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ORIGINAL RESEARCH

Trends and Disparities in Valvular Heart Disease Mortality in the United States From 1999 to 2020

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BACKGROUND: Percutaneous heart valve procedures have been increasingly performed over the past decade, yet real-world mortality data on valvular heart disease (VHD) in the United States remain limited.

METHODS AND RESULTS: We queried the Centers for Disease Control and Prevention's Wide-Ranging Online Data for Epidemiologic Research database among patients ≥15 years old from 1999 to 2020. VHD and its subtypes were listed as the underlying cause of death. We calculated age-adjusted mortality rate (AAMR) per 100 000 individuals and determined overall trends by estimating the average annual percent change using the Joinpoint regression program. Subgroup analyses were performed based on demographic and geographic factors. In the 22-year study, there were 446 096 VHD deaths, accounting for 0.80% of all-cause mortality (56 014 102 people) and 2.38% of the total cardiovascular mortality (18 759 451 people). Aortic stenosis recorded the highest mortality of VHD-related death in both male (109 529, 61.74%) and female (166 930, 62.13%) populations. The AAMR of VHD has declined from 8.4 (95% CI, 8.2–8.5) to 6.6 (95% CI, 6.5–6.7) per 100 000 population. Similar decreasing AAMR trends were also seen for the VHD subtypes. Men recorded higher AAMR for aortic stenosis and aortic regurgitation, whereas women had higher AAMR for mitral stenosis and mitral regurgitation. Mitral regurgitation had the highest change in average annual percent change in AAMR.

CONCLUSIONS: The mortality rate of VHD among the US population has declined over the past 2 decades. This highlights the likely efficacy of increasing surveillance and advancement in the management of VHD, resulting in improved outcomes.

Key Words: aortic valvular disease ■ mitral valvular disease ■ mortality ■ trend and disparity ■ valvular heart disease

Valvular heart disease (VHD) is one of the most common diseases in the United States, with an estimated prevalence of 2.5% among adults.[1–3] Among VHD, aortic and mitral valvular diseases are the 2 most diagnosed diseases in the recent era.[1,4] Management of VHD was limited to the surgical approach in the past. Newer, less invasive percutaneous valvular repair or replacement procedures have been introduced in the past decade. The first transcatheter aortic valve replacement (TAVR) valve was approved by the US Food and Drug Administration (FDA) in 2011, with subsequent iterative expansion of indication for use associated with continued improvement in design and associated procedural outcomes. In 2013, the FDA's approval of the MitraClip for transcatheter edge-to-edge repair transformed the management of mitral regurgitation (MR).[5] Recently, in 2022, the FDA further approved the second percutaneous PASCAL

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CLINICAL PERSPECTIVE

What Is New?

- There were decreasing trends in the overall age-adjusted mortality rate due to valvular heart disease and its subtypes from 1999 to 2020.
- Aortic stenosis was the most common type of valvular heart disease in patients who died from valvular heart disease.

What Are the Clinical Implications?

- Our findings highlight the improving survival of patients with valvular heart disease due to contemporary management algorithms and likely the increased use of transcutaneous aortic valve intervention.

Nonstandard Abbreviations and Acronyms

AAMR	age-adjusted mortality rate
AAPC	average annual percent change
APC	average percent change
AS	aortic stenosis
AR	aortic regurgitation
CDC WONDER	Centers for Disease Control and Prevention's Wide-Ranging Online Data for Epidemiologic Research
FDA	U.S. Food and Drug Administration
MR	mitral regurgitation
MS	mitral stenosis
SAVR	surgical aortic valve replacement
TAVR	transcatheter aortic valve replacement
TEER	transcatheter edge-to-edge-repair
VHD	valvular heart disease

transcatheter edge-to-edge repair system as a treatment for severe degenerative MR. The use of these transcatheter therapies is rising and has been associated with improved patient outcomes in clinical trials.[6–8]

Despite advances in the therapeutic approach to VHD, real-world data on the impact on population mortality are not well-established. Thus, we sought to analyze the trend in mortality due to VHD in the United States and to evaluate the changes in mortality following the introduction of these advanced approaches.

METHODS

Data Source

We declare that all supporting data are available within the article and the online supplementary files. We conducted a retrospective cross-sectional analysis using data obtained from the Centers for Disease Control and Prevention's Wide-Ranging Online Data for Epidemiologic Research (CDC WONDER). This online database contains national mortality and population data in the United States, and our topic of interest is based on the Multiple Cause of Death database. The database is encoded based on death certificates of US residents from January 1, 1999 to December 31, 2020, and contains information on the underlying cause of death along with demographic data.[9] *International Classification of Diseases, Tenth Revision* (*ICD-10*) was used to classify the causes of death for 1999 and beyond. This study approach has been validated in similar research on other topics of interest.[10–12] Our study did not require institutional review board approval because the population data are deidentified and publicly available. This research did not require informed consent because the population data are deidentified and publicly available.

Using the CDC WONDER from 1999 to 2020, we first evaluated demographics for all-cause mortality in the general population, followed by overall cardiovascular death and, eventually, mortality in VHD with its subtypes. To analyze age-adjusted mortality rate (AAMR; standardized to 2000 US Census proportions), we selected valvular heart disease (*ICD-10* codes I05–I08 and I34–I37) as the underlying cause of death. The World Health Organization defines the underlying cause of death as the disease or injury that initiates a sequence of events that leads directly to death.[9] Demographic features were used to stratify the study population based on age, sex, race, and geographic region of residence. Subsequently, we explored various subtypes of valvular heart disease, including MR (*ICD-10* I05.1, I34.0, I34.1), mitral stenosis (MS) (*ICD-10* I05.0, I34.2), aortic regurgitation (AR) (*ICD-10* I06.1, I35.1), and aortic stenosis (AS) (*ICD-10* I06.0, I35.0).[1,4] Individuals <15 years old or individuals with unknown age at the time of death on the death certificate were excluded from the data query.

Statistical Analysis

We obtained the AAMR for overall VHD and each subtype, stratified by sex, directly from the CDC WONDER database and charted the trends throughout the study period. The AAMR per 100 000 were calculated using the direct method by applying age-specific rates in a population of interest to the 2000 US Standard Population.[13] This allows for the reduction of confounding effects due to varying age structures and enables

meaningful comparisons across different populations. We used the Joinpoint regression program (Joinpoint V4.9.1.0; National Cancer Institute) to evaluate trends of AAMR in each subgroup. This method, as described in previous similar studies, determines the significance of AAMR changes over time using log-linear regression models where temporal variation occurred.[14,15] Annual percent change with 95% CI for the AAMR was calculated using the Monte Carlo permutation test at the identified line segments linking Joinpoint. Afterward, the weighted averages of the annual percent changes, also known as average annual percent change (AAPC), were calculated with corresponding 95% CI, which reflects the summary of the mortality trends in the study period. Statistical significance was set at $P \leq 0.05$ using a 2-tailed t test in all analyses. We also examined the percentage of mortality in each VHD subtype by age and sex groups. The population was further categorized into urban (large central metro, large fringe metro, medium metro, and small metro counties) and rural (micropolitan nonmetro and noncore nonmetro counties) according to the 2013 US Census classifications.

RESULTS

The baseline demographics of patients who met the inclusion criteria are shown in Table 1. In the 22-year study period from 1999 to 2020, there were 446 096 VHD deaths, accounting for 0.80% of all-cause mortality (56 014 102 people) and 2.38% of total cardiovascular mortality (18 759 451 people). The different valvular subtypes of VHD deaths are depicted in Figure 1. AS recorded the highest mortality of VHD-related death in both male (109 529, 61.74%) and female populations (166 930, 62.13%). This was followed by MR (19 001, 10.71%), AR (5995, 3.3%), and MS (2447, 1.38%) in men, and MR (33 907, 12.62%), MS (9655, 3.59%), and AR (5893, 2.19%) in women.

Table 1. Baseline Characteristics of All-Cause Mortality, Overall Cardiovascular Death, Valvular Heart Disease and its Subtypes

Demographic	All-cause, n (%) n=56 014 102	Cardiovascular death, n (%) n=18 759 451	VHD, n (%) n=446 096	AR, n (%) n=11 888	AS, n (%) n=276 459	MR, n (%) n=52 908	MS, n (%) n=12 102
Sex							
Women	27 975 534 (49.94)	9 569 325 (51.01)	268 684 (60.23)	5893 (49.57)	166 930 (60.38)	33 907 (64.09)	9655 (79.78)
Men	28 038 568 (50.06)	9 190 126 (48.99)	177 412 (39.77)	5995 (50.43)	109 529 (39.62)	19 001 (35.91)	2447 (20.22)
Age of death, y							
15–24	696 479 (1.24)	28 734 (0.15)	768 (0.17)	33 (0.28)	92 (0.03)	270 (0.51)	29 (0.24)
25–34	1 043 043 (1.86)	94 568 (0.50)	2305 (0.52)	144 (1.21)	190 (0.07)	605 (1.14)	84 (0.69)
35–44	1 783 349 (3.18)	328 697 (1.75)	4926 (1.10)	353 (2.97)	646 (0.23)	1157 (2.19)	279 (2.31)
45–54	3 869 682 (6.91)	979 367 (5.22)	11 315 (2.54)	771 (6.49)	2345 (0.85)	2114 (4.00)	741 (6.12)
55–64	6 885 039 (12.29)	1 933 512 (10.31)	23 278 (5.22)	1209 (10.17)	7314 (2.65)	3618 (6.84)	1383 (11.43)
65–74	10 034 288 (17.91)	3 008 892 (16.04)	48 599 (10.89)	1725 (14.51)	21 048 (7.61)	6883 (13.01)	2361 (19.51)
75–84	14 723 222 (26.28)	5 154 065 (27.47)	118 953 (26.67)	3020 (25.40)	69 231 (25.04)	15 276 (28.87)	3902 (32.24)
85+	16 979 000 (30.31)	7 231 616 (38.55)	235 952 (52.89)	4633 (38.97)	175 593 (63.52)	22 985 (43.44)	3323 (27.46)
Race							
American Indian or Alaska Native	345 850 (0.62)	85 803 (0.46)	1577 (0.35)	69 (0.58)	760 (0.27)	177 (0.33)	84 (0.69)
Asian or Pacific Islander	1 178 072 (2.10)	396 524 (2.11)	7723 (1.73)	318 (2.67)	3700 (1.34)	1280 (2.42)	446 (3.69)
Black	6 586 732 (11.76)	2 256 923 (12.03)	24 039 (5.39)	1395 (11.73)	10 629 (3.84)	3792 (7.17)	896 (7.40)
White	47 903 448 (85.52)	16 020 201 (85.40)	412 757 (92.53)	10 106 (85.01)	261 370 (94.54)	47 659 (90.08)	10 676 (88.22)
Census region							
Region 1	10 555 896 (18.85)	3 697 047 (19.71)	97 441 (21.84)	2236 (18.81)	64 196 (23.22)	11 030 (20.85)	2421 (20.00)
Region 2	13 061 398 (23.32)	4 388 498 (23.39)	110 504 (24.77)	2754 (23.17)	68 361 (24.73)	13 254 (25.05)	2960 (24.46)
Region 3	21 474 392 (38.34)	7 087 291 (37.78)	133 053 (29.83)	2889 (24.30)	78 898 (28.54)	16 308 (30.82)	3744 (30.94)
Region 4	10 922 416 (19.50)	3 586 615 (19.12)	105 098 (23.56)	4009 (33.72)	65 004 (23.51)	12 316 (23.28)	2977 (24.60)

AR indicates aortic regurgitation; AS, aortic stenosis; MR, mitral regurgitation; MS, mitral stenosis; and VHD, valvular heart disease.

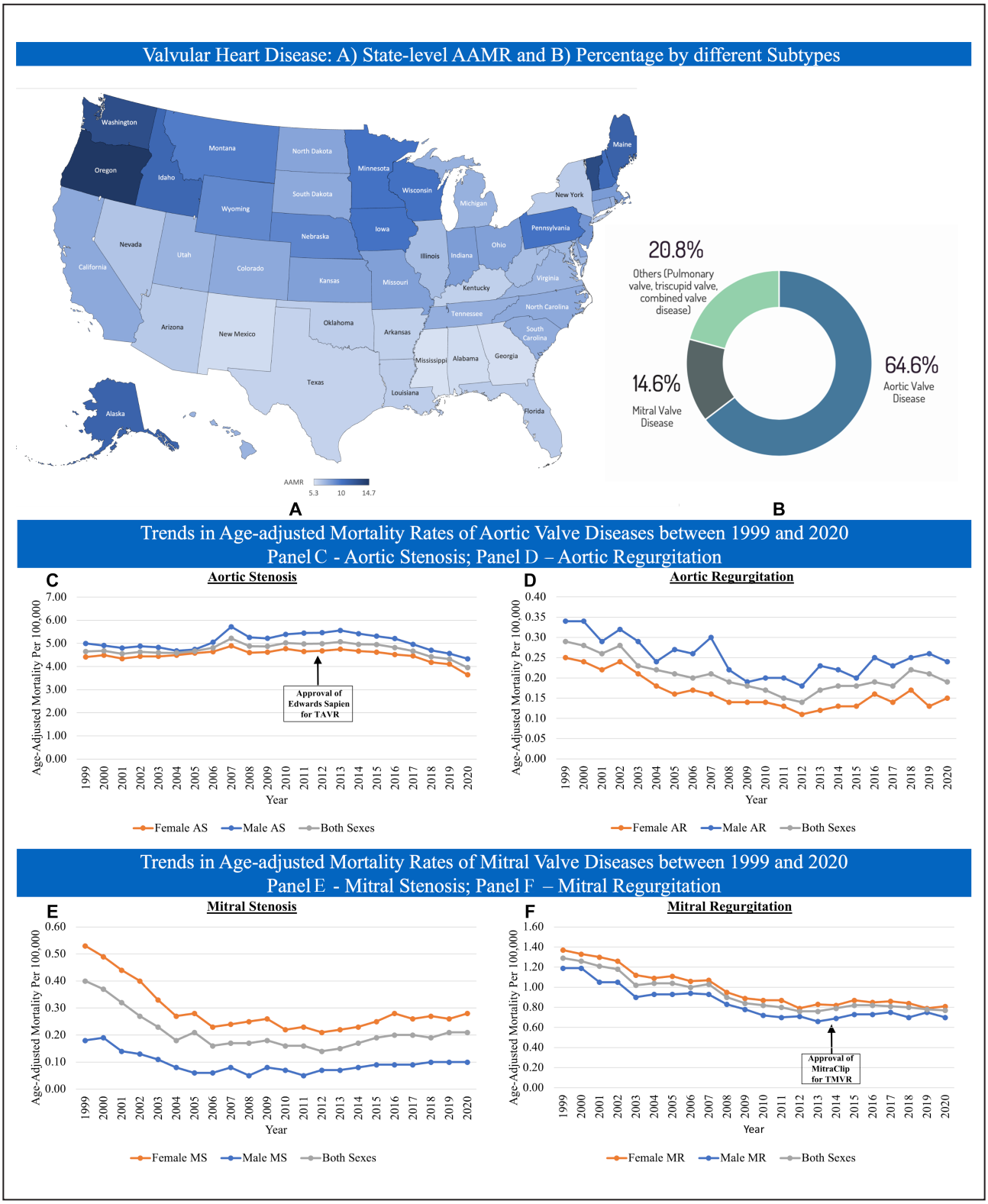

Figure 1. State-level age-adjusted mortality rate for VHD and trends in AAMR for VHD subtypes, stratified by sex, between 1999 and 2020.

AAMR indicates age-adjusted mortality rate; AR, aortic regurgitation; AS, aortic stenosis; MR, mitral regurgitation; MS, mitral stenosis; TAVR, transcatheter aortic valve replacement; TMVR, transcatheter mitral valve replacement; and VHD, valvular heart diseases.

Regional Differences

When overall VHD mortality was cross-examined based on regional differences, the South (census region 3) had the highest percentage of VHD mortality (133 053, 29.83%), followed by the Midwest (census region 2, 24.77%), the West (census region 4, 23.56%), and the Northeast (census region 1, 21.84%) (Table 2). The West had the highest AAMR of VHD (8.57 [95% CI, 8.52–8.63] per 100 000 people), followed by the Midwest (8.27 [95% CI, 8.22–8.32] per 100 000 people), Northeast (8.19 [95% CI, 8.13–8.24] per 100 000 people), and South (6.49 [95% CI, 6.45–6.52] per 100 000 people). When the AAMR of VHD subtypes was analyzed, the rates were the highest in the West (AS, 5.31 [95% CI, 5.27–5.35] per 100 000 people; MR, 1.02 [95% CI, 1.00–1.04] per 100 000 people; MS, 0.24 [95% CI, 0.23–0.24] per 100 000 people), except for AR, which was the highest in the Midwest (0.22 [95% CI, 0.21–0.23] per 100 000 people). The Northeast and South shared the lowest AAMR of AR (0.18 [95% CI, 0.18–0.19] per 100 000 people), and the South had the lowest AAMR for the other VHD subtypes (AS, 3.86 [95% CI, 3.83–3.89] per 100 000 people; MR, 0.79 [95% CI, 0.77–0.80] per 100 000 people; MS, 0.17 [95% CI, 0.16–0.18] per 100 000 people). In terms of urbanization, rural regions had a higher AAMR of overall VHDs compared with urban regions (8.28 [95% CI, 8.22–8.34] versus 7.57 [95% CI 7.55–7.60] per 100 000 people). In rural regions, the AAMR of VHD fluctuated from 8.31 (95% CI, 8.03–8.58) per 100 000 people in 1999 to 7.74 (95% CI, 7.50–7.98) per 100 000 people in 2020, with an AAPC of −0.07 (95% CI, −0.32 to 0.18). On the other hand, the AAMR of VHDs in urban regions had decreased from 8.37 (95% CI, 8.23–8.50) per 100 000 people in 1999 to 6.39 (95% CI, 6.29–6.48) per 100 000 people in 2020, with an AAPC of −0.89 (95% CI, −1.11 to −0.67) (Figures S1–S5).

Trends and AAPCs in AAMR Between 1999 and 2020

Figure 2 shows the trend in AAMR of overall VHD from 1999 to 2020. The AAMR of VHD decreased from 8.36 (95% CI, 8.24–8.48) per 100 000 people in 1999 to 6.61 (95% CI, 6.52–6.70) per 100 000 people in 2020, with an AAPC of −0.75 (95% CI, −0.97 to −0.52). When stratified by VHD subtypes, similar decreasing trends were seen in AS (from 4.65 [95% CI, 4.56–4.75] to 3.95 [95% CI, 3.88–4.02] per 100 000 people), AR (from 0.29 [95% CI, 0.26–0.31] to 0.19 [95% CI, 0.17–0.20] per 100 000 people), MR (from 1.29 [95% CI, 1.24–1.34] to 0.77 [95% CI, 0.74–0.80] per 100 000 people), and MS (from 0.40 [95% CI, 0.37–0.42] to 0.21 [95% CI, 0.19–0.23] per 100 000 people). During the study period, the AAMR of AS and AR were higher in men than in women. Female patients had higher AAMR of MR and MS than male patients. The AAPC in AAMR was higher in mitral diseases (MR, −2.47 [95% CI, −2.99 to −1.96] and MS, −2.37 [95% CI, −4.00 to −0.72]) than in aortic diseases (AR, −1.89 [95% CI, −2.94 to −0.83] and AS, −0.17 [95% CI, −0.61 to 0.26]) (Table 3). Most of the deaths seen in the VHD and its subtypes happened in the age group of ≥85 years old, except for MS, which occurred in the age group of 75 to 84 years old (Figure 3).

Proportionate Mortality

Overall, the proportionate mortality rate of cardiovascular death (total cardiovascular mortality divided by total all-cause mortality) has decreased from 40.55% in 1999 to 27.66% in 2020. The proportionate mortality of VHD (total VHD mortality divided by total cardiovascular mortality) showed an increment from 1.87% in 1999 to 2.32% in 2020. The proportionate mortality of VHD increased from 2.19% to 2.76% and 1.50% to 1.91% among men and women, respectively. This increment in proportionate mortality rate was seen in AS and AR, but MR and MS showed a decrease in proportionate mortality rate.

Trends in AAMR of Infective Endocarditis

Additional analysis was performed to assess trends in the AAMR of infective endocarditis during the study period (Figure S2). Our analysis revealed a mild decreasing trend in the AAMR of infective endocarditis

Table 2. Census Population and Cardiovascular and Valvular Heart Disease Deaths by Region

Population	Northeast (region 1), n (%)	Midwest (region 2), n (%)	South (region 3), n (%)	West (region 4), n (%)	Total, n (%)
Total population	989 744 746	1 174 560 460	1 998 181 533	1 247 162 472	5 409 649 211
All-cause mortality	10 555 896 (18.85)	13 061 398 (23.32)	21 474 392 (38.34)	10 922 416 (19.50)	56 014 102 (100)
Cardiovascular disease deaths	3 697 047 (19.71)	4 388 498 (23.39)	7 087 291 (37.78)	3 586 615 (19.12)	18 759 451 (100)
Valvular heart disease deaths	97 441 (21.84)	110 504 (24.77)	133 053 (29.83)	105 098 (23.56)	446 096 (100)
Aortic regurgitation deaths	2236 (18.81)	2754 (23.17)	2889 (24.30)	4009 (33.72)	11 888 (100)
Aortic stenosis deaths	64 196 (23.22)	68 361 (24.73)	78 898 (28.54)	65 004 (23.51)	276 459 (100)
Mitral regurgitation deaths	11 030 (20.85)	13 254 (25.05)	16 308 (30.82)	12 316 (23.28)	52 908 (100)
Mitral stenosis deaths	2421 (20.00)	2960 (24.46)	3744 (30.94)	2977 (24.60)	12 102 (100)

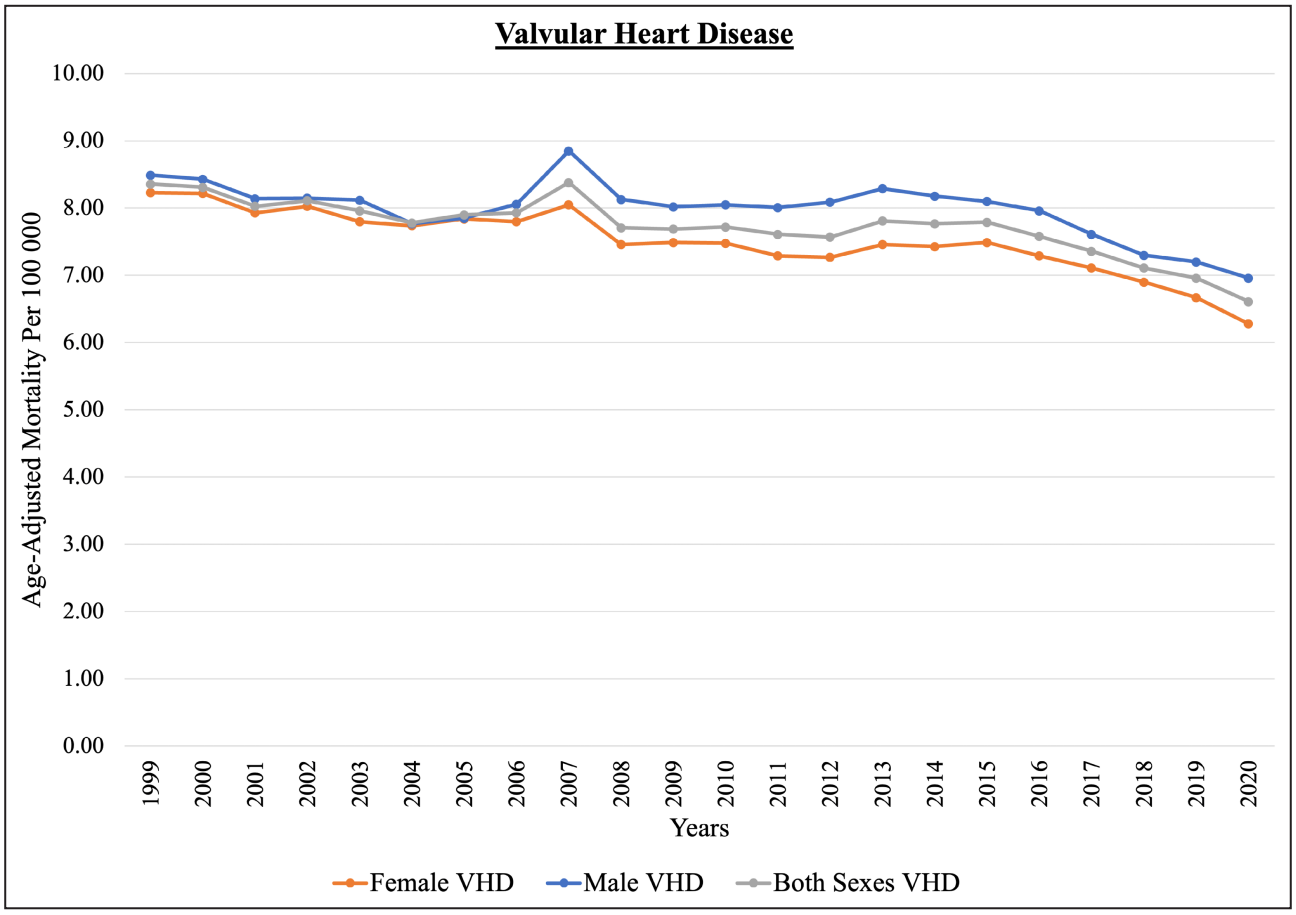

Figure 2. Trends in age-adjusted mortality rate for VHDs, stratified by sex, between 1999 and 2020.
VHD indicates valvular heart disease.

from 5.41 (95% CI, 5.31–5.51) per 100 000 people in 1999 to 5.32 (95% CI, 5.23–5.40) per 100 000 people in 2020.

DISCUSSION

This is a 22-year analysis of mortality data from the Centers for Disease Control and Prevention on the trend in the mortality rate of VHD and its subtypes. Our analysis showed that (1) VHD accounted for 0.8% of the all-cause mortality and 2.4% of the cardiovascular mortality in the United States during the study period. (2) There was a decreasing trend in the overall AAMR of VHD and its subtypes, with MR recording the highest annual percentage decrease in AAMR. (3) AS was the most common type of VHD in both female (62.1%) and male (61.7%) patients who died from VHD. (4) AAMR of aortic valve diseases was higher in men, and women had higher AAMR of mitral valve diseases throughout the study period.

Mortality is an objective indicator of a population's health. It is thus crucial to analyze the underlying cause of mortality and determine its trend so that better patient care can be delivered. One-third of the total deaths reported to the Centers for Disease Control and Prevention occurred because of cardiovascular events. VHD only accounted for 2.4% of total cardiovascular deaths. This is in line with a 30-year multinational study.[16]

The overall AAMR of VHD decreased from 1999 to 2020, possibly related primarily to advances in aortic valve therapy. AS is the most common type of VHD in the developed world, and the incidence is rising in accordance with the aging population.[17–19] Among reported deaths related to VHD, AS accounted for nearly two-thirds of the cases in both women and men. The AAMR of AS did not change much until 2012, when it started to decrease. This is likely due to the approval and increasing use of TAVR starting from 2012.[20–22] TAVR has been widely performed in the United States and has gradually surpassed surgical aortic valve replacement (Figure S3), with a higher proportion of TAVR versus surgical aortic valve replacement use in higher-risk patients. When stratified by age, our analysis further revealed a higher AAPC in patients

Table 3. Age-Adjusted Mortality Rate for Valvular Heart Disease With Its Subtypes in 1999 and 2020, and Average Annual Percent Change by Age Group

Diseases	Overall			15–64 years old			≥65 years old		
	1999 AAMR	2020 AAMR	Average annual percent change, (95% CI)	1999 AAMR	2020 AAMR	Average annual percent change, (95% CI) %	1999 AAMR	2020 AAMR	Average annual percent change, (95% CI) %
Valvular heart diseases	8.36 (8.24 to 8.48)	6.61 (6.52 to 6.70)	−0.75 (−0.97 to −0.52)	1.07 (1.02 to 1.11)	0.88 (0.84 to 0.92)	−0.96 (−1.61 to −0.31)	46.38 (45.66 to 47.10)	36.45 (35.93 to 36.97)	−0.73 (−1.00 to −0.45)
Aortic regurgitation	0.29 (0.26 to 0.31)	0.19 (0.17 to 0.20)	−1.89 (−2.94 to −0.83)	0.06 (0.05 to 0.07)	0.05 (0.04 to 0.06)	0.14 (−2.24 to 2.59)	1.47 (1.35 to 1.60)	0.91 (0.83 to 0.99)	−2.41 (−3.30 to −1.50)
Aortic stenosis	4.65 (4.56 to 4.75)	3.95 (3.88 to 4.02)	−0.17 (−0.61 to 0.26)	0.22 (0.20 to 0.24)	0.19 (0.18 to 0.21)	−0.06 (−0.78 to 0.66)	27.77 (27.22 to 28.33)	23.52 (23.10 to 23.93)	−0.18 (−0.64 to 0.28)
Mitral regurgitation	1.29 (1.24 to 1.34)	0.77 (0.74 to 0.80)	−2.47 (−2.99 to −1.96)	0.23 (0.21 to 0.25)	0.13 (0.12 to 0.15)	−2.97 (−3.56 to −2.37)	6.79 (6.51 to 7.06)	4.08 (3.91 to 4.25)	−2.39 (−2.91 to −1.86)
Mitral stenosis	0.40 (0.37 to 0.42)	0.21 (0.19 to 0.23)	−2.37 (−4.00 to −0.72)	0.12 (0.10 to 0.14)	0.05 (0.04 to 0.06)	−4.61 (−8.46 to −0.59)	1.84 (1.70 to 1.98)	1.06 (0.97 to 1.14)	−1.80 (−3.1 to −0.5)

AAMR indicates age-adjusted mortality rate.

>65 years old than those younger. Clinical trials of TAVR have not included patients with a bicuspid aortic valve, which affects younger patients, although observational data suggest equivalent early outcomes.[23] The 2019 US FDA approval for TAVR in low-risk patients expanded the approval to include patients regardless of aortic valve anatomy, paving the way for TAVR in bicuspid valves. Further randomized controlled trials are needed to better assess the role of TAVR and the long-term outcomes in this population, especially given the potential long-term consequences of TAVR being used in young patients as the initial procedure.[23–25]

The AAPC of decreased AAMR was the highest in mitral valve diseases, particularly MR. There may be multiple explanations for this. Mitral valve disease can be primary or secondary and is sensitive to associated cardiac function. Unlike AS, the prevalence of significant mitral valve disease, although greater than AS, is poorly defined and complicated by the presence of multiple subtypes. Improvements in outcomes of mitral regurgitation are therefore sensitive to multiple factors. Firstly, overall improvements in the algorithm for the management of MR in contemporary guidelines, including optimization of medical therapy for heart failure, and timely surgical and percutaneous interventions have been widely adopted.[26–29] Secondly, guidelines have recommended closer follow-up surveillance of patients with MR since 1998, facilitating timely intervention. Thirdly, decreases in the proportion of MR and most of MS mortality can be explained by the decreasing prevalence of rheumatic heart disease in the United States, due to improved prevention.[30–32] The trend toward earlier surgical intervention has been supported by long-term benefits in existing studies.[33,34] Additionally, the introduction of percutaneous repair of the mitral valve as an alternative treatment option for high-risk surgical patients has afforded these patients a safer and equally effective strategy compared with the surgical approach.[35] Despite the potential benefits of percutaneous mitral valve procedures, the impact of these procedures on mortality attributed to MR is likely small given the small proportion of patients with MR who have undergone percutaneous repair since FDA approval.[36,37] Further studies on the impact of percutaneous mitral intervention on overall mitral regurgitation outcomes are needed to explore contemporary trends as the use of percutaneous mitral valve procedures slowly increases (Figures S4 and S5).[35,38,39]

A steady decrease in the AAMR of MS was observed in our analysis from 1999 to early 2000s, with a plateau in mortality from the early 2000s. This initial change is likely associated with the significant reduction in rheumatic heart disease over the latter half of the 20th century in the United States in addition to the introduction of the Inoue balloon catheter in the mid-1990s providing a percutaneous option for therapy. The subsequent plateau is likely related to the lack of further evolution in management options coupled with the aging of the population and a proportional rise in patients with MS secondary to mitral annular calcification, for which no good percutaneous options are available.

Interestingly, our analysis showed that the mortality of men is higher than women across all types of aortic valve diseases. This is in contrast with mitral valve disease, where women have higher mortality.

Limitations

Our study has several limitations. The main limitation stems from the nature of the CDC WONDER database, which uses death certificates. These vital statistics data are subject to human error, which includes inaccurate assessment of the cause of death, misclassification of demographics, data loss, or errors during compilation. These reporting biases can lead to underreporting of VHD-related mortality, especially when mortality was not directly attributed to VHD itself. Secondly, the use

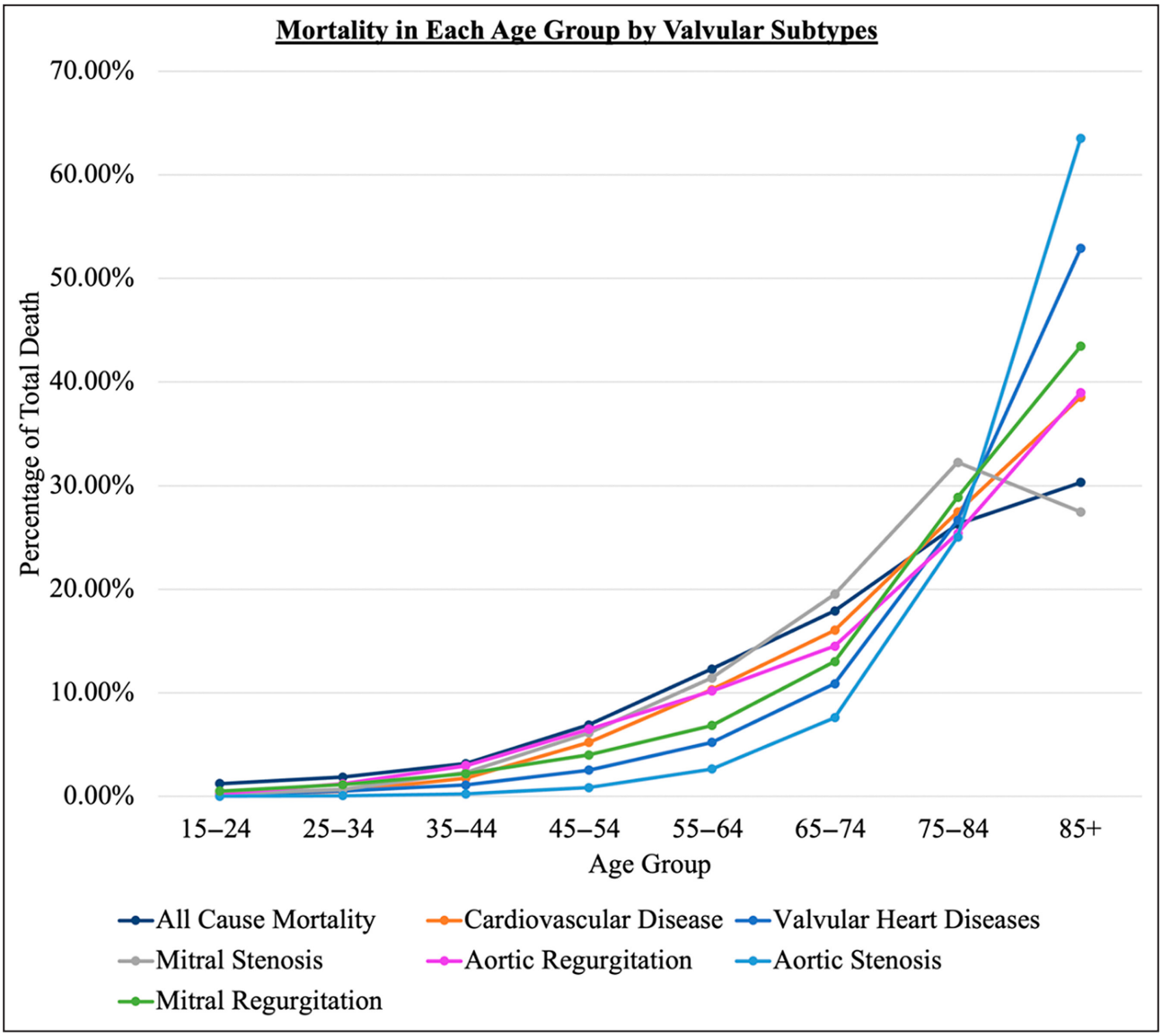

Figure 3. Percent of mortality due to cardiovascular disease and valvular heart disease with its subtypes in different age groups.

of *ICD-10* codes as filter criteria without access to associated clinical parameters limits our ability to further verify or understand clinical associations. Hence, the temporal relationship between the staging and cause of valvular heart disease and its mortality rate cannot be ascertained. Thirdly, this population study by its nature excluded individual-level data, such as comorbidity burden, duration of disease, medical treatment, or prior interventions, which are important confounders for mortality. Next, our study has a narrow set of definitions to classify VHD subtypes. We chose a diagnosis solely involving single-valve disease to isolate the impact of demographic data on particular valves, and this may lead to an underestimation of the actual nationwide burden of VHD mortality. Lastly, mortality data for tricuspid valve disease were unable to be explored due to data suppression with the low number of cases reported. Despite these limitations, our study sufficiently demonstrates the demographic and temporal relationship between VHD in the United States over the past 22 years. It provides valuable insights into the effectiveness of contemporary VHD management strategies. This study approach has been validated in similar research on another topic of interest.[10–12]

CONCLUSIONS

Our study emphasized the contemporary trend of death due to VHD and its subtypes in the recent era.

There were decreasing trends in the overall mortality rate due to VHD and its subtypes over the past 2 decades. This highlights the improving survival of

patients with VHD due to contemporary management algorithms and likely the increased use of transcutaneous aortic valve intervention.

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Supplemental Material

Figures S1–S5

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