Original Investigation

Trends in Aortic Valve Replacement for Elderly Patients in the United States, 1999-2011

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IMPORTANCE There is a need to describe contemporary outcomes of surgical aortic valve replacement (AVR) as the population ages and transcatheter options emerge.

OBJECTIVE To assess procedure rates and outcomes of surgical AVR over time.

DESIGN, SETTING, AND PARTICIPANTS A serial cross-sectional cohort study of 82 755 924 Medicare fee-for-service beneficiaries undergoing AVR in the United States between 1999 and 2011.

MAIN OUTCOMES AND MEASURES Procedure rates for surgical AVR alone and with coronary artery bypass graft (CABG) surgery, 30-day and 1-year mortality, and 30-day readmission rates.

RESULTS The AVR procedure rate increased by 19 (95% CI, 19-20) procedures per 100 000 person-years over the 12-year period (P<.001), with an age-, sex-, and race-adjusted rate increase of 1.6% (95% CI, 1.0%-1.8%) per year. Mortality decreased at 30 days (absolute decrease, 3.4%; 95% CI, 3.0%-3.8%; adjusted annual decrease, 4.1%; 95% CI, 3.7%- 4.4%) per year and at 1 year (absolute decrease, 2.6%; 95% CI, 2.1%-3.2%; adjusted annual decrease, 2.5%; 95% CI, 2.3%-2.8%). Thirty-day all-cause readmission also decreased by 1.1% (95% CI, 0.9%-1.3%) per year. Aortic valve replacement with CABG surgery decreased, women and black patients had lower procedure and higher mortality rates, and mechanical prosethetic implants decreased, but 23.9% of patients 85 years and older continued to receive a mechanical prosthesis in 2011.

CONCLUSIONS AND RELEVANCE Between 1999 and 2011, the rate of surgical AVR for elderly patients in the United States increased and outcomes improved substantially. Medicare data preclude the identification of the causes of the findings and the trends in procedure rates and outcomes cannot be causally linked. Nevertheless, the findings may be a useful benchmark for outcomes with surgical AVR for older patients eligible for surgery considering newer transcatheter treatments.

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Aortic valve disease in the United States is a major cardiovascular problem that is likely to grow as the population ages.[1-5] Aortic valve replacement is the standard treatment even for very elderly patients despite its risks in this age group.[6] With transcatheter aortic valve replacement emerging as a less invasive option,[7-9] contemporary data from real-world practice are needed to provide a perspective on the outcomes that are being achieved with surgery.

Changes in practice during the past decade are partly due to growing recognition that the benefits of aortic valve replacement extend to extremes in patient age.[10,11] There is also a recommendation for consideration of earlier, preemptive aortic valve replacement in selected asymptomatic patients[12] and strong guidance that bioprostheses rather than mechanical valves be used for patients 65 years or older.[13,14] There is also uncertainty about the benefit of performing coronary artery bypass graft (CABG) surgery during aortic valve replacement in patients with stable coronary disease.[8,15,16] Previous studies have indicated that rates of aortic valve replacement are increasing and outcomes are improving[17-20] but do not provide population-based rates and long-term follow-up.[17-20]

We therefore studied aortic valve replacement among Medicare fee-for-service beneficiaries between 1999 and 2011. We calculated trends in rates of surgical aortic valve replacement and outcomes defined as mortality, readmission, and length of stay. In addition, we compared the outcomes of patients who had CABG surgery and aortic valve replacement with those who had replacement alone and assessed rates of use of mechanical prostheses, which generally are not recommended for patients 65 years or older in the absence of another reason for anticoagulation.[21,22] Because variation in patterns of care and outcomes across subgroups may indicate opportunities for quality improvement, we also calculated these trends by age, sex, and race.

Methods

Study Sample

Institutional review board approval for this study was obtained through the Yale University Human Investigation Committee. We identified all Medicare fee-for-service patients from January 1, 1999, to December 31, 2011, using the inpatient administrative data from the Centers for Medicare & Medicaid Services (CMS). We identified patients who underwent aortic valve replacement based on the principal discharge diagnosis (*International Classification of Diseases, Ninth Revision, Clinical Modification* codes 35.21 [aortic valve surgery replacement with bioprosthesis], and 35.22 [aortic valve surgery replacement with mechanical prosthesis]; eTable 1 in the Supplement). We excluded 566 patients who underwent aortic valve repair, 37 412 who underwent aortic valve replacement with concomitant mitral valve surgery, and 4007 who underwent tricuspid valve surgery from the years 1999 to 2011, and 2961 who had endocarditis as their principal diagnosis. For a small group of patients who had more than 1 aortic valve replacement during any of the study years—a proportion that decreased over time (n=389, or 1.5% in 1999 and 44 or 0.1% in 2011)—we selected the first procedure. We linked aortic valve replacement data with Medicare denominator files to obtain mortality information and to determine the eligibility of the beneficiaries and their length of time in the fee-for-service program.

Patient Characteristics

We collected data on patients' age, sex, race, and common comorbidities. Race was determined from the Medicare denominator files, which used patient-reported data from the Social Security Administration.[23] We selected 21 comorbidities in categories of cardiovascular disease (hypertension, diabetes mellitus, atherosclerotic disease, unstable angina, prior myocardial infarction, prior heart failure, peripheral vascular disease, stroke, non-stroke cerebrovascular disease), geriatric conditions (dementia, functional disability, malnutrition), and miscellaneous (renal failure, chronic obstructive pulmonary disease, pneumonia, respiratory failure, liver disease, cancer, major psychiatric disorders, depression, and trauma) based on the method used by CMS for profiling hospitals for acute myocardial infarction and heart failure.[24,25] We identified comorbidities from diagnosis codes of all patient hospitalizations for any cause, primary or secondary, up to 1 year before the initial hospitalization for aortic valve replacement. Comorbidity data from 1998 were used for patients who underwent an aortic valve replacement in 1999.

Outcomes

Use of Aortic Valve Replacement, With and Without CABG Surgery, and Type of Aortic Valve Replacement

We calculated person-years for each beneficiary to account for new enrollment, disenrollment, or death during an index year. For each year, we linked person-year data with aortic valve replacement hospitalization data to obtain rates of aortic valve replacement by dividing the total number of aortic valve replacements by the corresponding person-years of beneficiaries.[26] Using CABG codes (*ICD-9*, 36.1x), we determined the proportion of aortic valve replacement performed with and without CABG surgery (eTable 1 in the Supplement). We also determined the type of aortic valve replacement performed using codes for replacement with bioprosthesis and replacement with mechanical prosthesis, as described above.

Mortality, Length of Stay, and 30-Day Readmission

In-hospital mortality was defined as deaths occurring during the index aortic valve replacement-specific hospitalization. To standardize the follow-up period, we used 30-day and 1-year mortality rates, defined as the rate of deaths due to all causes that occurred within 30 days or 1 year from the first procedure date during the index hospitalization for aortic valve replacement. We divided length of stay into 2 phases: *preprocedure length of stay*, defined as the difference in days between the procedure and admission dates, and *postprocedure length of stay*, defined as the difference in days between the discharge and procedure dates. We defined 30-day readmission as rehospitalizations for all causes occurring within 30 days from the date of discharge, using November 30, 2011, as the final date of discharge for complete follow-up.[26,27]

Statistical Analysis

We express the rate of aortic valve replacement per 100 000 person-years, the rates of mortality and readmission as percentages, and length of stay as median (interquartile range) days. We used the Mantel-Haenszel χ^2 test to determine the statistical significance of temporal changes in observed outcomes and patient characteristics. To evaluate changes in rates of aortic valve replacement, we fit a mixed-effects model with a Poisson link function and state-specific random intercepts, adjusting for age, sex, and race. To estimate changes in the rates of mortality (30-day and 1-year), we used the same mixed model with a logit-link function and hospital-specific random intercepts, adjusting for patient age, sex, race, and comorbidities. To assess change in rates of 30-day readmission, we constructed a Cox proportional hazards model with death as a censoring event and adjusting for age, sex, race and comorbidity. We used the method developed by Lin et al[28] to check the adequacy of the Cox regression model and found the proportional hazards assumption was satisfied.

All models included an ordinal time variable ranged from 0 to 12, corresponding to the years 1999 to 2011, to represent the annual changes in outcomes. The incidence rate ratio (RR) of the time variable was used to represent the age-, sex-, and race-adjusted annual changes in the aortic valve replacement rate, and the odds ratio (OR) and hazard ratio (HR) of the time variable were used to represent the age-, sex-, and race-

Table 1. Characteristics of Patients Hospitalized for Aortic Valve Surgery, 1999-2011

	No. (%) of Patients						
Patient Characteristics	1999	2001	2003	2005	2007	2009	2011
No. of patients	24 568	26 598	28 186	28 687	28 039	30 418	31 380
Demographics							
Age, mean (SD), y	76.1 (5.9)	76.4 (5.9)	76.5 (6.0)	76.5 (6.2)	76.8 (6.3)	76.9 (6.5)	77.1 (6.7)
Women	10 509 (42.8)	11 234 (42.2)	11 873 (42.1)	11 902 (41.5)	11 644 (41.5)	12 364 (40.6)	12 645 (40.3)
White	23 033 (93.8)	24 958 (93.8)	26 365 (93.5)	26 780 (93.4)	26 239 (93.6)	28 504 (93.7)	29 316 (93.4)
Black	857 (3.5)	870 (3.3)	940 (3.3)	936 (3.3)	896 (3.2)	962 (3.2)	1013 (3.2)
Other race[a]	678 (2.8)	770 (2.9)	881 (3.1)	971 (3.4)	904 (3.2)	952 (3.1)	1051 (3.3)
Risk factors and cardiovascular conditions							
Hypertension	12 736 (51.8)	14 940 (56.2)	16 238 (57.6)	16 901 (58.9)	16 881 (60.2)	18 544 (61.0)	20 613 (65.7)
Diabetes mellitus	5168 (21.0)	5852 (22.0)	6660 (23.6)	7204 (25.1)	7130 (25.4)	7841 (25.8)	8679 (27.7)
Atherosclerotic disease	14 904 (60.7)	16 231 (61.0)	17 214 (61.1)	17 194 (59.9)	16 430 (58.6)	17 372 (57.1)	17 954 (57.2)
Unstable angina	1321 (5.4)	1293 (4.9)	1143 (4.1)	948 (3.3)	830 (3.0)	797 (2.6)	778 (2.5)
Prior myocardial infarction	929 (3.8)	1027 (3.9)	1067 (3.8)	1096 (3.8)	1046 (3.7)	1250 (4.1)	1270 (4.0)
Prior heart failure	4510 (18.4)	4743 (17.8)	4824 (17.1)	4732 (16.5)	4493 (16.0)	4957 (16.3)	5534 (17.6)
Peripheral vascular disease	1363 (5.5)	1582 (5.9)	1727 (6.1)	1746 (6.1)	1696 (6.0)	1904 (6.3)	1991 (6.3)
Stroke	226 (0.9)	278 (1.0)	281 (1.0)	289 (1.0)	293 (1.0)	307 (1.0)	379 (1.2)
Cerebrovascular disease other than stroke	1014 (4.1)	1157 (4.3)	1095 (3.9)	1144 (4.0)	1078 (3.8)	1138 (3.7)	1228 (3.9)
Geriatric conditions							
Dementia	276 (1.1)	318 (1.2)	360 (1.3)	404 (1.4)	424 (1.5)	540 (1.8)	688 (2.2)
Functional disability	210 (0.9)	211 (0.8)	237 (0.8)	202 (0.7)	228 (0.8)	310 (1.0)	336 (1.1)
Malnutrition	337 (1.4)	396 (1.5)	512 (1.8)	611 (2.1)	779 (2.8)	1218 (4.0)	1433 (4.6)
Other conditions							
Renal failure	601 (2.4)	775 (2.9)	951 (3.4)	1226 (4.3)	2122 (7.6)	2554 (8.4)	3271 (10.4)
Chronic obstructive pulmonary disease	4656 (19.0)	5362 (20.2)	5784 (20.5)	6170 (21.5)	5759 (20.5)	4595 (15.1)	5092 (16.2)
Pneumonia	1673 (6.8)	1830 (6.9)	1963 (7.0)	2226 (7.8)	2163 (7.7)	2779 (9.1)	3042 (9.7)
Respiratory failure	558 (2.3)	569 (2.1)	590 (2.1)	625 (2.2)	925 (3.3)	1107 (3.6)	1414 (4.5)
Liver disease	170 (0.7)	189 (0.7)	210 (0.7)	221 (0.8)	193 (0.7)	240 (0.8)	306 (1.0)
Cancer	1188 (4.8)	1237 (4.7)	1338 (4.7)	1373 (4.8)	1304 (4.7)	1372 (4.5)	1487 (4.7)
Major psychiatric disorders	208 (0.8)	245 (0.9)	236 (0.8)	250 (0.9)	241 (0.9)	318 (1.0)	362 (1.2)
Depression	488 (2.0)	688 (2.6)	849 (3.0)	876 (3.1)	889 (3.2)	960 (3.2)	1203 (3.8)
Trauma in past year	724 (2.9)	810 (3.0)	1009 (3.6)	1080 (3.8)	1058 (3.8)	986 (3.2)	1182 (3.8)

[a] Other race includes Asian, Hispanic, North American Native, or other not specified.

comorbidity-adjusted annual changes in mortality and readmission rates, respectively. We repeated models for age, sex, and race subgroups.

Dr Wang performed all analyses using SAS version 9.2 (SAS Institute Inc). Statistical tests were 2-sided at a significance level of .05.

Results

Patient Characteristics and Comorbidities

The final sample consisted of 409 591 889 records, representing 82 755 924 beneficiaries aged 65 years or older with at least 1 month of enrollment in Medicare fee-for-service during the study period (2 542 827 477 person-years). Patient age, sex, and race remained mostly unchanged over time but several comorbidities were more commonly coded, including hypertension (51.8% in 1999, 65.7% in 2011), diabetes mellitus (21.0% in 1999, 27.7% in 2011), and renal failure (2.4% in 1999, 10.4% in 2011). Atherosclerotic disease (60.7% in 1999, 57.2% in 2011) and history of heart failure (18.4% in 1999, 17.6% in 2011) were reported less frequently (P <.001 for trend) (**Table 1** and eTable 2, in the Supplement).

Rates of Aortic Valve Replacement

Rates of aortic valve replacement increased by 19 (95% CI, 19-20) procedures per 100 000 person-years between 1999 and 2011 (93 in 1999, 112 in 2011; P < .001 for trend); the rate of aortic valve replacement without CABG surgery increased (40 in 1999, 64 in 2011; increase, 24 [95% CI, 23-24] procedures per 100 000 person-years; P < .001 for trend) and the rate of aortic valve replacement with CABG surgery decreased (53 in 1999, 48 in 2011; decrease, 5 [95% CI, 4-5] procedures per 100 000 person-years; P < .001 for trend). Procedure rates increased in all age, sex, and race strata, most notably in patients 75 years or older (**Table 2** and eTable 3,

Table 2. Hospitalization Rates for Aortic Valve Surgery, 1999-2011

	1999	2001	2003	2005	2007	2009	2011
Person-years	26 479 079	27 553 904	28 821 487	29 157 293	27 899 732	27 343 436	27 958 093
No. of patients							
Overall	24 568	26 598	28 186	28 687	28 039	30 418	31 380
AVR							
Without CABG	10 589	11 778	12 735	13 140	13 635	15 994	17 901
With CABG	13 979	14 820	15 451	15 547	14 404	14 424	13 479
Rates per 100 000 person-years							
Overall	93	97	98	98	100	111	112
Age, y							
65-74	82	81	82	81	79	86	86
75-84	125	134	136	138	147	167	168
≥85	48	53	56	58	64	79	91
Sex							
Men	131	136	136	137	138	153	154
Women	67	69	71	70	73	80	80
Race							
White	100	104	106	107	109	122	123
Black	42	40	41	41	42	45	45
Other race[a]	48	48	48	51	49	51	51
AVR							
Without CABG	40	43	44	45	49	58	64
With CABG	53	54	54	53	52	53	48

Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft.

[a] Other race includes Asian, Hispanic, North American Native, or other not specified.

in the Supplement). The findings did not change substantially after accounting for age, sex, race, and state.

The age-, sex-, and race-adjusted change was 1.6% (95% CI, 1.0%-1.8%; incidence RR, 1.016 [95% CI, 1.01-1.018]) increase per year for all aortic valve replacement procedures, 4.1% (95% CI, 3.9%-4.2%; incidence RR, 1.041 [95% CI, 1.039-1.042]) increase per year for aortic valve replacement without CABG surgery, and 0.5% (95% CI, 0.2%-0.6%; incidence RR, 0.995 [95% CI, 0.994-0.998]) decrease per year for aortic valve replacement with CABG surgery. The direction of change was similar by age, sex, and race strata except for a small increase in rates of aortic valve replacement with CABG surgery among patients 75 years or older (eFigure, eTable 4 in the Supplement).

Rates of Mortality

Between 1999 and 2011, 30-day mortality rates decreased an absolute 3.4% (95% CI, 3.0%-3.8%) for all aortic valve replacement, an absolute 3.1% (95% CI, 2.6%-3.7%) for aortic valve replacement without CABG surgery, and an absolute 3.2% (95% CI, 2.6%-3.8%) for aortic valve replacement with CABG surgery. One-year mortality rates also decreased by an absolute 2.6% (95% CI, 2.1%-3.2%) for all aortic valve replacements, 2.2% (95% CI 1.5% to 3.0%) for aortic valve replacement without CABG surgery, and 2.4% (95% CI 1.6% to 3.2%) for aortic valve replacement with CABG surgery. The decreases were similar among all age, sex, and race strata (**Table 3** and eTable 5, in the Supplement) and did not change substantially after accounting for patient characteristics and hospital. Age-, sex-, and race-comorbidity-adjusted decreases in 30-day mortality rates were 4.1% (95% CI, 3.7%-4.4%) per year (OR, 0.959; 95% CI, 0.956-0.963) for overall aortic valve replacement, 4.7% (95% CI, 4.2%-5.3%) per year (OR, 0.953, 95% CI, 0.947-0.958) for aortic valve replacement without CABG, and 3.4% (95% CI, 2.9%-3.8%) per year (OR, 0.966; 95% CI, 0.962-0.971) for aortic valve replacement with CABG surgery. Similarly, the age-, sex-, and race-comorbidity-adjusted decreases in 1-year mortality rates were 2.5% (95% CI, 2.3%-2.8%) per year (OR, 0.975; 95% CI, 0.972-0.977) for all aortic valve replacement, 2.8% (95% CI, 2.3%-3.2%) per year (OR 0.972, 95% CI, 0.968-0.977) for aortic valve replacement without CABG surgery, and 2.1% (95% CI, 1.7%-2.5%) per year (OR, 0.979; 95% CI, 0.975-0.983) for aortic valve replacement with CABG surgery. The decreases were seen among all age, sex, and race strata with the exception of a nonstatistically significant estimate of no change in 1-year mortality among nonwhite nonblack women undergoing aortic valve surgery with CABG surgery (eFigure, eTables 6 and 7 in the Supplement). Although decreases in mortality were comparable within sex and race strata, women nevertheless had higher 30-day and 1-year mortality than men, and black patients had higher mortality than white patients in every study year.

Length of Stay and Rates of Readmission

Median length of stay was unchanged (Table 3 and eTable 5, in the Supplement). Thirty-day readmission rates decreased slightly for aortic valve replacement procedures overall and with and without CABG surgery (Table 3). Age-, sex-, and race-comorbidity-adjusted decreases in 30-day readmission rates were 1.1% (95% CI, 0.9%-1.3) per year (HR, 0.989; 95% CI, 0.987-0.991) for overall aortic valve replacement, 1.3% (95% CI, 1.1%-1.6%) per year (HR, 0.987, 95% CI, 0.984-0.989) for aortic valve replacement without CABG surgery and 0.8% (95% CI, 0.5%-1.1%) per year (HR, 0.992; 95% CI, 0.989-0.995) for aortic valve replacement with CABG surgery (eFigure, eTable 8 in the Supplement).

Table 3. Outcomes of Aortic Valve Replacement Surgery, 1999-2011

	% (95% CI)						
	1999	2001	2003	2005	2007	2009	2011
Overall							
No. of patients	24 568	26 598	28 186	28 687	28 039	30 418	31 380
In-hospital mortality rates, %	7.1 (6.81-7.46)	6.7 (6.42-7.03)	6.5 (6.24-6.82)	5.5 (5.26-5.79)	5.1 (4.82-5.34)	4.9 (4.62-5.10)	3.8 (3.56-3.99)
30-d Mortality rates							
Overall	7.6 (7.27-7.93)	7.3 (6.97-7.60)	7.1 (6.85-7.45)	6.0 (5.69-6.24)	5.5 (5.25-5.79)	5.5 (5.21-5.72)	4.2 (3.95-4.39)
Age, y							
65-74	5.9 (5.43-6.35)	5.7 (5.29-6.19)	5.6 (5.15-6.02)	4.6 (4.17-4.96)	4.5 (4.16-4.97)	4.2 (3.86-4.61)	3.3 (2.94-3.59)
75-84	8.2 (7.72-8.70)	7.8 (7.37-8.28)	7.6 (7.15-8.02)	6.3 (5.96-6.75)	5.6 (5.26-6.02)	5.7 (5.34-6.10)	4.4 (4.07-4.73)
≥85	12.3 (11.0-13.8)	10.8 (9.60-12.1)	11.1 (9.99-12.4)	9.3 (8.27-10.4)	8.1 (7.18-9.10)	8.1 (7.23-8.94)	5.8 (5.12-6.49)
Sex							
Men	6.9 (6.44-7.29)	6.6 (6.22-7.01)	6.6 (6.21-6.98)	5.2 (4.91-5.59)	4.8 (4.51-5.17)	5.0 (4.67-5.31)	3.7 (3.48-4.03)
Women	8.6 (8.05-9.13)	8.2 (7.70-8.72)	7.9 (7.43-8.41)	7.0 (6.52-7.45)	6.5 (6.04-6.94)	6.2 (5.74-6.59)	4.8 (4.42-5.17)
Race							
White	7.5 (7.16-7.84)	7.2 (6.91-7.56)	7.2 (6.87-7.50)	5.9 (5.61-6.17)	5.4 (5.12-5.67)	5.4 (5.13-5.66)	4.1 (3.88-4.33)
Black	9.5 (7.58-11.6)	9.0 (7.15-11.1)	6.7 (5.19-8.49)	7.9 (6.26-9.82)	7.8 (6.14-9.77)	6.0 (4.61-7.72)	5.0 (3.77-6.57)
Other race	8.7 (6.69-11.1)	6.9 (5.20-8.91)	6.6 (5.04-8.43)	6.2 (4.75-7.88)	6.9 (5.30-8.71)	7.0 (5.50-8.85)	5.1 (3.88-6.65)
AVR							
Without CABG	6.6 (6.15-7.11)	6.5 (6.02-6.91)	5.9 (5.48-6.30)	4.8 (4.44-5.18)	4.6 (4.24-4.95)	4.5 (4.22-4.87)	3.5 (3.21-3.75)
With CABG	8.3 (7.89-8.82)	7.9 (7.51-8.38)	8.2 (7.77-8.64)	6.9 (6.54-7.35)	6.4 (5.99-6.80)	6.5 (6.09-6.90)	5.1 (4.76-5.51)
1-y Mortality rate							
Overall	13.6 (13.1-14.0)	13.7 (13.3-14.2)	13.4 (13.0-13.8)	12.6 (12.2-13.0)	11.9 (11.6-12.3)	11.5 (11.2-11.9)	10.9 (10.6-11.3)
Age, y							
65-74	10.5 (9.89-11.1)	10.3 (9.74-10.9)	10.0 (9.46-10.6)	9.6 (9.02-10.1)	8.8 (8.27-9.37)	8.3 (7.77-8.79)	8.2 (7.67-8.66)
75-84	14.6 (14.0-15.3)	15.0 (14.4-15.6)	14.3 (13.7-14.9)	13.3 (12.8-13.9)	12.8 (12.3-13.4)	12.4 (11.9-12.9)	11.1 (10.6-11.6)
≥85	22.2 (20.4-24.0)	20.9 (19.3-22.6)	22.6 (21.0-24.2)	19.9 (18.5-21.4)	18.2 (16.9-19.6)	17.7 (16.5-18.9)	17.5 (16.4-18.6)
Sex							
Men	12.8 (12.3-13.4)	12.9 (12.4-13.5)	12.5 (12.0-13.0)	11.6 (11.1-12.1)	11.1 (10.7-11.6)	11.0 (10.5-11.4)	10.6 (10.1-11.0)
Women	14.5 (13.9-15.2)	14.9 (14.2-15.5)	14.7 (14.1-15.4)	14.0 (13.4-14.6)	13.1 (12.5-13.7)	12.4 (11.8-13.0)	11.5 (10.9-12.0)
Race							
White	13.3 (12.9-13.8)	13.6 (13.2-14.1)	13.4 (13.0-13.9)	12.4 (12.0-12.8)	11.7 (11.4-12.1)	11.4 (11.0-11.8)	10.8 (10.5-11.2)
Black	17.7 (15.2-20.5)	17.2 (14.8-19.9)	14.7 (12.5-17.1)	17.9 (15.5-20.6)	16.3 (13.9-18.9)	14.7 (12.5-17.1)	14.1 (12.0-16.4)
Other race	15.6 (13.0-18.6)	13.2 (10.9-15.9)	11.7 (9.64-14.0)	12.8 (10.7-15.0)	13.5 (11.3-15.9)	12.9 (10.9-15.2)	11.1 (9.29-13.2)
AVR							
Without CABG	12.1 (11.5-12.7)	12.4 (11.9-13.1)	11.5 (11.0-12.1)	10.1 (9.61-10.7)	10.4 (9.90-10.9)	10.0 (9.57-10.5)	9.9 (9.44-10.3)
With CABG	14.7 (14.2-15.3)	14.8 (14.2-15.4)	15.0 (14.5-15.6)	14.6 (14.1-15.2)	13.4 (12.9-14.0)	13.2 (12.7-13.8)	12.3 (11.8-12.9)
Length-of-stay, median (IQR), d							
Total	7 (5)	7 (5)	7 (5)	7 (5)	7 (5)	7 (5)	7 (5)
Preprocedure	1 (3)	1 (3)	1 (3)	1 (3)	0 (2)	0 (2)	0 (2)
Postprocedure	6 (4)	6 (5)	6 (5)	6 (5)	6 (5)	6 (5)	6 (5)
30-Readmission rates							
Overall	21.5 (20.9-22.0)	20.9 (20.4-21.4)	21.1 (20.6-21.6)	20.9 (20.5-21.4)	21.2 (20.7-21.6)	20.7 (20.2-21.1)	19.6 (19.2-20.0)
AVR							
Without CABG	20.6 (19.8-21.4)	20.0 (19.3-20.8)	20.1 (19.3-20.8)	19.5 (18.8-20.2)	20.1 (19.4-20.8)	19.9 (19.3-20.6)	19.0 (18.5-19.6)
With CABG	22.2 (21.5-22.9)	21.7 (21.0-22.4)	22.0 (21.3-22.7)	22.2 (21.5-22.8)	22.2 (21.5-22.9)	21.5 (20.8-22.2)	19.9 (19.2-20.6)

Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft surgery; IQR, interquartile range.

Type of Valve Surgery

Use of bioprostheses in aortic valve replacement increased from 44.1% in 1999 to 72.7% in 2011 ($P < .001$). Conversely, mechanical prosethetic implants decreased from 55.9% to 27.3% ($P<.001$). Among age, sex, and race strata in 2011, use of bioprostheses was highest for patients who were 85 years or older, men, and white (eTable 9 in the Supplement). In 1999, 46.2% of patients 85 years or older received a mechanical prosthesis, decreasing to 23.9% in 2011.

Discussion

Our study describes a national increase in the rates of aortic valve replacement and a reduction in mortality, readmission, and length of stay for Medicare beneficiaries undergoing the procedure from 1999 through 2011. Rates of aortic valve replacement without CABG surgery increased while rates of aortic valve replacement with it decreased, but adjusted annual decreases in 30-day mortality were comparable for either procedure. Mechanical aortic valve prostheses continued to be used in about a quarter of elderly patients in 2011.

Several studies have investigated this topic with less contemporary cohorts, but direct comparison between our results and those of other studies is difficult because other studies looked at smaller cohorts and few provided a comprehensive national perspective or reported standardized short- and long-term outcomes.[8,18,19,29,30] Goodney et al,[31] using Medicare data from 1994 to 1999, reported that in-hospital mortality for aortic valve replacement (54% performed with CABG surgery) was 8.8%, ranging from 6% to 13%. Lee et al,[19] using the Society of Thoracic Surgeons database, showed that operative mortality for aortic valve replacement decreased from 5.6% during the years 1993-1997 to 4.4% during the years 2003-2007. Brown et al[18] focused on aortic valve replacement without CABG surgery in the Society of Thoracic Surgeons database and reported higher survival rates, with age-, sex-, and race-comorbidity-adjusted operative mortality decreasing from 3.5% to 2.4% between 1997 and 2006. Our data set extended to 2011, and we found higher mortality for patients undergoing aortic valve replacement without CABG surgery (6.6% in 1999 and 3.5% in 2011), which we believe is likely due to the older age of our population and our use of 30-day (rather than in-hospital) mortality as an outcome measure. In addition to providing more contemporary estimates, our study provides longer-term (1-year) mortality outcomes, data on readmission, and outcomes from centers that may not have been captured in Society of Thoracic Surgeons data.

Across all years of observation, we found lower procedure rates and higher mortality in black patients than in white patients. Racial differences in aortic valve disease or black patients being referred at a later stage of illness and having less access to the procedure may be factors.[32-36] Similarly for women, procedure rates were lower and mortality was higher. A report from the Society of Thoracic Surgeons database of patients undergoing aortic valve replacement without CABG surgery described a similar finding: fewer patients undergoing the procedure were women (43% women vs 57% men) and mortality was higher among women (2006 mortality: 3.2% in women, 2.1% in men).[19] We could not determine reasons for any differences from the Medicare data set, but they point to a worthwhile direction for future investigation. Encouragingly, mortality rates declined among all subgroups from 1999 to 2011, although residual differences persisted.

There are several potential explanations for the increase in the use of aortic valve replacement among older adults, including better access to specialized health care centers and enhanced awareness of the therapeutic benefit of aortic valve replacement independent of patient age among health care professionals.[11] The increase in age and comorbidities among patients undergoing aortic valve replacement suggest that the recommendation to perform preemptive aortic valve surgery earlier in the disease course had not taken hold during the study period. Although the largest increase in rates of aortic valve replacement occurred in those aged 85 years or older, a group in which the rate of 1-year mortality was 17.5% by 2011, these patients still underwent surgery less commonly than those aged 75 through 84 years, despite the known increasing prevalence of aortic stenosis with advancing age.[1] This finding suggests that there is a significant residual population of very elderly patients with aortic stenosis for whom transcatheter aortic valve replacement may emerge as a common treatment modality. In that context, our findings could provide a useful benchmark of outcomes with surgical aortic valve replacement among eligible patients who may also be considering transcatheter aortic valve replacement.

Approximately 50% of aortic valve replacement procedures were performed with CABG surgery, and we could not determine from our data whether the decrease in aortic valve replacement with CABG surgery over time reflected changing coronary anatomy among the study population (eg, lower prevalence of lesions amenable to surgical revascularization), an increasing use of preprocedural or postprocedural percutaneous coronary intervention, or some other factor. The treatment of chronic coronary artery disease in the setting of aortic valve replacement is uncertain and evolving.[15] CABG surgery continues to be performed during aortic valve replacement in cases of anatomical coronary obstruction. Future studies are needed to investigate whether the current practice of aortic valve replacement plus CABG surgery for patients with stable coronary artery disease is preferable to other strategies such as aortic valve replacement plus watchful waiting, aortic valve replacement plus percutaneous coronary intervention (hybrid procedure), or transcatheter aortic valve replacement plus percutaneous coronary intervention.[8]

Previous studies reported a progressive shift toward the use of bioprostheses in the aortic position, but rates of use of mechanical prostheses are still quite high.[17,18,37] The debate surrounding the optimal prosthesis for elderly patients remains unresolved.[30,38,39] In similar instances of clinical uncertainty, some experts recommend shared decision making.[40] The 1998 guidelines for managing valvular heart disease from the American Heart Association and the American College of Cardiology recommended the use of bioprosthetic valves in the aortic position for patients 65 years or older.[13,38,39] Our administrative data, however, lacked detailed information that could explain the high rate of use of mechanical prostheses. Small native aortic valve annulus or preexisting clinical conditions for anticoagulation may represent some appropriate uses of mechanical prostheses in the elderly. The high rates of mechanical prostheses that we observed in 2011 raise concern about whether this practice is in the best interest of patients.

This study has several limitations. First, our findings are observational and multiple factors may have accounted for the observed trends (eg, patient selection, health care system changes, secular changes). We cannot determine the underlying causes due to the limitations of administrative data. Second, our mortality adjustment models used comorbidity information based on administrative data and did not include some relevant clinical information that could have improved the modeling process, such as patient functional status, left ventricular function, the pathological process associated with aortic valve dysfunction, previous cardiac surgery, or the distinction between elective or urgent aortic valve replacement.[41] Third, we used Medicare claims data to infer trends in the type of surgery performed (bioprosthetic implant or mechanical prostheses). Because we used codes for the primary diagnosis, aortic valve disease may have been misclassified as the primary diagnosis in cases of aortic dissection or aneurysm with concomitant aortic valve disease. However, this would represent a very small number of patients. Fourth, our cohort was limited to Medicare fee-for-service beneficiaries, and thus we cannot comment on trends among patients enrolled in Medicare managed care programs or among patients younger than 65 years. Because more patients have enrolled in Medicare managed care programs over time,[42] the Medicare fee-for-service population may have changed and therefore affected the observed trends. However, we are reporting rates that take into account any change in the denominator over the years. Finally, the use of inpatient claims limited our ability to include comorbidity information in our procedure rate model, so we were therefore unable to estimate the influence of changes in patient comorbidity on patient selection for an aortic valve replacement.

Conclusions

We found an increase in rates of aortic valve replacement and an improvement in mortality and other outcomes among Medicare beneficiaries over a 12-year period. Rates of aortic valve replacement with CABG surgery decreased, older patients are still receiving mechanical prostheses despite recommendations to the contrary, and women and black patients experienced higher mortality than men and white patients. These findings may provide a useful benchmark for outcomes of aortic valve replacement surgery for older patients eligible for surgery considering newer transcatheter treatments.

ARTICLE INFORMATION

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