JACC: CARDIOVASCULAR INTERVENTIONS VOL. 18, NO. 18, 2025

PUBLISHED BY ELSEVIER

ORIGINAL RESEARCH

STRUCTURAL

Acceleration Time/Ejection Time Ratio Compared to Mean Gradient as a Predictor of Clinical Outcomes Post-TAVR

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ABSTRACT

BACKGROUND Transcatheter aortic valve replacement (TAVR) is a significant treatment option for patients with severe aortic stenosis. Aortic valve (AV) mean gradient (MG) is frequently used to assess prosthetic valve function. Although MG is a helpful measure of valve performance, it depends on cardiac output and pressure recovery, which can be important confounders.

OBJECTIVES The aims of this study were to explore TAVR valve hemodynamic status using the acceleration time (AT)/ejection time (ET) ratio and to compare AT/ET and MG correlations with post-TAVR clinical outcomes.

METHODS This retrospective cohort study involves patients >18 years of age undergoing TAVR between 2016 and 2020. AV AT/ET was measured within 3 months post-TAVR. A total of 1,900 patients were classified into 2 groups: those with AV AT/ET ≥ 0.35 and those with AV AT/ET < 0.35. Baseline characteristics, echocardiographic measurements, heart failure hospitalization (HFH), and mortality were assessed between the groups.

RESULTS AT/ET ≥ 0.35 was associated with an increase in 1-year HFH ($P < 0.001$ at 1 year) and was not associated with mortality. Patients with AV MG >20 mm Hg had comparable 1-year HFH ($P = 0.46$ at 1 year) and mortality compared with those with AV MG <20 mm Hg. More patients with self-expanding valves (23.2%) had AT/ET ≥0.35 than those who received balloon-expandable valves (12.7%) ($P = 0.001$).

CONCLUSIONS Post-TAVR AT/ET ≥0.35 can potentially predict clinical outcomes such as HFH. AT/ET may explain the discrepancy between self-expanding and balloon-expandable valves in measured hemodynamic status and outcomes. (JACC Cardiovasc Interv. 2025;18:2270–2279) © 2025 by the American College of Cardiology Foundation.

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received April 5, 2025; revised manuscript received July 7, 2025, accepted July 24, 2025.

ISSN 1936-8798/$36.00 https://doi.org/10.1016/j.jcin.2025.07.037

Transcatheter aortic valve replacement (TAVR) has significantly advanced over the past few years.[1,2] There is an increasing need to understand aortic valve (AV) function post-procedure, particularly with new mid-term data and concerns about long-term durability. Echocardiography remains a key method for evaluating AV. Although mean and peak gradients are traditional measures,[3] studies have shown inaccuracies when used alone.[4-6] Additionally, a 2024 randomized controlled trial and another key study from 2021 revealed no link between post-TAVR gradients and outcomes, calling into question their clinical utility.[7,8] Another important measure is the dimensionless valve index (DVI), which remains controversial in the TAVR population because of conflicting evidence.[9]

One promising parameter is the acceleration time (AT)/ejection time (ET) ratio, which is an echocardiographic measure that assesses the time from the start of blood flow through the AV to its peak velocity (AT) relative to the total ET from the left ventricle (LV) during systole (ET). A higher AT/ET ratio indicates increased resistance across the valve, which helps evaluate the severity of aortic stenosis (AS)[10-12] and its impact on the LV.[10,13] Previous research has demonstrated that a higher ratio is associated with increased mortality in patients with moderate to severe AS and those with low-gradient severe AS.[14,15] Another study indicated that AT/ET ≥0.35 strongly predicts clinical outcomes in patients with severe AS[16] as well as clinical outcomes and need for AV replacement in patients with paradoxical low-flow AS.[17] However, data on AT/ET in post-TAVR prosthetic valves are limited.

To date, no significant studies have researched the clinical usefulness of the AT/ET ratio in the post-TAVR patient population. Therefore, the aim of this study was to explore the predictive value of the AT/ET ratio in comparison with mean gradient (MG) for clinical outcomes following TAVR in patients receiving balloon-expandable valves (BEVs) and self-expanding valves (SEVs).

METHODS

STUDY DESIGN. The present study was a retrospective analysis of data from a single high-volume center, using records obtained from the Cleveland Clinic database. This study received approval from the Institutional Review Board. A total of 2,630 patients underwent the TAVR procedure from January 2016 to December 2020 and were followed for 1 year. A heart team decided to conduct this procedure on the basis of established criteria. AV AT/ET ratio was measured using post-TAVR echocardiographic images. All patients were >18 years of age; inclusion and exclusion criteria are described in Figure 1. The patient population was divided into 2 groups on the basis of AV AT/ET value: those with ratios ≥0.35 and those with ratios <0.35. Previous studies have demonstrated the usefulness of the 0.35 threshold.[16,17] Baseline characteristics and echocardiographic measurements were assessed. Afterward, we studied clinical outcomes such as heart failure hospitalization (HFH) and mortality between the groups according to the postprocedural AT/ET ratio and AV MG. All analyses were performed using complete case analysis.

ECHOCARDIOGRAPHIC MEASUREMENTS. Patients underwent transthoracic echocardiography within 3 months after undergoing TAVR. The echocardiograms were obtained by operators adhering to established guidelines.[18] Echocardiographic parameters included the following variables: LV ejection fraction (LVEF), heart rate, blood pressure (BP), maximum size of the aorta, AV area, left atrial volume, left atrial diameter, AV MG, AV peak gradient, LV end-diastolic volume, LV end-systolic volume, LV outflow tract (LVOT) diameter, LVOT maximum velocity, LVOT stroke volume, AV resistance, stroke volume index, DVI, and AV AT/ET ratio. The AV AT/ET ratio was calculated using continuous-wave Doppler echocardiography (Figure 2). AT was defined as the interval from the onset of systolic flow to its peak velocity. In contrast, ET was calculated from the start to the completion of systolic flow.[19]

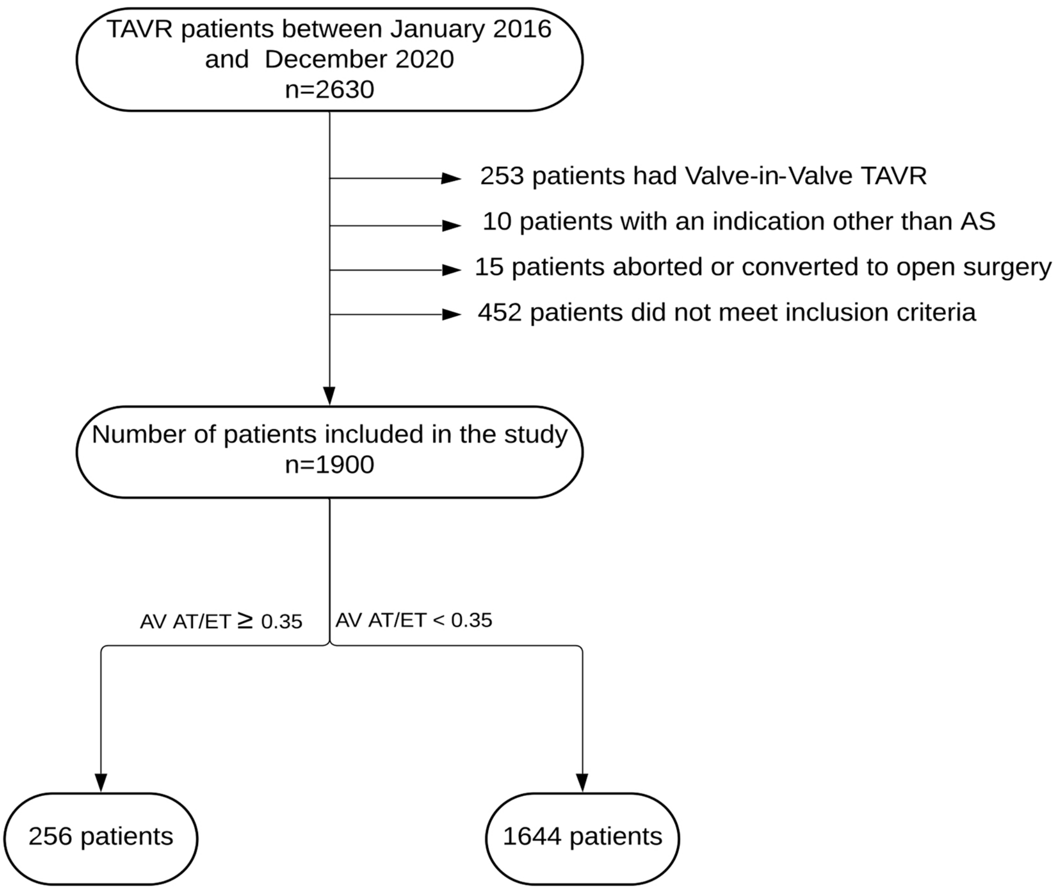
CLINICAL OUTCOMES. The clinical outcomes assessed included mortality and HFH. The impact of AV AT/ET and AV MG on all-cause mortality and HFH at 1-year follow-up was retrospectively studied.

STATISTICAL ANALYSIS. Baseline and procedural characteristics of a categorical nature are expressed as frequency (percentage of patients), while continuous variables are expressed as mean ± SD. Independent-samples Student's *t*-tests and chi-square tests were used to compare the 2 groups. We analyzed clinical outcomes at 1-year follow-up,

ABBREVIATIONS AND ACRONYMS

AS = aortic stenosis
AT = acceleration time
AV = aortic valve
BEV = balloon-expandable valve
BMI = body mass index
BP = blood pressure
DVI = dimensionless valve index
ET = ejection time
HFH = heart failure hospitalization
LV = left ventricular
LVEF = left ventricular ejection fraction
LVOT = left ventricular outflow tract
MG = mean gradient
SEV = self-expanding valve
STS = Society of Thoracic Surgeons
TAVR = transcatheter aortic valve replacement

FIGURE 1 **Diagram Showing Inclusion and Exclusion Criteria**



Initial inclusion and exclusion criteria and how patients were divided into 2 groups according to acceleration time (AT)/ejection time (ET) ratio. AS = aortic stenosis; AV = aortic valve; TAVR = transcatheter aortic valve replacement.

which were presented as the count of the first event per patient within the given period. We compared the 2 groups' mortality and HFH outcomes using the Kaplan-Meier method, with statistical comparisons made using the log-rank test. In addition, we conducted a competing risk analysis for HFH and mortality, stratified by an AT/ET ratio cutoff of 0.35. We used the multivariate and univariate Cox proportional hazards model to compare clinical outcomes. We adjusted multivariate regression model for age, sex, and body mass index (BMI), which were derived from the baseline covariates considered for the Society of Thoracic Surgeons (STS)/American College of Cardiology TVT (Transcatheter Valve Therapy) Registry's in-hospital and 30-day mortality models.[20] Additionally, we accounted for the STS risk score, as this score is one of the primary tools for assessing risk in patients with symptomatic severe AS undergoing TAVR in the United States. Generally, lower STS risk scores are associated with better outcomes.[20] Analysis was also adjusted for heart rate and BP to determine clinical outcomes, as lower BP was significantly associated with higher AT/ET in previous studies, and an increase or a decrease in heart rate can physiologically affect this measurement.[21] Adjusted HRs with 95% CIs and Cox regression model *P* values are reported. *P* values <0.05 were considered to indicate statistical significance.

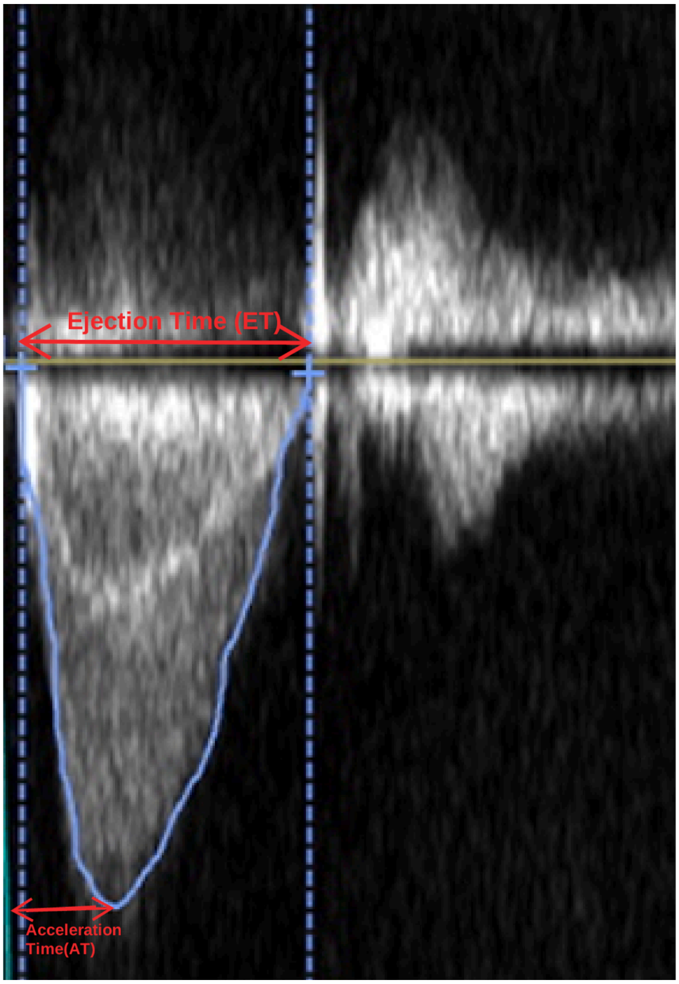
Analysis was conducted using SPSS version 23.0 (IBM) and RStudio version 4.4.1 (Posit).

RESULTS

BASELINE CHARACTERISTICS. Among 1,900 patients included, 256 (13.5%) had AV AT/ET ≥0.35 and 1,644 (86.5%) had AV AT/ET <0.35 (Table 1). Baseline characteristics were similar, though the AT/ET ≥0.35 group had higher BMI ($P = 0.02$) and a greater proportion of men ($P = 0.01$). Analysis of medical history, including coronary artery disease, stroke, hypertension, diabetes mellitus, and atrial fibrillation, as well as NYHA functional class III or IV and STS risk score, showed no significant difference between the groups. Prior permanent pacemaker or implantable cardioverter-defibrillator placement was more common in the AV AT/ET ≥0.35 group (12.2% vs 11.2%; $P = 0.007$), while carotid disease was more frequent in the AV AT/ET <0.35 group ($P = 0.04$). Preprocedural laboratory measurements were comparable between the groups, and procedural details such as the rates of predilation and postdilation were also similar.

ECHOCARDIOGRAPHIC CHARACTERISTICS. We compared echocardiographic variables between the 2 groups according to the AT/ET ratio. Table 2 summarizes echocardiographic findings in both groups. Patients with AV AT/ET ≥0.35 had lower BPs (125 ± 21 mm Hg vs 134 ± 21 mm Hg; $P < 0.001$) and lower LVEFs (52.3% ± 14% vs 57.8% ± 10%; $P < 0.001$). However, patients with AV AT/ET ≥0.35 had higher heart rates (75 ± 12 beats/min vs 70 ± 12 beats/min; $P < 0.001$) and higher LV end-diastolic and end-systolic volumes. AV MG, AV peak gradient, AV area, DVI, stroke volume index, AV resistance, and other echocardiographic variables were comparable between the groups.

FIGURE 2 Visual Representation of How the AT/ET Ratio Was Measured



Continuous-wave Doppler echocardiographic image of the aortic valve. The vertical lines represent the aortic jet velocity, while the horizontal lines represent time. AT was measured from the start of systole to the peak aortic jet velocity and ET as the time from the beginning of systole to the end of ejection. Abbreviations as in Figure 1.

CLINICAL OUTCOMES. We compared clinical outcomes, such as mortality and HFH, at 1 year post-TAVR. Table 3 summarizes clinical outcomes in both groups. Initially, we analyzed the entire population with univariable and multivariable Cox regression models, and the results for multivariable regression model showed a significant association of postprocedural AV AT/ET ≥0.35 with more frequent HFH (33 [12.8%] vs 87 [5.2%] events) at 1 year (HR: 2.25; 95% CI: 1.43-3.53; $P < 0.001$). However, no difference was seen in mortality (22 [8.5%] vs 119 [7.2%] events). Postprocedural AV MG ≥20 mm Hg was not associated with mortality (3 [5.6%] vs 106 [7%] events) or HFH (2 [3.7%] vs 114 [7.5%] events) after adjusting for confounders. Subgroup analysis showed higher HFH in patients who received SEVs (HR: 6.79; 95% CI: 1.66-27.66; $P = 0.007$) and BEVs (HR: 1.89; 95% CI: 1.15-3.12; $P = 0.01$) for AT/ET ≥0.35. In Figures 3 and 4, Kaplan-Meier curves provide a visual representation of 1-year HFH-free survival across both valve types. The Central Illustration summarizes the AT/ET and AV MG association with HFH for the entire patient population and shows

TABLE 1 Baseline Characteristics

	AT/ET ≥0.35 (n = 256)	AT/ET <0.35 (n = 1,644)	*P* Value
General			
Age, y	78 ± 10	79 ± 8	0.13
BMI, kg/m^2	29.9 ± 7	28.9 ± 6	0.02
Female	90 (35.2)	717 (43.6)	0.01
Male	166 (64.8)	927 (56.4)	
White race	243 (94.9)	1,520 (92.5)	0.38
Black race	7 (2.7)	62 (3.8)	
Other race	6 (2.3)	62 (3.8)	
History			
Prior PPM or ICD	48 (18.8)	204 (12.4)	0.007
Pacemaker	43 (16.8)	193 (11.7)	0.03
ICD	18 (7)	45 (2.7)	0.001
Previous MV surgery	6 (2.3)	34 (2.1)	0.81
Coronary artery disease	133 (52)	857 (52.1)	1.00
Prior PCI	80 (31.3)	489 (29.7)	0.66
Prior CABG	74 (28.9)	427 (26)	0.32
Known left main coronary artery disease	29 (11.3)	147 (8.9)	0.25
Myocardial infarct	54 (21.1)	358 (21.8)	0.87
Prior stroke	33 (12.9)	200 (12.2)	0.76
Transient ischemic attack	26 (10.2)	162 (9.9)	0.91
Carotid artery disease	47 (18.4)	398 (24.2)	0.04
Peripheral artery disease	164 (64.1)	1,100 (66.9)	0.39
Hypertension	223 (87.1)	1,494 (90.9)	0.07
Diabetes mellites	99 (38.7)	623 (37.9)	0.84
Current/recent smoker	16 (6.3)	68 (4.1)	0.14
Dialysis	11 (4.3)	52 (3.2)	0.35
Chronic lung disease	110 (43)	694 (42.2)	0.84
NYHA functional class III or IV	186 (72.7)	1,214 (73.8)	0.70
Prior cardiac shock	2 (0.8)	7 (0.4)	0.35
Porcelain aorta	7 (2.7)	26 (1.6)	0.20
Atrial fibrillation or flutter	115 (44.9)	678 (41.2)	0.28
STS risk score	6.4 ± 5	5.8 ± 4	0.07
Predilation	62 (24.2)	374 (22.7)	0.63
Postdilation	75 (29.3)	563 (34.2)	0.14
Balloon-expandable valve	223 (12.7)	1,535 (87.3)	0.001
Self-expanding valve	33 (23.2)	109 (76.8)	
Preprocedural			
Hematocrit	38.6 ± 5	38.6 ± 5	1.00
Hemoglobin	12.5 ± 1	12.5 ± 1	0.81
Creatinine	1.2 ± 0.8	1.2 ± 1	0.10

Values are mean ± SD or n (%).

AT = acceleration time; BMI = body mass index; CABG = coronary artery bypass graft; ET = ejection time; ICD = implantable cardioverter-defibrillator; MV = mitral valve; PCI = percutaneous coronary intervention; PPM = permanent pacemaker; STS = Society of Thoracic Surgeons.

TABLE 2 Echocardiographic Variables

	AT/ET ≥0.35	AT/ET <0.35	*P* Value
Heart rate, beats/min	75 ± 12	70 ± 12	<0.001
Blood pressure, mm Hg	125 ± 21	134 ± 21	<0.001
LVEF, %	52.3 ± 14	57.8 ± 10	<0.001
Maximal aortic size, cm	3.3 ± 0.5	3.2 ± 0.5	0.25
AV area, cm^2	3.6 ± 1.5	3.2 ± 1.6	0.68
LA volume, mL	85 ± 33	77 ± 29	0.10
LA diameter, cm	4.4 ± 0.9	4.5 ± 0.7	0.75
AV mean gradient, mm Hg	10.4 ± 6.3	10.6 ± 4	0.49
AV peak gradient, mm Hg	19.7 ± 12	20.8 ± 8	0.13
LV end-diastolic volume, mL	109 ± 49	98 ± 37	0.03
LV end-systolic volume, mL	53 ± 41	42 ± 26	0.01
LVOT diameter, cm	2.3 ± 0.3	2.5 ± 0.4	0.40
LVOT maximum velocity, m/s	1.07 ± 0.2	1.09 ± 0.2	0.18
LVOT stroke volume, mL	109 ± 40	117 ± 51	0.75
Aortic valve resistance, dyne · s · cm^{-5}	80 ± 51	85 ± 44	0.34
Stroke volume index	26.1 ± 11	26.8 ± 11	0.37
Dimensionless valve index	0.54 ± 0.1	0.54 ± 0.1	0.94

Values are mean ± SD.

AV = aortic valve; LA = left atrial; LV = left ventricular; LVEF = left ventricular ejection fraction; LVOT = left ventricular outflow tract; other abbreviations as in Table 1.

Kaplan-Meier curves with log-rank *P* values. Adjusted 1-year clinical outcomes were analyzed using Cox proportional hazards models adjusted for age, sex, BMI, STS risk score, heart rate, and BP. We used AT/ET <0.35 and AV MG <20 mm Hg as a reference group.

DISCUSSION

In this study, post-TAVR AV AT/ET ≥0.35 was associated with increased HFH but not mortality (Figure 5). MG did not predict outcomes, aligning with prior studies showing its limited utility post-TAVR. Patients with higher AT/ET ratios had distinct hemodynamic profiles, including lower LVEF and BP, as well as a higher proportion of patients who received SEVs.

Although the MG is a helpful measure of valve performance, it depends on cardiac output and pressure recovery, which can be important confounders. Many studies have demonstrated how echocardiographic AV MG measurement might overestimate the true transvalvular gradient.[22] In addition, several studies show no association of post-TAVR AV MGs with clinical outcomes.[7,8] More recently, research studies have been conducted on patients with mild, moderate, and severe AS using an AT/ET ratio threshold of 0.32[21] or 0.35.[16] One study demonstrated that the AT/ET ratio was associated with both echocardiographic and computed tomographic measurements of AS severity.[10] Most of these studies highlight the importance of a specific AT/ET ratio cutoff.

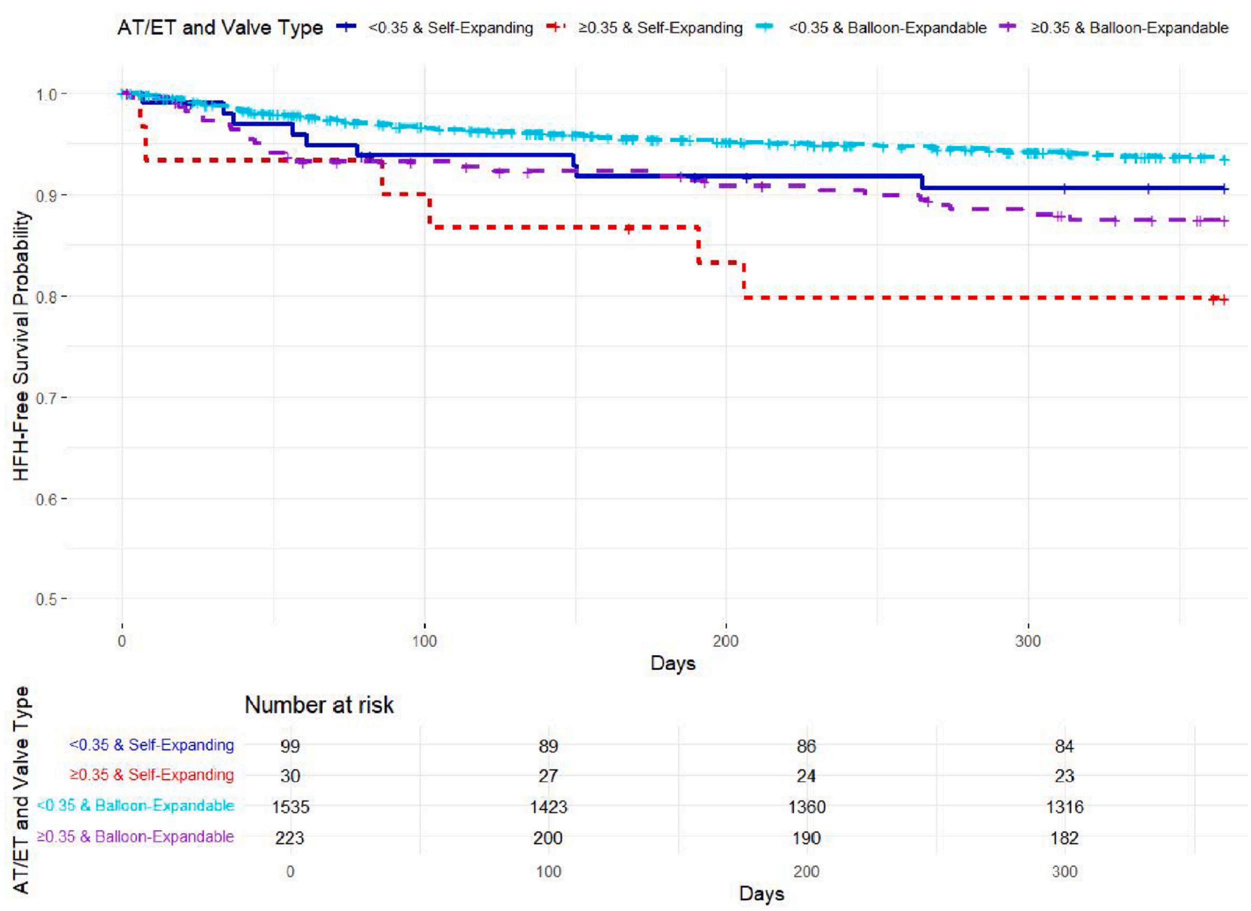
To the best of our knowledge, the present study constitutes the first and largest cohort of post-TAVR patients whose clinical outcomes, such as

TABLE 3 Cox Univariable and Multivariable Regression Model for Clinical Outcomes

		Univariate Analysis			Multivariate Analysis		
Outcome	Variable	HR	95% CI	*P* Value	HR	95% CI	*P* Value
HFH	All valve types: AT/ET ≥0.35 to <0.35 (reference)	2.10	1.41-3.10	<0.001	2.25	1.43-3.53	<0.001
	BEVs: AT/ET ≥0.35 to <0.35 (reference)	2.01	1.31-3.08	0.001	1.9	1.15-3.12	0.01
	SEVs: AT/ ET ≥0.35 to <0.35 (reference)	2.25	0.8-6.33	0.12	6.79	1.66-27.66	0.007
	All valve types: MG ≥20 to <20 mm Hg (reference)	0.52	0.13-2.11	0.36	0.58	0.14-2.42	0.46
	BEVs: MG ≥20 to <20 mm Hg (reference)	0.27	0.03-1.98	0.20	0.28	0.05-2.43	0.28
	SEVs: MG ≥20 to <20 mm Hg (reference)	6.80	0.87-52.9	0.06	14.02	0.93-210.9	0.06
All-cause mortality	All valve types: AT/ET ≥0.35 to <0.35 (reference)	1.18	0.74-1.86	0.47	1.20	0.70-2.05	0.50
	All valve types: MG ≥20 to <20 mm Hg (ref)	0.85	0.27-2.68	0.78	1.20	0.36-3.85	0.76

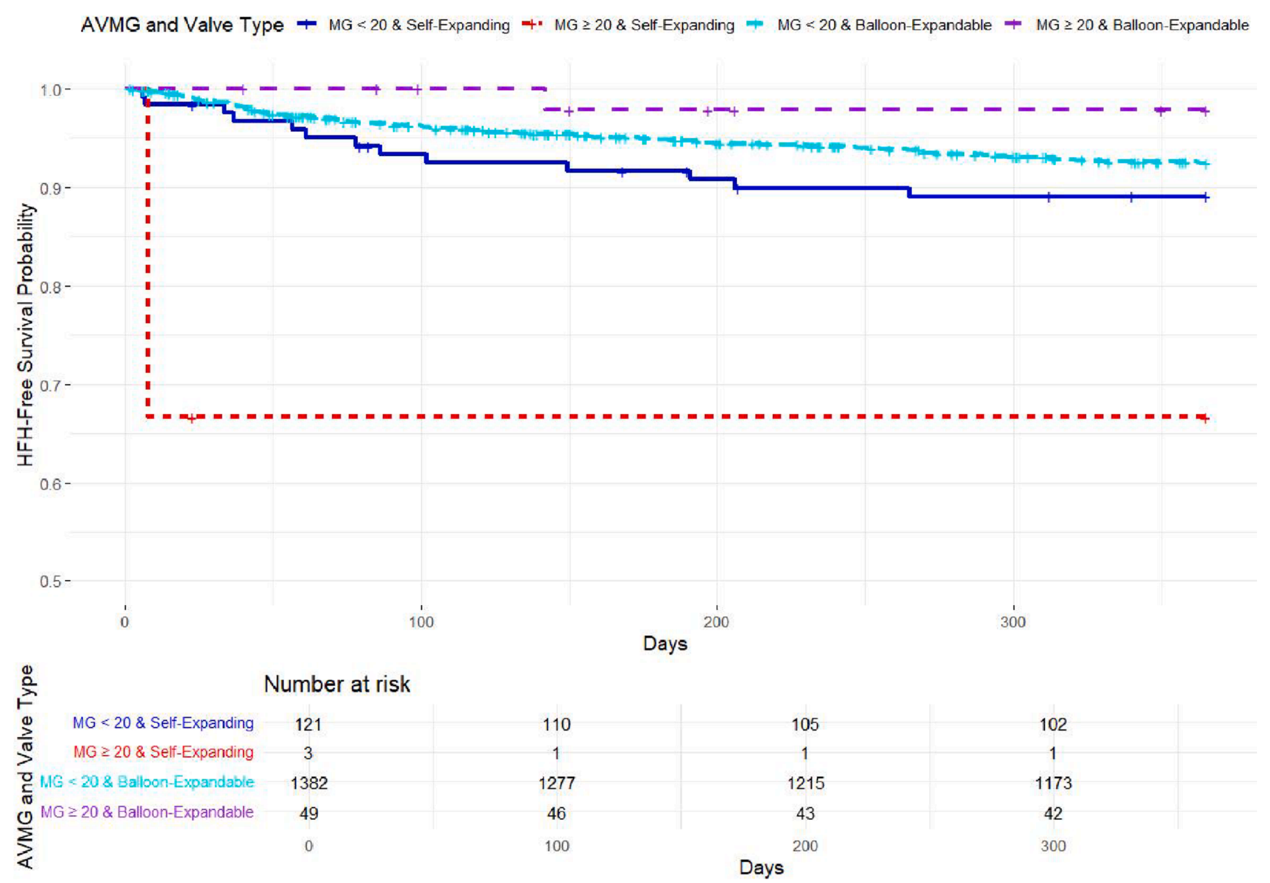
Adjusted for Society of Thoracic Surgeons risk score, body mass index, age, sex, blood pressure, and heart rate.
HFH = heart failure hospitalization; MG = mean gradient; other abbreviations as in Table 1.

FIGURE 3 AT/ET Association With HFH 1 Year After Transcatheter Aortic Valve Replacement



Kaplan-Meier curve showing that AT/ET ratio ≥0.35 predicts 1-year heart failure hospitalization (HFH)-free survival after transcatheter aortic valve replacement with balloon-expandable and self-expanding valves. Abbreviations as in Figure 1.

FIGURE 4 **AVMG Association With HFH 1 Year After Transcatheter Aortic Valve Replacement**



Kaplan-Meier curve showing that aortic valve mean gradient (AVMG) ≥20 mm Hg predicts 1-year HFH-free survival after transcatheter aortic valve replacement with balloon-expandable and self-expanding valves. MG = mean gradient; other abbreviations as in Figures 1 and 3.

HFH and mortality, were assessed using AV AT/ET. It is also the first study to describe the AT/ET ratio association with different valve types, such as BEVs and SEVs.

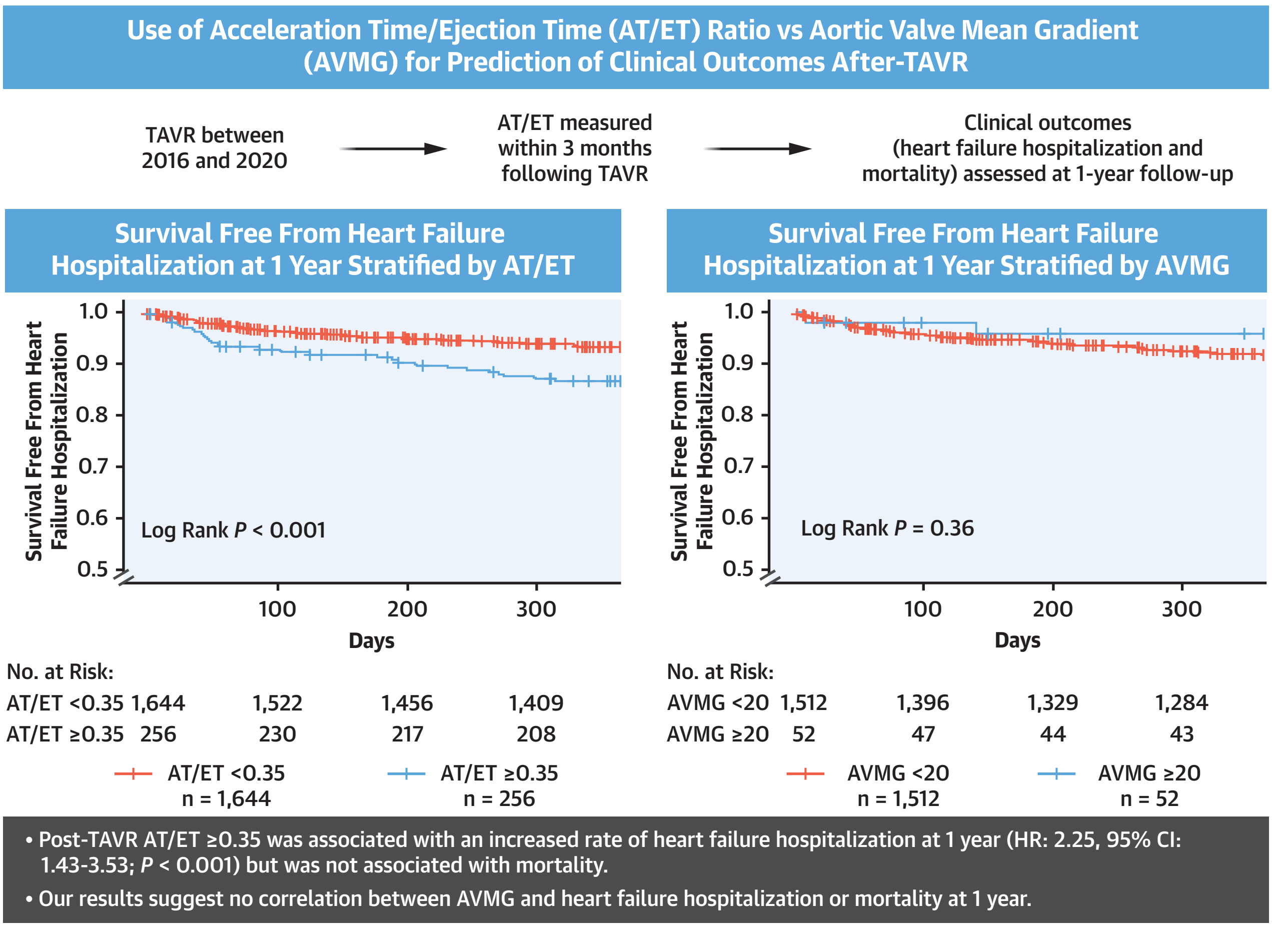
The findings suggest that AT/ET ratio could be crucial in assessing prosthetic valve functionality. A higher AT/ET ratio in SEVs vs BEVs might explain the discrepancy in conventionally measured hemodynamic status and outcomes between these prosthetic valve types.[23]

These findings suggest that AT/ET may better reflect clinical risk and functional status post-TAVR than MG. Although promising, the retrospective design and single-center setting warrant cautious interpretation and external validation.

STUDY LIMITATIONS. This study was conducted at a single high-volume center, was retrospective, and was not randomized. Therefore, despite efforts to adjust for them, it is prone to the typical biases associated with retrospective analyses, such as potential residual confounders. Acknowledging that a study conducted at a single high-volume referral center might exhibit selection bias is essential.

Another limitation is that this study was focused on symptomatic patients who underwent TAVR; thus, it likely excluded many asymptomatic patients

CENTRAL ILLUSTRATION AT/ET Ratio Compared With AVMG as Predictors of HFH Post-TAVR



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Measurement of acceleration time (AT)/ejection time (ET) ratio (top left corner) and aortic valve mean gradient (AVMG) (top right corner). The illustration also shows how these different methods predict heart failure hospitalization (HFH). The graph in the bottom left corner shows the association of AT/ET ratio with 1-year HFH for the entire population. The graph in the top right corner shows the association of AVMG with 1-year HFH for the entire population. Log-rank *P* value and Cox regression adjusted *P* value, which have been carefully adjusted to account for potential confounding factors, are shown for both graphs. TAVR = transcatheter aortic valve replacement.

with AS who were not considered for TAVR and may exhibit different characteristics and outcomes. The primary subjects of this research are patients with moderate and severe AS who underwent the TAVR procedure.

CONCLUSIONS

It has been shown that postprocedural AV MG is commonly elevated in patients who receive BEVs because of valve shape, which decreases AV area and flow.[24,25] However, our study demonstrated that a significantly greater number of patients who received SEVs had AT/ET ≥0.35 compared with the BEV patient cohort. Therefore, AT/ET ratio might explain the discrepancy between SEVs and BEVs in conventionally measured hemodynamic status and outcomes. In the entire patient population, we found that postprocedural AT/ET ≥0.35 was associated with increased 1-year HFH. When we

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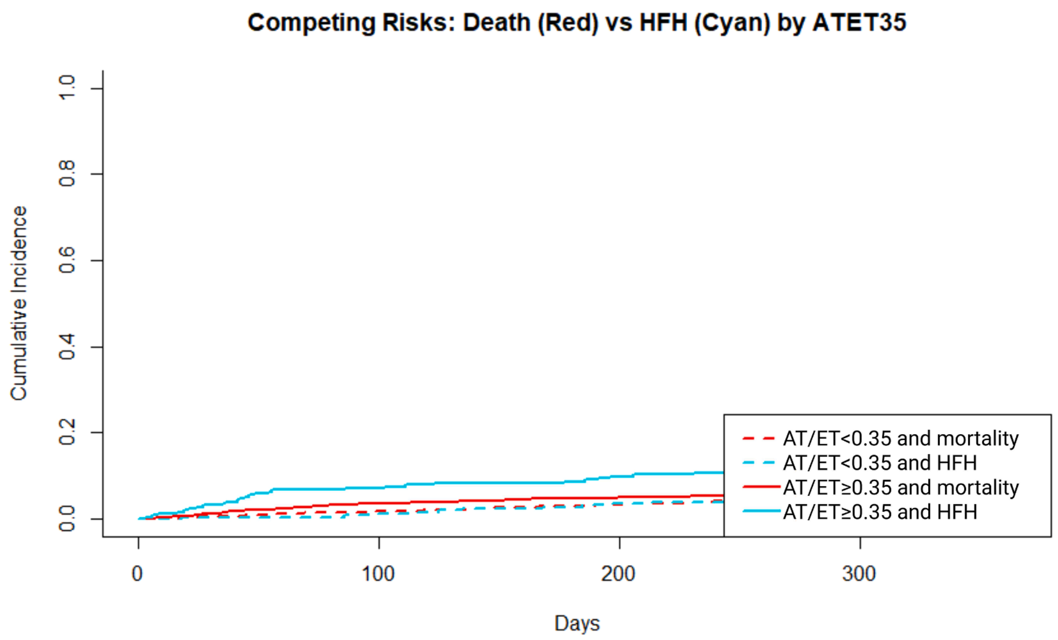
FIGURE 5 Competing Risk Analysis for HFH and Mortality Stratified by AT/ET Ratio



Incidence of HFH and mortality as a competing risk differentiated by AT/ET ratio. The incidence of both mortality and HFH was higher in the AT/ET ≥ 0.35 group, but the difference was significant only for HFH. Abbreviations as in Figures 1 and 3.

separated clinical outcomes for patients who received BEVs and SEVs, results showed that AT/ET ≥0.35 was associated with increased 1-year HFH rates for both SEVs and BEVs. AV MG was not associated with HFH or mortality, supporting previous findings.[7,8] These results suggest that AT/ET may be a more reliable marker of prosthetic valve performance and a useful predictor of clinical outcomes after TAVR.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

This study was possible with a generous gift from Jennifer and Robert McNeil. The funders had no role in the design and conduct of the study; the collection, analysis, and interpretation of the data; or the manuscript's preparation, review, or approval. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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PERSPECTIVES

WHAT IS KNOWN? AT/ET ratio has been shown to be associated with AS severity, and increased values have been linked to worse outcomes in patients with native AS. However, the significance of AT/ET is understudied in prosthetic valves.

WHAT IS NEW? This is the largest scale study demonstrating the association between post-TAVR AT/ET ratio and clinical outcomes. For the first time in the literature, this study shows that AT/ET ≥0.35 predicts HFH post-TAVR and highlights differences by valve type.

WHAT IS NEXT? AT/ET ratio may improve assessment of prosthetic valve function and risk stratification in TAVR patients. Early identification of individuals with elevated postprocedural AT/ET ratios could help identify those at risk for cardiac decompensation, allowing the investigation of timely interventions to prevent adverse outcomes in these patients.

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KEY WORDS balloon-expandable valve, echocardiography, self-expanding valve