mixed CHF" in the NIS database. As the NIS database lacks quantitative data on HF, such as EF, a correlation cannot with be made with certainty using the terms systolic, diastolic, and mixed CHF with terminologies of HFrEF, HFpEF, and HFbEF/HFmrEF, respectively, as there may be an overlap. For instance, patients with CHF who have EFs below 40% or between 40% and 50% may have concurrent diastolic dysfunction. The severity of HF assessed using echocardiography (eg, EF) or functional classification (eg, New York Heart Association grading) is also not available from NIS.

Patients with less severe forms of CHF may not have experienced the same benefits of aortic valve replacement. The population studied was composed of patients with AS resulting from congenital and degenerative causes. Whether outcomes differ by the cause of AS is unclear.[27,28] Thus, future prospective studies are needed to verify the impact of the severity of HF and the etiology of AS.

The current research considered data from a specific time frame of 2012 to 2015. As equipment and techniques have steadily advanced in recent years, these data may not reflect current outcomes and practices. For example, the use of newer-generation prosthetic aortic valves, balloon-expandable devices (vs self-expanding devices), or transfemoral vascular access (vs nontransfemoral vascular approaches) can affect TAVR outcomes.[29,30]

The NIS database can be used to examine retrospectively various factors that may be associated with clinical outcomes. However, owing to the aforementioned limitations, future studies can use results from such studies to conduct prospective trials examining this association while controlling for various factors. The main findings of this study demonstrate that the type of CHF does not significantly influence hospital mortality in patients undergoing TAVR or SAVR. Patients with diastolic CHF had shorter hospital stays and incurred lower hospital costs than did patients with systolic or mixed CHF who underwent SAVR. In addition, patients with systolic CHF who underwent TAVR had an increased risk of acute deep vein thrombosis and acute kidney failure because of multifactorial clinical and procedural etiologies. Finally, the risk for conduction abnormalities and subsequent permanent pacemaker implantation is high with diastolic CHF in both TAVR and SAVR. These associations should be examined prospectively (eg, cohort studies) with standardized definitions of HF and controlling for perioperative confounders that may impact inpatient outcomes.

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