Discordant Severity Grading in Right Ventricular Dysfunction: Prognostic Implications of Conventional Parameters versus Three-Dimensional Echocardiography–Derived Ejection Fraction

Máté Tolvaj, MD, PhD, Elena Surkova, MD, PhD, Denisa Muraru, MD, PhD, Yasufumi Nagata, MD, PhD, Masaharu Kataoka, MD, Yosuke Nabeshima, MD, PhD, Noela Radu, MD, PhD, Alexandra Simona Buta, MD, Alexandra Clement, MD, PhD, Bálint Lakatos, MD, PhD, Alexandra Fábián, MD, PhD, Andrea Ferencz, MD, Márton Tokodi, MD, PhD, Tímea Katalin Turschl, MD, Michele Tomaselli, MD, PhD, Francesco Perelli, MD, PhD, Masaaki Takeuchi, MD, PhD, Béla Merkely, MD, PhD, Dsc, Luigi P. Badano, MD, PhD, and Attila Kovács, MD, PhD, Dsc, *Budapest, Hungary; London and Cambridge, United Kingdom; Milan, Italy; Kitakyushu and Saga, Japan; and Bucharest and Iasi, Romania*

Aims: The 2025 American Society of Echocardiography guidelines on the right heart introduce severity grading for right ventricular (RV) dysfunction based on individual functional parameters. However, single-parameter assessment may result in inconsistent diagnosis of RV dysfunction and discordant grading of its severity. We aimed to investigate the prognostic value and discordance among RV functional echocardiographic parameters.

Methods: We analyzed two- and three-dimensional echocardiographic data from 3 centers, including 1,146 consecutive patients followed for the composite end point of all-cause mortality and heart failure hospitalization. RV dysfunction severity was graded using the guideline-recommended cutoff values for tricuspid annular plane systolic excursion (TAPSE), fractional area change (FAC) and free-wall longitudinal strain (FWLS) and compared with severity assessment based on RV ejection fraction (RVEF).

Results: Over a median follow-up of 3.2 years, 261 patients (23%) met the composite end point. Assessed by RVEF, worsening RV dysfunction categories carried a higher risk of the composite end point, which was significant between mild versus normal and moderate versus mild dysfunction (hazard ratio [HR] = 2.385 [95% CI, 1.720-3.307], $P < .001$; and HR = 1.581 [95% CI, 1.066-2.346], $P = .023$), but not between severe versus moderate dysfunction. TAPSE and FWLS did not show a significant difference in risk between the dysfunction categories. FAC identified a significant risk difference between adjacent severity categories only for moderate versus mild dysfunction (HR = 1.928 [95% CI, 1.309-2.840], $P < .001$). Agreement with RVEF in patients with dysfunction was poor for TAPSE (quadratic weighted $\kappa = 0.06$, $P = .132$) and fair for FAC and FWLS ($\kappa = 0.34$, $P < .001$, and $\kappa = 0.30$, $P < .001$, respectively).

From the Heart and Vascular Center (M.T., B.L., A.F, A.F., M.T., T.K.T., B.M., A.K.); Department of Experimental Cardiology and Surgical Techniques, (M.T., A.K.); and Institute for Clinical Data Management (A.K.), Semmelweis University, Budapest, Hungary; Royal Brompton and Harefield Hospitals, Part of Guy's and St Thomas' NHS Foundation Trust (E.S.); National Heart and Lung Institute, Imperial College London, London (E.S.); and Research and Early Clinical Development, Cardiovascular, Renal and Metabolism, BioPharmaceuticals R&D, AstraZeneca, Cambridge, United Kingdom (E.S.); Department of Cardiology, Istituto Auxologico Italiano, IRCCS, San Luca Hospital (D.M., N.R., A.S.B., A.C., M.T, F.P., L.P.B.), and Department of Medicine and Surgery, University of Milano-Bicocca, Milan, Italy (D.M., M.T., L.P.B.); Second Department of Internal Medicine, University of Occupational and Environmental Health (Y.N., M.K.); and Department of Cardiovascular Medicine, Tobata General Hospital, Kitakyushu (M.T.); and Department of Cardiovascular Medicine, Saga University, Saga (Y.N.), Japan; Carol Davila University of Medicine and Pharmacy, Prof. Dr. C. C. Iliescu Institute (N.R.), and Department of Cardiology, Prof. Dr. C.C. Iliescu Emergency Institute for Cardiovascular Diseases (A.S.B.), Bucharest; and Internal Medicine Department, "Grigore T. Popa," University of Medicine and Pharmacy, Iasi (A.C.), Romania.

Drs. Badano and Kovács contributed equally to this work.

Garvan C. Kane, MD, PhD, served as guest editor for this report.

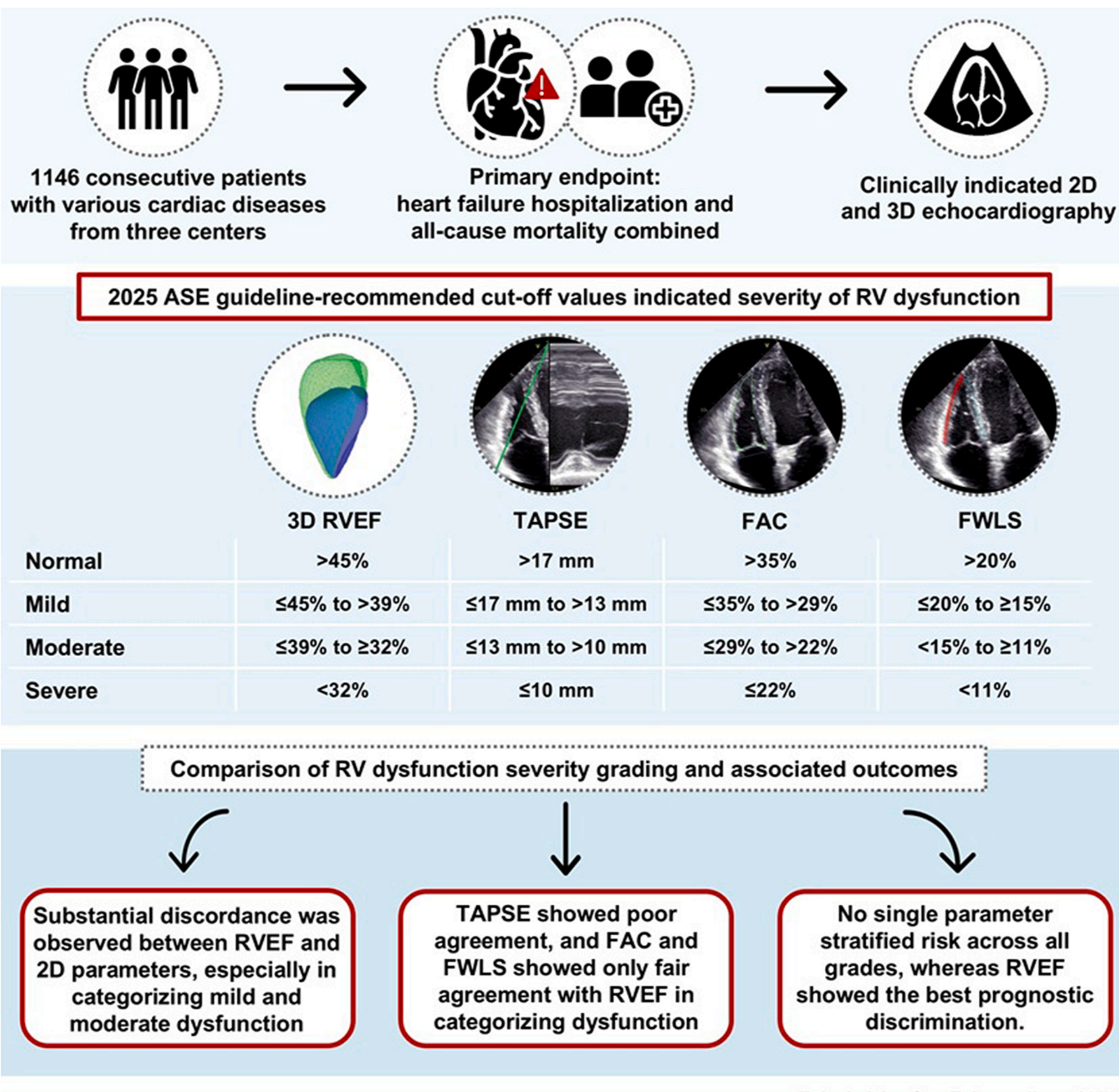
Reprint requests: Attila Kovács, MD, PhD, DSc, Heart and Vascular Center, Semmelweis University, 68 Városmajor Street, Budapest 1122, Hungary (E-mail: *attila.kovacs@semmelweis.hu*).

0894-7317

https://doi.org/10.1016/j.echo.2026.05.005

Conclusion: Significant discordance exists between conventional echocardiographic parameters of RV function and RVEF in grading RV systolic dysfunction. None of the individual RV functional parameters provided consistent risk stratification across all severity categories. RVEF showed the most consistent overall risk discrimination, whereas FAC and FWLS provided partial prognostic stratification. (J Am Soc Echocardiogr 2026;39:728-40.)

Keywords: 3D echocardiography, Right ventricular ejection fraction, Tricuspid annular plane systolic excursion, Free-wall longitudinal strain, Fractional area change



Central Illustration In a cohort with various cardiac diseases, substantial discordance was observed between RVEF and conventional RV functional parameters when using the 2025 ASE guideline-recommended cutoff values for grading RV dysfunction severity. This discordance impacts risk stratification.

Abbreviations

2D = Two-dimensional

3D = Three-dimensional

3DE = Three-dimensional echocardiography

ASE = American Society of Echocardiography

EDVi = End-diastolic volume index

EF = Ejection fraction

ESVi = End-systolic volume index

FAC = Fractional area change

FWLS = Free-wall longitudinal strain

HF = Heart failure

HR = Hazard ratio

LV = Left ventricle, ventricular

RV = Right ventricle, ventricular

RVEF = Right ventricular ejection fraction

SVi = Stroke volume index

TAPSE = Tricuspid annular plane systolic excursion

WASE = World Alliance of Societies of Echocardiography

INTRODUCTION

Comprehensive evaluation of right ventricular (RV) systolic function is essential for risk stratification and clinical management across a broad range of cardiac diseases.[1-4] In recognition of the RV's critical prognostic role, the 2025 guidelines from the American Society of Echocardiography (ASE) introduced an updated framework for right heart assessment, including, for the first time, a standardized grading system for RV systolic dysfunction severity.[5]

The guidelines propose cutoff values to classify RV systolic dysfunction as mild, moderate, or severe, using well-established echocardiographic indices such as tricuspid annular plane systolic excursion (TAPSE), fractional area change (FAC), free-wall longitudinal strain (FWLS), and three-dimensional (3D) echocardiography–derived RV ejection fraction (RVEF).[6-9] However, these parameters reflect different physiological components of RV contraction and may yield discordant estimates of dysfunction severity when applied in isolation.[10] Such inconsistency may become even more pronounced with the adoption of multiclass severity grading, potentially limiting clinical interpretability and confidence in decision-making.

See page 741 in issue for related content.

Among available metrics, 3D RVEF is often regarded as the most comprehensive echocardiographic measure of RV systolic function, as it accounts for the chamber's complex geometry without relying on geometric assumptions.[11,12] Nevertheless, disagreement between RVEF and conventional indices remains frequent in clinical practice, even when single abnormality thresholds are used.[10] Whether the newly recommended severity grades improve prognostic stratification or introduce further classification conflict has not yet been systematically evaluated, and their relationship with adverse clinical outcomes remains unvalidated.

Accordingly, this study aims to evaluate the extent of discordance between TAPSE, FAC, FWLS, and RVEF in identifying and grading RV systolic dysfunction severity. Additionally, it seeks to assess the prognostic utility of the newly proposed ASE severity categories for these parameters.

METHODS

Study Design and Population

This multicenter retrospective study included patients with a broad spectrum of cardiovascular conditions who underwent clinically indicated two-dimensional (2D) and 3D transthoracic echocardiography between December 2014 and March 2021 at the University of Occupational and Environmental Health (Kitakyushu, Japan), Istituto Auxologico Italiano, IRCCS (Milan, Italy), and Semmelweis University Heart and Vascular Center (Budapest, Hungary). The patients from the latter 2 centers were also included in a previous study investigating the disagreement between conventional parameters and RVEF in the detection of RV systolic dysfunction.[10]

Patients were eligible if the following criteria were met: (1) availability of complete full-volume 3D datasets for both the left ventricle (LV) and the RV; (2) adequate image quality and temporal resolution for reliable volumetric analysis; and (3) availability of follow-up data. All patients underwent standardized 2D and 3D echocardiographic imaging protocols. Image quality was assessed subjectively, based on factors including dataset optimization for depth and width, signal-to-noise ratio, volume rate (≥20 volumes/s), and complete visualization of the endocardial borders of both ventricles. Quality was rated on a 5-point scale (1 = poor, 5 = excellent); datasets that were deemed to be of poor quality were excluded from further analysis.

Demographic and clinical variables, including age, anthropometric data (weight, height, body surface area, body mass index), hemodynamic parameters (systolic and diastolic blood pressure, heart rate), cardiovascular risk factors, comorbidities, and medical history, were extracted from hospital electronic health records. Given the retrospective design, written informed consent was waived. The study complied with the Declaration of Helsinki and was approved by the institutional ethics committees at all participating centers (University of Occupational and Environmental Health approval no. CR25-085, Istituto Auxologico Italiano approval no. 2021_05_18_13, Semmelweis University approval no. 190/2020).

Two- and Three-Dimensional Echocardiography

Transthoracic echocardiographic examinations were performed using commercially available ultrasound platforms (Vivid E9, E95 with 4V or 4Vc-D probe, GE Vingmed Ultrasound; and iE33, EPIQ 7 and 7G with X5-1 probe, Philips Medical Systems). A standardized acquisition protocol was employed across all centers, including the acquisition of 2D image loops from parasternal, apical, and subxiphoid views. All image data were digitally archived in raw-data format and analyzed offline using commercially available software packages (EchoPAC BT12, GE Vingmed, and TomTec Imaging). TAPSE, RV end-diastolic and end-systolic area, FAC, and RV systolic pressure were measured according to current guidelines.[5]

In addition to conventional 2D imaging, electrocardiogram-gated full-volume 3D datasets were reconstructed from 4 to 6 consecutive cardiac cycles, optimized for left or right heart assessment. Left heart–focused datasets were analyzed using semiautomated, commercially available software (AutoLVQ, EchoPAC; and 4D LV-Analysis 3, TomTec Imaging) to derive left ventricular (LV) end-diastolic volume index (EDVi), end-systolic volume index (ESVi), stroke volume index (SVi), and ejection fraction (EF),

HIGHLIGHTS

- We compared 2D parameters and 3D RVEF in grading RV dysfunction severity.
- Substantial discordance exists between RVEF and conventional parameters.
- Discordance was the greatest in mild and moderate dysfunction.
- No single RV parameter consistently stratified risk across all severity grades.
- RVEF demonstrated the strongest ability to distinguish prognostically distinct groups.

providing a comprehensive evaluation of global LV systolic function. Concerning the right heart, 3D RV EDVi, ESVi, SVi, EF, and septal and 2D FWLS were quantified (4D RV-Function 2, TomTec Imaging).[13,14] All echocardiographic analyses were performed at the respective institutions by attending physicians with at least 3 years of experience in advanced echocardiographic postprocessing.

Assessment of RV Systolic Function

RV systolic function was classified according to the 2025 ASE guidelines.[5] TAPSE was classified as normal at values >17 mm, mildly reduced from ≤17 mm to >13 mm, moderately reduced from ≤13 mm to >10 mm, and severely reduced at ≤10 mm. FAC was considered normal at >35%, mildly reduced from ≤35% to >29%, moderately reduced from ≤29% to >22%, and severely reduced at ≤22%. FWLS was defined in absolute values as normal at

Table 1 Demographic and clinical characteristics

	Overall (*n* = 1,146)	Primary end point not met (*n* = 885)	Primary end point met (*n* = 261)	*P* value
Baseline demographic characteristics				
Age, years	61.5 ± 16.6	60.3 ± 16.5	65.4 ± 16.3	**<.001**
Gender, male	765 (66.9)	593 (67.0)	172 (65.9)	.774
Height, m	1.67 ± 0.11	1.67 ± 0.11	1.66 ± 0.11	.440
Weight, kg	68.8 ± 16.0	69.0 ± 15.7	68.0 ± 16.8	.350
BSA, m	1.77 ± 0.25	1.78 ± 0.24	1.76 ± 0.26	.274
BMI, kg/m^2	24.5 ± 4.2	24.6 ± 4.2	24.3 ± 4.4	.365
Systolic blood pressure, mm Hg	126.5 ± 20.5	128.0 ± 20.3	121.7 ± 20.3	**<.001**
Diastolic blood pressure, mm Hg	73.4 ± 12.5	74.0 ± 12.6	71.5 ± 12.3	**.009**
Heart rate, bpm	70.0 ± 14.9	68.9 ± 14.2	74.0 ± 16.5	**<.001**
Risk factors and medical history				
History of smoking	278 (24.3)	218 (24.6)	60 (23.0)	.617
Diabetes	259 (22.6)	185 (20.9)	74 (28.4)	**.013**
Dyslipidemia	517 (45.1)	410 (46.3)	107 (41.0)	.139
Hypertension	670 (58.5)	513 (57.9)	157 (60.2)	.510
Coronary artery disease	365 (31.8)	275 (31.1)	90 (34.5)	.306
2D echocardiographic parameters				
TAPSE, mm	18.7 ± 5.9	19.2 ± 5.9	17.1 ± 5.7	**<.001**
FAC, %	35.6 ± 10.0	36.7 ± 9.6	31.9 ± 10.5	**<.001**
RV SLS, %	13.3 ± 5.5	14.0 ± 5.3	10.8 ± 5.4	**<.001**
FWLS, %	24.2 ± 6.7	25.1 ± 6.5	21.1 ± 6.4	**<.001**
3D echocardiographic parameters				
LV EDVi, mL/m^2	85.1 ± 35.0	81.9 ± 31.7	95.9 ± 42.8	**<.001**
LV ESVi, mL/m^2	47.2 ± 32.3	43.5 ± 28.8	59.3 ± 39.6	**<.001**
LV SVi, mL/m^2	38.0 ± 13.7	38.4 ± 13.4	36.6 ± 14.5	.062
LVEF, %	48.4 ± 15.0	50.1 ± 14.1	42.5 ± 16.3	**<.001**
RV EDVi, mL/m^2	74.9 ± 28.1	71.2 ± 25.2	87.0 ± 33.6	**<.001**
RV ESVi, mL/m^2	40.9 ± 21.1	37.4 ± 17.8	52.6 ± 26.4	**<.001**
RV SVi, mL/m^2	33.9 ± 11.4	33.8 ± 11.0	34.4 ± 12.7	.440
RVEF, %	46.9 ± 9.6	48.5 ± 8.7	41.2 ± 10.3	**<.001**

BMI, Body mass index; *BSA*, body surface area; *SLS*, septal longitudinal strain.
Continuous variables are presented as means ± SD; categorical variables are reported as frequencies (%). Strain parameters are reported in absolute values. Significant *P* values are indicated in bold.

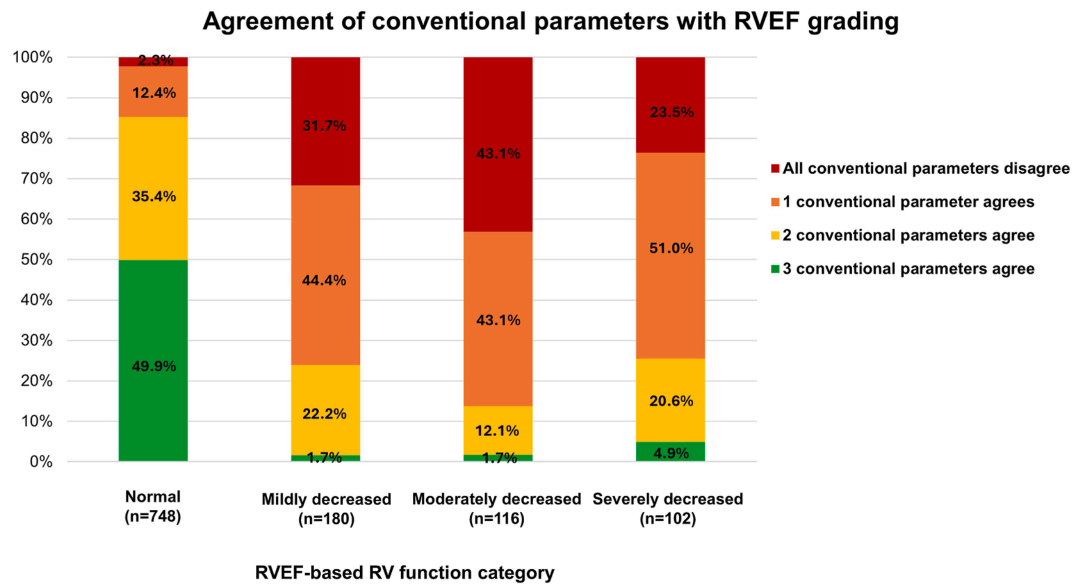


Figure 1 Agreement of conventional parameters with RVEF-based RV systolic function grading visualized using percentage stacked bar graphs.

>20%, mildly reduced from ≤20% to ≥15%, moderately reduced from <15% to ≥11%, and severely reduced at <11%. For RVEF, normal function was defined as >45%, mildly reduced from ≤45% to >39%, moderately reduced from ≤39% to ≥32%, and severely reduced at <32%.

Study Outcomes

The primary objective was to evaluate the discordance in the severity grading of RV systolic function between conventional echocardiographic parameters (TAPSE, FAC, and FWLS) and 3D echocardiography–derived (3DE-derived) RVEF.

Follow-up data (heart failure [HF] hospitalization, date of HF hospitalization, status [dead or alive], date of death) were obtained from institutional records and national healthcare databases. The primary end point was a composite of HF hospitalization and all-cause mortality. The secondary end points were HF hospitalization and all-cause mortality separately. HF hospitalization was defined as hospital admission for worsening signs and symptoms of HF, requiring intravenous treatment aimed at managing fluid overload and hemodynamic compromise.

Statistical Analysis

Statistical analysis was performed using SPSS (ver. 25, IBM), Stata (ver. 19, StataCorp), R (ver. 4.1.2, R Foundation for Statistical Computing), and GraphPad Prism (ver. 9.5.1, GraphPad Software). Continuous variables are expressed as mean ± SD or median and interquartile range, whereas categorical variables are reported as percentages. After verifying the normal distribution of variables using the Kolmogorov-Smirnov and Shapiro-Wilk test, the clinical and echocardiographic characteristics were compared with unpaired Student *t* test or Mann-Whitney *U* test for continuous variables and chi-squared or Fisher's exact test for categorical variables, as appropriate. Multiple group comparisons (>2) were performed using 1-way analysis of variance or Welch's analysis of variance and χ^2 or Fisher exact test, as appropriate. Outcomes of different groups based on their classification by RV parameters were visualized via Kaplan-Meier curves and compared using log-rank tests. For the composite end point and all-cause death, Cox proportional hazards models were used to compute hazard ratios (HRs) with 95% CIs. For HF hospitalization, subdistribution HRs with 95% CIs were estimated using Fine-Gray competing risk regression, with all-cause death treated as the competing event. Proportional-hazards assumptions were verified using Schoenfeld residual-based tests. Quadratic weighted kappa (κ) was used to assess the concordance between the RV parameters, and the results were interpreted based on conventional Landis and Koch thresholds. Sankey diagrams were constructed using SankeyMATIC (https://sankeymatic.com) to visualize the volume of reclassified patients caused by the discordance between conventional parameters and RVEF in RV systolic function grading. For missing measurements, pairwise exclusion was applied when constructing the Sankey diagrams. To further assess the relationship between RV functional parameters as continuous variables and the risk of the composite end point, we derived pointwise estimates of the univariable and multivariable hazard ratio curves, along with their corresponding CIs, using the smoothHR package in R, with reference values defined according to the mean values reported in the World Alliance of Societies of Echocardiography (WASE) study.[15-17] A 2-sided *P* value of <.05 was considered statistically significant.

RESULTS

Baseline Clinical and Echocardiographic Characteristics and Their Association with Outcomes

A total of 1,146 patients were included in this 3-center study, comprising 396 patients from the University of Occupational and Environmental Health (Kitakyushu, Japan), 393 patients from the Istituto Auxologico Italiano, IRCCS (Milan, Italy), and 357 patients from the Heart and Vascular Center of Semmelweis University (Budapest, Hungary). The initial total cohort consisted of 1,352 patients, of whom 206 (15%) were excluded due to the absence of complete 3D full-volume datasets for either the RV or LV (n = 87),

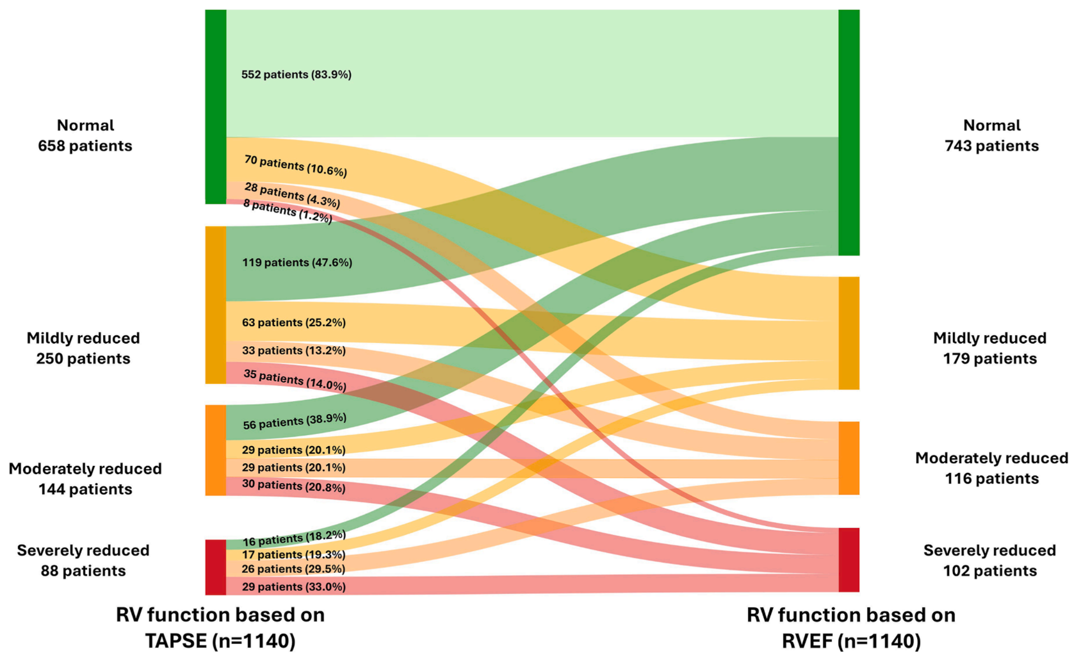


Figure 2 Disagreement in the classification of RV systolic dysfunction between TAPSE and 3DE-derived RVEF visualized by the rate of reclassification using a Sankey diagram. *Green flows* represent patients with normal RV function; *yellow, orange, and red flows* represent patients with mild, moderate, and severe RV dysfunction by RVEF, respectively.

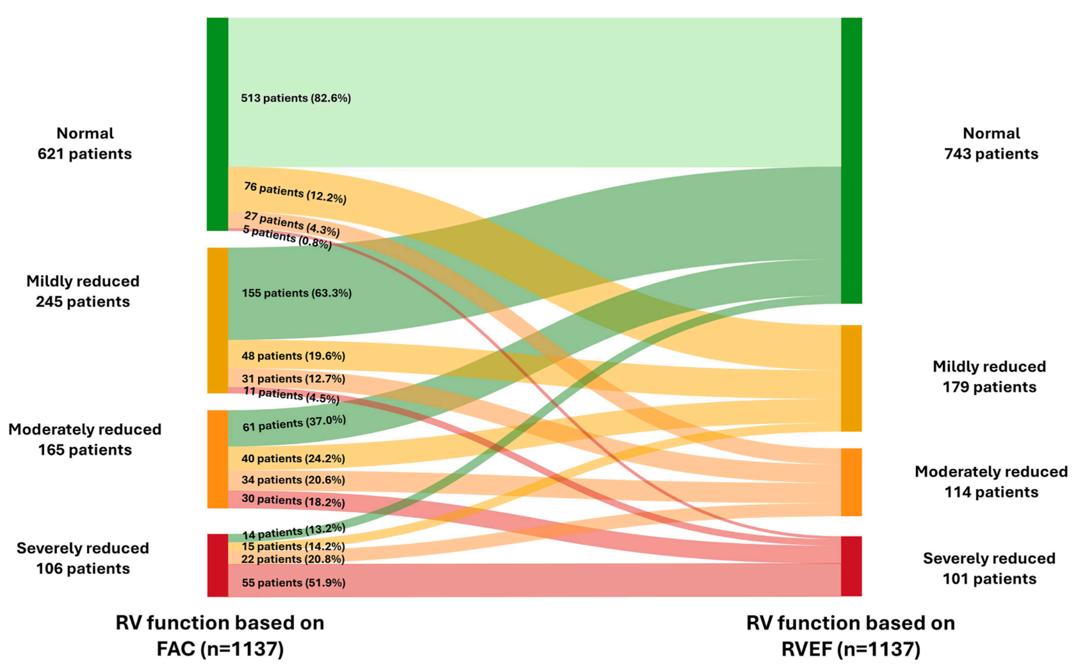


Figure 3 Disagreement in the classification of RV systolic dysfunction between FAC and 3DE-derived RVEF visualized by the rate of reclassification using a Sankey diagram. *Green flows* represent patients with normal RV function; *yellow, orange, and red flows* represent patients with mild, moderate, and severe RV dysfunction by RVEF, respectively.

suboptimal 3D image quality precluding RV or LV analysis ($n = 105$), the presence of arrhythmias or stitching artifacts ($n = 8$), unavailable follow-up ($n = 5$), and duplicate records ($n = 1$).

The study population represented a broad range of cardiac conditions including patients with aortic valve disease ($n = 146$, 13%), mitral valve disease ($n = 123$, 11%), heart transplant ($n = 91$, 8%), nonischemic dilated cardiomyopathy ($n = 136$, 12%), ischemic cardiomyopathy ($n = 137$, 12%), acute coronary syndrome ($n = 167$, 15%), other forms of cardiomyopathy ($n = 146$, 13%), and various other cardiac conditions ($n = 200$, 17%).

During the median follow-up time of 3.2 years (interquartile range, 1.5-4.3), 261 (23%) patients met the primary end point.

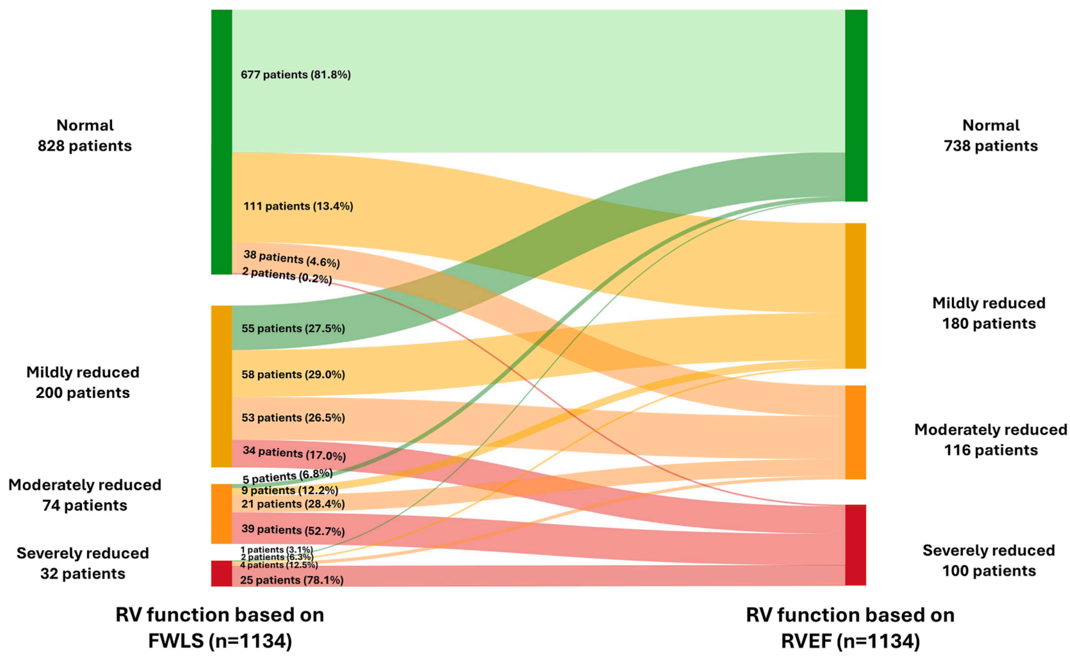


Figure 4 Disagreement in the classification of RV systolic dysfunction between FWLS and 3DE-derived RVEF visualized by the rate of reclassification using a Sankey diagram. *Green flows* represent patients with normal RV function; *yellow, orange, and red flows* represent patients with mild, moderate, and severe RV dysfunction by RVEF, respectively.

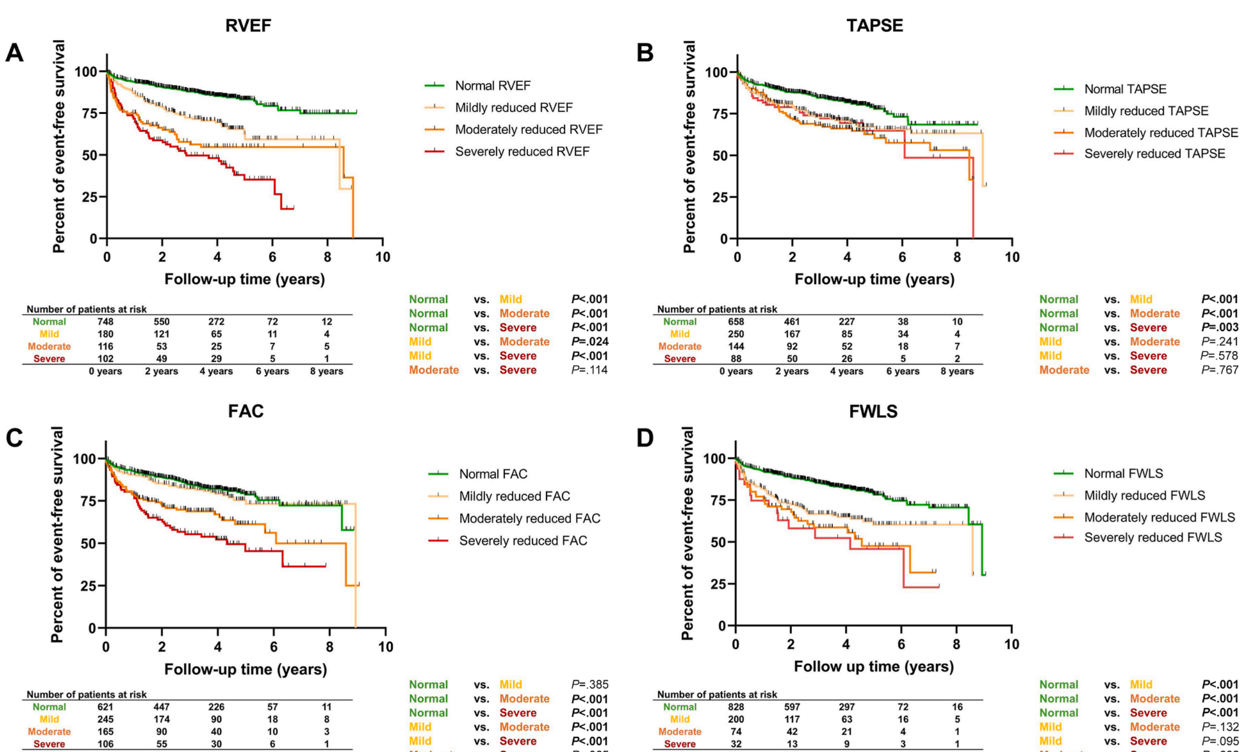


Figure 5 Risk analysis regarding the primary end point of patients classified into RV function categories based on RVEF **(A)**, TAPSE **(B)**, FAC **(C)**, and FWLS **(D)**, visualized via Kaplan-Meier curves.

HF hospitalization occurred in 162 (14%) cases, and 153 (13%) individuals died during the follow-up period. Demographic and clinical characteristics of the study cohort, as well as a comparison of patients who met the primary end point, are presented in Table 1. A comparison by center is also available in Supplemental Table S1.

Hypertension (58%), dyslipidemia (45%), coronary artery disease (32%), and diabetes mellitus (23%) were the most prevalent

Table 2 Univariable Cox regression models predicting the primary end point

	HR [95% CI]	*P* value
RVEF-based assessment		
Mild dysfunction vs normal function	2.385 [1.720-3.307]	**<.001**
Moderate dysfunction vs normal function	3.770 [2.655-5.353]	**<.001**
Severe dysfunction vs normal function	5.205 [3.758-7.210]	**<.001**
Moderate vs mild dysfunction	1.581 [1.066-2.346]	**.023**
Severe vs mild dysfunction	2.183 [1.504-3.168]	**<.001**
Severe vs moderate dysfunction	1.381 [0.931-2.046]	.108
TAPSE-based assessment		
Mild dysfunction vs normal function	1.663 [1.235-2.240]	**.001**
Moderate dysfunction vs normal function	2.072 [1.484-2.894]	**<.001**
Severe dysfunction vs normal function	1.931 [1.252-2.978]	**.003**
Moderate vs mild dysfunction	1.246 [0.868-1.790]	.233
Severe vs mild dysfunction	1.161 [0.736-1.832]	.521
Severe vs moderate dysfunction	0.932 [0.576-1.507]	.773
FAC-based assessment		
Mild dysfunction vs normal function	1.180 [0.841-1.657]	.337
Moderate dysfunction vs normal function	2.276 [1.638-3.164]	**<.001**
Severe dysfunction vs normal function	3.297 [2.343-4.639]	**<.001**
Moderate vs mild dysfunction	1.928 [1.309-2.840]	**<.001**
Severe vs mild dysfunction	2.793 [1.874-4.162]	**<.001**
Severe vs moderate dysfunction	1.448 [0.980-2.140]	.063
FWLS-based assessment		
Mild dysfunction vs normal function	2.198 [1.640-2.945]	**<.001**
Moderate dysfunction vs normal function	3.073 [2.082-4.535]	**<.001**
Severe dysfunction vs normal function	3.609 [2.117-6.150]	**<.001**
Moderate vs mild dysfunction	1.398 [0.912-2.144]	.124
Severe vs mild dysfunction	1.642 [0.937-2.878]	.083
Severe vs moderate dysfunction	1.174 [0.634-2.176]	.609

Significant *P* values are indicated in bold.

comorbidities in the study cohort. Patients who met the primary end point were older, exhibited higher resting heart rates, and had a greater prevalence of diabetes, as shown in Table 1. These clinical features, along with the aforementioned comorbidity, were identified as significant predictors of the primary outcome in univariable Cox regression analysis (Supplemental Table S2). Notably, all examined 2D and 3D echocardiographic parameters of RV size and systolic function, with the exception of LV and RV SVi, significantly differed between patients who met the primary end point and those who did not (Table 1) and were also associated with the incidence of the primary end point during follow-up, including LV SVi (Supplemental Table S2).

RV Dysfunction Grading and Reclassification

RVEF measurements were available in all 1,146 cases, while TAPSE was measured in 1,140 cases, FAC in 1,137 cases, and FWLS in 1,134 cases, respectively.

According to RVEF, 748 patients (65%) demonstrated normal RV function, while 180 (16%) had mild, 116 (10%) had moderate, and 102 (9%) had severe RV dysfunction. Agreement between RVEF and the 3 conventional parameters was limited. Among patients with normal RVEF, full agreement across all 3 conventional echocardiographic parameters (TAPSE, FAC, FWLS) was observed in 50%, and 2-parameter agreement was present in an additional 35%. In contrast, 2% of the patients with mildly and moderately reduced RVEF showed complete concordance among the 3 conventional echocardiographic parameters, whereas only 5% of those with severely reduced RVEF demonstrated full agreement among the 3 conventional echocardiographic parameters. Importantly, complete disagreement among the 3 conventional parameters was observed in 32%, 43%, and 24% of patients with mildly, moderately, and severely reduced RVEF (Figure 1).

Using TAPSE, 658 patients (58%) were classified as having normal RV function, while 250 (22%) had mild, 144 (13%) moderate, and 88 (8%) severe RV dysfunction. In comparison to RVEF-based classification, agreement within the dysfunction categories was remarkably limited, with rates of 25% for mild, 20% for moderate, and 33% for severe dysfunction. A substantial proportion of patients with RV dysfunction based on TAPSE values were reclassified as having normal function by RVEF, including nearly half of those initially categorized as mild RV dysfunction, approximately one-third of those classified as moderate, and around one-fifth of those classified as severe RV dysfunction (Figure 2).

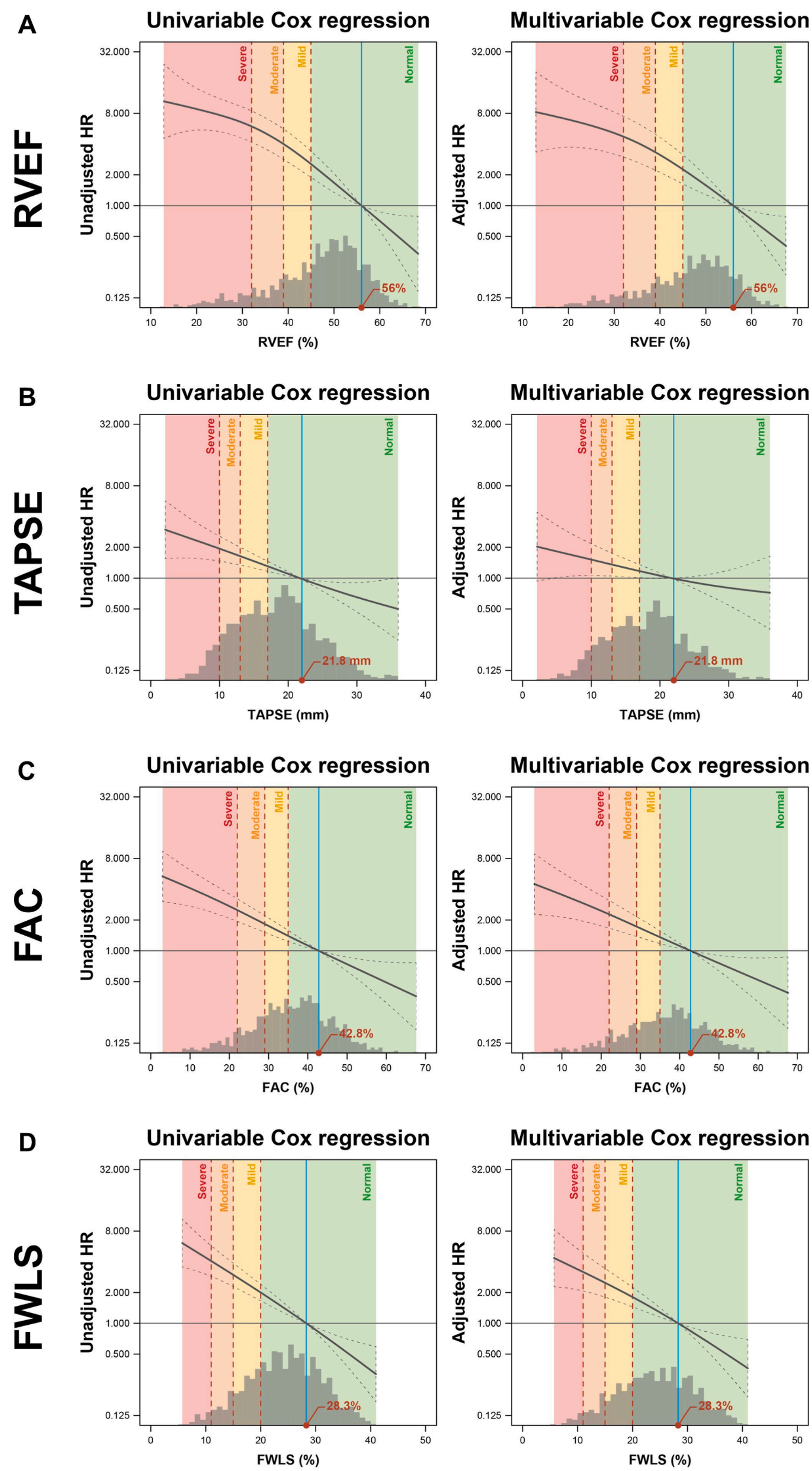


Figure 6 Relationships between RV functional parameters—**(A)** RVEF; **(B)** TAPSE; **(C)** FAC; and **(D)** FWLS—and the risk of the composite end point. Mean values of RV functional parameters defined in the WASE study were used as reference values (indicated by *vertical blue lines*).[16,17] *Red dashed vertical lines* indicate guideline-recommended cutoffs for grading RV dysfunction severity. In addition to the given RV functional parameter, each multivariable Cox model included age, sex, LVEF, body mass index, systolic blood pressure, diabetes, and study center as covariates.

Using FAC, 621 patients (55%) were categorized as having normal RV function, while 245 (22%) had mild, 165 (15%) moderate, and 106 (9%) severe RV dysfunction. The agreement with RVEF-based classification remained low, particularly for mild (20%) and moderate (21%) RV dysfunction, although it was higher for the severe category (52%). Notably, approximately two-thirds of patients with mild RV dysfunction based on FAC values and more than one-third with moderate RV dysfunction were reclassified to the normal category by RVEF (Figure 3).

Using FWLS, 828 patients (73%) were found to have normal RV function, while 200 (18%) had mild, 74 (7%) moderate, and 32 (3%) severe RV dysfunction. The agreement rates with RVEF for the mild and moderate RV dysfunction categories remained modest, at 29% and 28%, respectively. Conversely, the severe category showed an agreement rate of 78% with RVEF, the highest among the conventional parameters. The highest rate of reclassification to normal function occurred in the mildly reduced FWLS group, affecting nearly one-third of patients (Figure 4).

Across the 4-grade RV function scale, RVEF showed statistically significant but variable agreement with conventional echocardiographic indices (Supplemental Table S3). Both TAPSE and FAC demonstrated moderate concordance with RVEF (quadratic weighted κ = 0.51 [95% CI, 0.45-0.57], $P < .001$; and κ = 0.57 [95% CI, 0.51-0.63], $P < .001$, respectively), while FWLS exhibited the strongest association with RVEF, demonstrating substantial agreement (κ = 0.65 [95% CI, 0.60-0.71], $P < .001$).

By excluding patients with normal RVEF and normal TAPSE, FAC, or FWLS (1 parameter at a time), we generated 3 separate cohorts of RV dysfunction for severity-specific agreement analysis (Supplemental Table S4). In these analyses, concordance declined markedly. In the RVEF versus TAPSE dysfunction cohort (n = 363), agreement was poor. TAPSE showed no meaningful agreement beyond chance (κ = 0.06 [95% CI, −0.04 to 0.16], P = .132). In the RVEF versus FAC dysfunction cohort (n = 318) and RVEF versus FWLS dysfunction cohort (n = 285), agreements were fair (κ = 0.34 [95% CI, 0.23-0.45], $P < .001$, and κ = 0.30 [95% CI, 0.21-0.38], $P < .001$, respectively).

Association of the Severity Categories with Outcomes

The outcomes of patients with different RV function according to each study parameter were visualized using Kaplan-Meier curves (Figure 5), and the number of events in each group is provided in Supplemental Table S5. Using RVEF-based grading, patients with mild RV dysfunction had a more than twofold increased risk of meeting the primary end point compared to those with normal RV function (unadjusted HR = 2.385 [95% CI, 1.720-3.307], $P < .001$). Furthermore, patients with moderate RV dysfunction also showed a higher risk than patients with mild RV dysfunction (unadjusted HR = 1.581 [95% CI, 1.066-2.346], P = .023). However, no significant difference was observed between patients with severe and moderate RV dysfunction (unadjusted HR = 1.381 [95% CI, 0.931-2.046], P = .108; Figure 5A). The full risk comparison of the RV functional categories based on RVEF is provided in Table 2.

According to TAPSE, patients with mild, moderate, and severe RV dysfunction exhibited a nearly twofold higher risk compared to patients with normal RV function (unadjusted HRs = 1.663 [95% CI, 1.235-2.240], P = .001; 2.072 [95% CI, 1.484-2.894], $P < .001$, and 1.931 [95% CI, 1.252-2.978], P = .003, respectively). However, pairwise comparisons among the patients with different grades of RV dysfunction revealed no statistically significant differences (Figure 5B, Table 2).

FAC–based grading showed that patients with normal RV function and those with mild RV dysfunction had a similar incidence of the primary end point (unadjusted HR = 1.180 [95% CI, 0.841-1.657], P = .337). In contrast, patients with moderate and severe RV dysfunction exhibited significantly higher risks than patients with normal RV function (unadjusted HRs = 2.276 [95% CI, 1.638-3.164], $P < .001$; and 3.297 [95% CI, 2.343-4.639], $P < .001$, respectively). Additionally, patients with moderate RV dysfunction showed a nearly twofold higher risk compared to patients with mild RV dysfunction (unadjusted HR = 1.928 [95% CI, 1.309-2.840], $P < .001$), although no significant difference was observed between patients with moderate and severe RV dysfunction (unadjusted HR = 1.448 [95% CI, 0.980-2.140], P = .063; Figure 5C, Table 2).

Using FWLS-based grading, patients with mild, moderate, and severe RV dysfunction had a higher occurrence of the primary end point compared to those with normal function (unadjusted HRs = 2.198 [95% CI, 1.640-2.945], $P < .001$; 3.073 [95% CI, 2.082-4.535], $P < .001$; and 3.609 [95% CI, 2.117-6.150], $P < .001$, respectively). However, no significant differences in outcome were observed between patients with RV dysfunction (Figure 5D, Table 2).

Findings were consistent for HF hospitalization and all-cause mortality considered separately in univariable analysis (Supplemental Tables S6 and S7).

In multivariable models adjusting for age, sex, LVEF, body mass index, systolic blood pressure, diabetes, and center, RVEF grading remained independently associated with the primary outcome (Supplemental Table S8). Patients with mild RV dysfunction demonstrated a nearly twofold increased risk of meeting the primary end point compared to those with normal function (adjusted HR = 1.967 [95% CI, 1.352-2.863], $P < .001$). Patients with moderate RV dysfunction also showed a higher risk relative to those with mild dysfunction (adjusted HR = 1.768 [95% CI, 1.141-2.740], P = .011). In contrast, TAPSE-based categories showed limited independent prognostic separation, with significance retained only for moderate dysfunction versus normal function (adjusted HR = 1.800 [95% CI, 1.214-2.670], P = .003). FAC–based assessment revealed that patients with moderate and severe RV dysfunction exhibited substantially higher risks than those with normal RV function (adjusted HRs = 2.064 [95% CI, 1.393-3.060], $P < .001$; and 2.742 [95% CI, 1.790-4.199], $P < .001$, respectively). Additionally, patients with moderate and severe RV dysfunction had a nearly twofold higher risk than those with mild RV dysfunction (adjusted HRs = 1.805 [95% CI, 1.160-2.808], P = .009; and 2.397 [95% CI, 1.514-3.795], $P < .001$, respectively). Patients with mild, moderate, and severe FWLS-based RV dysfunction showed a twofold higher risk compared to patients with normal RV function in the multivariable analysis as well (adjusted HRs = 2.081 [95% CI, 1.485-2.916], $P < .001$; 2.110 [95% CI, 1.333-3.341], P = .001; and 2.311 [95% CI, 1.255-4.256], P = .007, respectively).

Using the same covariates, the difference in risk between RV dysfunction categories based on each RV functional parameter was assessed regarding the secondary end points (Supplemental Tables S9 and S10).

When modeled as continuous variables, RVEF, FAC, and FWLS demonstrated consistent associations with the composite end point, with progressively increasing risk at lower values across both univariable and multivariable models (Figure 6A, 6C, and 6D). In contrast, TAPSE exhibited a comparatively flatter risk gradient, with substantial attenuation after multivariable adjustment (Figure 6B).

DISCUSSION

This multicenter study evaluated the concordance between conventional echocardiographic parameters and 3DE-derived RVEF in grading the severity of RV systolic dysfunction and assessed the associations of the newly proposed ASE severity categories with clinical outcomes (Central Illustration). In this large cohort of patients with diverse cardiac conditions we found that (1) there is substantial discordance between RVEF and conventional RV functional parameters, particularly within the RV dysfunction categories; (2) in patients with RV dysfunction, TAPSE showed slight agreement, while FAC and FWLS showed a fair agreement with RVEF; (3) severity categories derived from conventional parameters showed limited ability to differentiate incremental risk across dysfunction grades; (4) despite the absence of statistically significant separation between moderate and severe dysfunction categories, RVEF provided the strongest prognostic discrimination and remained independently associated with outcome after adjustment for clinically relevant covariates; and (5) these findings underscore the need for validated, disease-sensitive multiparametric frameworks to support clinically meaningful RV dysfunction grading.

Conventional indices such as TAPSE, FAC, and FWLS remain widely used for RV systolic function assessment because they are accessible and well established in clinical workflows.[18-20] Their broad availability, relative technical simplicity, and lower dependence on image quality support their clinical practicality, particularly in settings where advanced 3D imaging is not routinely feasible. However, these parameters provide only partial surrogates of RV performance and do not fully capture the chamber's complex geometry, contraction pattern, and regional mechanics. These limitations likely contribute to the substantial disagreement previously demonstrated between abnormality thresholds of conventional indices and RVEF with important clinical implications.[10] The present study extends these observations by showing that the newly proposed multiclass ASE severity grading system introduces even greater discordance between parameters, particularly in mild and moderate dysfunction categories, and does not consistently reflect progressive risk across severity levels.

Among the conventional parameters, TAPSE showed particularly low concordance with RVEF. Agreement rates remained below 30% in mild and moderate dysfunction, with frequent reclassification to normal function when compared to RVEF. Even in severe dysfunction, concordance remained modest. FAC and FWLS showed greater agreement, especially in advanced dysfunction categories. In severe dysfunction, the agreement reached over 50% in the case of FAC and 70% in the case of FWLS; however, the overall agreement remained only fair. These findings highlight the clinical challenge of interpreting conflicting severity classifications when different parameters suggest divergent grades of RV impairment and underscore that readily obtainable conventional indices may not be interchangeable with more comprehensive measures of RV performance.

Beyond the inherent 2D and regional nature of conventional parameters, discordance is also expected because each parameter reflects distinct physiological components of RV dysfunction.[1] TAPSE predominantly captures longitudinal basal motion, FAC incorporates both longitudinal and radial shortening, FWLS reflects free-wall myocardial deformation, and RVEF integrates global chamber performance. Therefore, reliance on isolated indices may lead to inconsistent grading and potentially suboptimal clinical decision-making. Beyond these physiological differences, the observed discordance may also partly reflect methodological variability inherent to the multicenter design, including intersite differences in image acquisition, the use of multiple imaging vendors, and reader-dependent measurement variability; nevertheless, this heterogeneity enhances the external validity of the study by reflecting real-world clinical practice. Nonetheless, adjustment for center did not substantially change the observed associations.

Importantly, conventional severity grades showed limited prognostic stratification. TAPSE, in particular, did not appear to have a meaningful role in severity-based risk stratification in this cohort, as it failed to differentiate between dysfunction categories associated with distinct levels of risk, suggesting a plateau effect. The higher event rate in the moderate group than in the severe group further underscores the restricted discriminatory performance of TAPSE-based categorization, together with the influence of sample size, category distribution, and clinical heterogeneity. These may indicate that TAPSE is only suitable for detecting RV systolic dysfunction rather than grading its severity. FWLS showed limited discriminatory capacity across severity groups and demonstrated a modest separation across dysfunction grades when all-cause mortality was the end point. Interestingly, FAC thresholds did not adequately separate normal from mild dysfunction, suggesting reduced sensitivity for early impairment. Ideally, a severity grading system should detect subtle dysfunction while also reflecting a stepwise increase in risk across mild, moderate, and severe categories. Collectively, these findings raise the possibility that single-parameter grading may be insufficient and that guideline-recommended severity thresholds may not optimally separate risk in unselected, heterogeneous populations. This also highlights that alternative severity thresholds could yield different and potentially more clinically meaningful risk stratification in such cohorts.

In contrast, RVEF demonstrated the most consistent prognostic utility, consistent with prior evidence of its independent association with outcomes across diverse cardiac conditions.[2,21-25] Although the moderate and severe dysfunction groups did not show a statistically significant difference, RVEF-based grading provided the clearest distinction between clinically relevant risk strata, even after multivariable adjustment. Importantly, the lack of significant discrimination between moderate and severe dysfunction was consistent across all assessed RV parameters, suggesting that this finding may reflect a broader limitation of the current severity grading framework rather than a weakness of any individual metric. Such a pattern raises the possibility that a 4-grade classification may be excessively granular for prognostic stratification in a heterogeneous population, or alternatively, that the currently recommended cutoff values do not provide optimal separation of risk in the more advanced stages of RV dysfunction. Previous work by Muraru *et al.*[26] proposed alternative partition values validated for cardiac death and major adverse cardiac events, suggesting that optimal thresholds may vary across populations and disease substrates. Similarly, expert initiatives—such as the Tricuspid Valve Academic Research Consortium—have proposed RV dysfunction grading cutoffs in specific contexts, such as tricuspid regurgitation, although these remain primarily trial oriented and require prospective validation.[27] From a clinical perspective, however, the applicability of RVEF must be weighed against its practical limitations. Acquisition and analysis of 3D datasets are more technically demanding than conventional RV measures and are more dependent on image quality, operator expertise, and dedicated software. As a result, although RVEF may provide superior prognostic stratification, it may not be obtainable in all patients in routine practice.

Our results emphasize that no single echocardiographic metric can reliably grade RV dysfunction across all severity categories and stratify prognosis. These findings support the growing consensus that multiparametric approaches are needed, particularly when clinical decisions depend on accurate severity classification.[19,28] In PARAGON-HF, the presence of ≥2 abnormal RV functional parameters was associated with markedly worse outcomes, whereas isolated abnormalities were not.[29]

However, rather than relying on generic multiparametric combinations, a more tailored strategy may be warranted. In such a framework, simpler and more readily obtainable parameters, such as TAPSE, may still be useful for initial rapid screening (with the exception of the post-open-heart surgery setting). FWLS may aid in detecting subtle, early dysfunction, whereas RVEF provides a more comprehensive assessment of global RV performance, particularly in advanced disease stages. In selected contexts, evaluation of more advanced dysfunction may be further refined by combining RVEF with a complementary parameter. However, the present study was not designed to derive or validate a formal stepwise diagnostic algorithm; accordingly, this proposed framework should be regarded as hypothesis generating and as a potential direction for future investigation. Ultimately, multiparametric frameworks should be driven by clinical context and feasibility and validated within specific disease populations. Emerging approaches incorporating composite scores or machine learning–based models may further refine RV risk stratification.[1]

LIMITATIONS

This study has several limitations that have to be considered. First, the retrospective multicenter design may have introduced selection bias, and the use of different imaging vendors may have contributed to measurement variability, potentially limiting generalizability. In addition, intercenter variability (including differences in patient population characteristics, image acquisition, and analysis workflows) and interobserver variability may have contributed to the observed discordance between RV functional parameters. Second, the clinical applicability of the findings should be interpreted with recognition of the feasibility limitations of 3D RVEF acquisition, as the exclusion of patients with suboptimal 3D datasets may have introduced selection bias and may limit generalizability. Nevertheless, the analyzed cohort is representative of a tertiary care population, the multicenter and multiplatform setting reflects real-world clinical practice, and the availability of long-term follow-up enhances the clinical relevance of the findings. Third, as RVEF is not an external gold standard for assessing RV systolic function, our analyses were limited to interparameter comparisons rather than validation against a definitive reference standard. Fourth, the severity categories of RV dysfunction were unevenly distributed, potentially limiting statistical power for comparisons across advanced grades. Fifth, cause-specific mortality was unavailable, precluding assessment of the cardiovascular mortality end point. Lastly, the external validity and generalizability of the results require confirmation in prospective studies across disease-specific cohorts.

CONCLUSION

Substantial discordance exists between conventional echocardiographic parameters and RVEF in identifying and grading RV systolic dysfunction, with particularly high reclassification rates in the mild and moderate dysfunction categories. In the presence of RV dysfunction, FAC showed the highest concordance with RVEF among conventional metrics, although the level of agreement remained only fair. None of the individual RV functional parameters provided consistent risk stratification across all severity categories. RVEF showed the most consistent overall risk discrimination, whereas FAC and FWLS provided partial prognostic stratification. These findings support the need for validated and clinically tailored multiparametric approaches to RV functional assessment beyond current guideline cutoffs.

DISCLOSURES

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve the language of the article. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

REVIEW STATEMENT

Given her role as *JASE* Editor-in-Chief, Patricia A. Pellikka, MD, and given his role as *JASE* Associate Editor, Luigi P. Badano, MD, PhD, had no involvement in the peer review of this article and have no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to guest editor Garvan C. Kane, MD.

CONFLICTS OF INTEREST

B.K.L., A.F., and A.K. report personal fees from Argus Cognitive, outside the submitted work. E.S. is an employee and shareholder of AstraZeneca and reports speaker honoraria from GE Healthcare and 123sonography, outside of the submitted work. All other authors report no competing interests that are directly or indirectly related to the work submitted for publication.

M. Tolvaj was supported by the 2025-2.1.1-EKÖP-2025-00014 (EKÖP-2025-596) University Research Scholarship Programme of the Ministry for Culture and Innovation from the source of the National Research, Development, and Innovation Fund and by the EFOP-3.6.3-VEKOP-16-2017-00009 project. Project 2024-1.2.3-HU-RIZONT-2024-00057 has been implemented with support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development, and Innovation Fund, financed under the 2024-1.2.3-HU-RIZONT funding scheme. Project no. RRF-2.3.1-21-2022-00003 has been implemented with the support provided by the European Union. This project was also supported by a grant from the National Research, Development, and Innovation Office (NKFIH) of Hungary (FK 142573 to AK). M. Tokodi and A.K. were supported by the Janos Bolyai Research Scholarship of the Hungarian Academy of Sciences.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.echo.2026.05.005.

REFERENCES

1. Kovacs A, Magunia H, Nicoara A, et al. Challenges and opportunities in assessing right ventricular structure and function: a roadmap for standardization, clinical implementation and research. Nat Rev Cardiol 2025;23:60-77.
2. Surkova E, Muraru D, Genovese D, et al. Relative prognostic importance of left and right ventricular ejection fraction in patients with cardiac diseases. J Am Soc Echocardiogr 2019;32:1407-15.e3.
3. Konstam MA, Kiernan MS, Bernstein D, et al. Evaluation and management of right-sided heart failure: a scientific statement from the American Heart Association. Circulation 2018;137:e578-622.
4. Sanz J, Sánchez-Quintana D, Bossone E, et al. Anatomy, function, and dysfunction of the right ventricle: JACC state-of-the-art review. J Am Coll Cardiol 2019;73:1463-82.
5. Mukherjee M, Rudski LG, Addetia K, et al. Guidelines for the echocardiographic assessment of the right heart in adults and special considerations in pulmonary hypertension: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr 2025;38:141-86.
6. Aloia E, Cameli M, D'Ascenzi F, et al. TAPSE: an old but useful tool in different diseases. Int J Cardiol 2016;225:177-83.
7. Justin ZL, See-Wei L, Ahmed KP, et al. Comparison of tricuspid annular plane systolic excursion with fractional area change for the evaluation of right ventricular systolic function: a meta-analysis. Open Heart 2018;5:e000667.
8. Muraru D, Haugaa K, Donal E, et al. Right ventricular longitudinal strain in the clinical routine: a state-of-the-art review. Eur Heart J Cardiovasc Imaging 2022;23:898-912.
9. Kitano T, Nabeshima Y, Nagata Y, et al. Prognostic value of the right ventricular ejection fraction using three-dimensional echocardiography: systematic review and meta-analysis. PLoS One 2023;18:e0287924.
10. Tolvaj M, Kovács A, Radu N, et al. Significant disagreement between conventional parameters and 3D echocardiography-derived ejection fraction in the detection of right ventricular systolic dysfunction and its association with outcomes. J Am Soc Echocardiogr 2024;37:677-86.
11. Sayour AA, Tokodi M, Celeng C, et al. Association of right ventricular functional parameters with adverse cardiopulmonary outcomes: a meta-analysis. J Am Soc Echocardiogr 2023;36:624-33.e8.
12. Badano LP, Baratto C, Liberatore M, et al. Invasive validation of right ventricular stroke volume and tricuspid regurgitant volume obtained from three-dimensional echocardiography. J Am Soc Echocardiogr 2025;39:333-41.
13. Lang RM, Badano LP, Tsang W, et al., American Society of Echocardiography; European Association of Echocardiography. EAE/ASE recommendations for image acquisition and display using three-dimensional echocardiography. Eur Heart J Cardiovasc Imaging 2012;25:3-46.
14. Badano LP, Kolias TJ, Muraru D, et al. Standardization of left atrial, right ventricular, and right atrial deformation imaging using two-dimensional speckle tracking echocardiography: a consensus document of the EACVI/ASE/industry task force to standardize deformation imaging. Eur Heart J Cardiovasc Imaging 2018;19:591-600.
15. Meira-Machado L, Cadarso-Suárez C, Gude F, et al. smoothHR: an R package for pointwise nonparametric estimation of hazard ratio curves of continuous predictors. Comput Math Methods Med 2013;2013:745742.
16. Investigators W, Addetia K, Miyoshi T, et al. Two-Dimensional echocardiographic right ventricular size and systolic function measurements stratified by sex, Age, and ethnicity: results of the world alliance of societies of echocardiography study. J Am Soc Echocardiogr 2021;34:1148-11457.e1.
17. Investigators W, Addetia K, Miyoshi T, et al. Normal values of three-dimensional right ventricular size and function measurements: results of the world alliance societies of echocardiography study. J Am Soc Echocardiogr 2023;36:858-66.e1.
18. Ajmone MN, Michalski B, Cameli M, et al. EACVI survey on standardization of cardiac chambers quantification by transthoracic echocardiography. Eur Heart J Cardiovasc Imaging 2020;21:119-23.
19. Soliman-Aboumarie H, Joshi SS, Cameli M, et al. EACVI survey on the multi-modality imaging assessment of the right heart. Eur Heart J Cardiovasc Imaging 2022;23:1417-22.
20. Muraru D, Petersen SE, Dweck MR, et al. EACVI Survey on the Current multi-modality imaging practice in patients with tricuspid regurgitation. Eur Heart J Imaging Methods Pract 2026;4:qyag008.
21. Nagata Y, Wu VC, Kado Y, et al. Prognostic value of right ventricular ejection fraction assessed by transthoracic 3D echocardiography. Circ Cardiovasc Imaging 2017;10:e005384.
22. Tolvaj M, Tokodi M, Lakatos BK, et al. Added predictive value of right ventricular ejection fraction compared with conventional echocardiographic measurements in patients who underwent diverse cardiovascular procedures. Imaging 2021;13:130-7.
23. Tomaselli M, Penso M, Badano LP, et al. Sex-specific differences in right heart remodelling and patient outcomes in secondary tricuspid regurgitation. Eur Heart J Cardiovasc Imaging 2025;27:104-14.
24. Ladányi Z, Lakatos BK, Clement A, et al. Mechanical adaptation of the right ventricle to secondary tricuspid regurgitation and its association with patient outcomes. J Am Soc Echocardiogr 2025;38:601-12.
25. Badano LP, Penso M, Tomaselli M, et al. Advanced echocardiography and cluster analysis to identify secondary tricuspid regurgitation phenogroups at different risk. Revista Esp Cardiol (Engl Ed) 2025;78:838-47.
26. Muraru D, Badano LP, Nagata Y, et al. Development and prognostic validation of partition values to grade right ventricular dysfunction severity using 3D echocardiography. Eur Heart J Cardiovasc Imaging 2020;21:10-21.
27. Hahn RT, Lawlor MK, Davidson CJ, et al. Tricuspid valve academic research consortium definitions for tricuspid regurgitation and trial endpoints. J Am Coll Cardiol 2023;82:1711-35.
28. Peyrou J, Parsaï C, Chauvel C, et al. Echocardiographic assessment of right ventricular systolic function in a population of unselected patients before cardiac surgery: a multiparametric approach is necessary. Arch Cardiovasc Dis 2014;107:529-39.
29. Lu H, Inciardi RM, Abanda M, et al. Multiparametric assessment of right ventricular dysfunction in heart failure: an analysis from PARAGON-HF. J Am Heart Assoc 2025;14:e037380.