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ORIGINAL RESEARCH

# Recommended Criteria to Define Right Ventricular Dysfunction in Severe Secondary Tricuspid Regurgitation

## Association With Outcome

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ABSTRACT

**BACKGROUND** The TVARC (Tricuspid Valve Academic Research Consortium) and the ASE (American Society of Echocardiography) have proposed echocardiography cutoffs to define right ventricular (RV) dysfunction in secondary tricuspid regurgitation (STR), although these thresholds have not yet been validated.

**OBJECTIVES** This study aims to evaluate the prognostic value of the proposed thresholds for the main RV function parameters in a large real-world STR cohort.

**METHODS** Consecutive patients with ≥ moderate-to-severe STR were included. RV function was assessed by tricuspid annular plane systolic excursion (TAPSE), fractional area change, right ventricular global longitudinal strain, and right ventricular free wall longitudinal strain (RVFWLS). The study outcome was the composite of all-cause mortality and heart failure hospitalization, censored for tricuspid valve intervention.

**RESULTS** A total of 1,550 patients (mean age: 69 ± 13 years, 50% men) were included. During a median follow-up of 22 months (Q1-Q3: 3-63 months), 703 patients (45%) reached the composite endpoint. All proposed cutoffs were associated with outcomes in univariable Cox analyses, but after multivariable adjustment, mainly strain parameters remained significant. A multiparametric approach combining echocardiographic measures was evaluated, and a stepwise combined grading using TAPSE and RVFWLS showed the strongest association with the composite endpoint; the different grades of RV dysfunction (mild, moderate, and severe, respectively) also remained independently associated (overall value of $P < 0.001$ and $P < 0.005$ for TVARC and ASE cutoffs, respectively) with the endpoint.

**CONCLUSIONS** The TVARC and ASE cutoffs for RV dysfunction showed prognostic value in patients with significant STR. Combining TAPSE and RVFWLS may provide a pragmatic, exploratory framework for risk stratification of these patients. (JACC Cardiovasc Imaging. 2026;19:1297-1310) © 2026 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

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**ABBREVIATIONS AND ACRONYMS**

**3D** = 3-dimensional

**LVEF** = left ventricular ejection fraction

**RV** = right ventricular

**RVEF** = right ventricular ejection fraction

**RVFAC** = right ventricular fractional area change

**RVFWLS** = right ventricular free wall longitudinal strain

**RVGLS** = right ventricular global longitudinal strain

**STR** = secondary tricuspid regurgitation

**TAPSE** = tricuspid annular plane systolic excursion

**TR** = tricuspid regurgitation

**TVI** = tricuspid valve intervention

Significant tricuspid regurgitation (TR) affects 0.55%-2.7% of the population, increases with age, and is associated with adverse outcomes.[1-3] Despite available surgical and transcatheter tricuspid valve interventions (TVI), referral is often delayed until advanced heart failure or end-organ damage is present.[4,5] Both European[6] and American[7] guidelines base the indication for intervention on TR severity, symptoms, anatomical considerations, and importantly, the presence and severity of pulmonary hypertension and right ventricular (RV) dysfunction.[8] Several echocardiographic parameters have been proposed for the evaluation of RV function including tricuspid annular plane systolic excursion (TAPSE), right ventricular fractional area change (RVFAC), tissue Doppler imaging-derived tricuspid lateral annular systolic velocity wave (S′), right ventricular global longitudinal strain (RVGLS), right ventricular free wall longitudinal strain (RVFWLS), or 3-dimensional (3D) echocardiography right ventricular ejection fraction (RVEF).[9,10] Recently, the TVARC (Tricuspid Valve Academic Research Consortium) and the ASE (American Society of Echocardiography) proposed specific cutoffs for each of these parameters to define different degrees of RV dysfunction in patients with TR (**Table 1**).[11,12] Accordingly, the 2025 European guidelines recommend a multiparametric approach and, for the first time, implement these reference values to define (severe) RV dysfunction in the recommendation for intervention.[6] However, the proposed cutoffs are based only on multinational reports of normative data and expert consensus,[10,11] and still require real-world and outcome-based validation. We therefore evaluated their association with clinical outcomes in a large cohort of patients with significant secondary tricuspid regurgitation (STR) and explored a pragmatic multiparametric approach to detect subclinical RV dysfunction, to support earlier referral for TVI, and to provide more refined risk stratification.

## METHODS

**STUDY GROUPS.** All patients diagnosed with significant (defined as ≥ moderate-to-severe[13]) TR between January 2000 and September 2016 were identified from the departmental adult echocardiography database of the Leiden University Medical Centre (Leiden, the Netherlands). Patients with nonsevere TR, active endocarditis, known congenital heart disease, prior TVI, and missing relevant clinical data or inadequate echocardiographic acoustic windows were excluded from the current analysis. Additionally, patients with primary TR were excluded and only patients with significant STR were selected for the current analysis (**Figure 1**).

Demographic and clinical data were retrospectively collected from the departmental Cardiology Information System (EPD-Vision, Leiden University Medical Centre). The Institutional Review Board of the Leiden University Medical Centre approved the observational design and retrospective analysis of clinically acquired data, and waived the need for written informed consent. The study was conducted in accordance with the principles of the Helsinki Declaration. The data underlying this paper will be shared on reasonable request to the corresponding author.

**CLINICAL AND ECHOCARDIOGRAPHIC VARIABLES.** Baseline demographic, clinical, laboratory, and echocardiographic variables were evaluated at the time of first diagnosis of significant TR on transthoracic echocardiography. Comprehensive transthoracic echocardiograms were performed at rest using a commercially available system (Vivid 7, E9 and E95 systems, GE-Vingmed). All images were digitally stored for off-line analysis (EchoPAC, version 113.0.3, 202-204, GE-Vingmed). Echocardiograms were prospectively reanalyzed and all variables described in the current study were measured from the original, digitized echocardiogram, according to current guidelines.[10,14,15] From the apical 4- and 2-chamber views, left ventricular volumes were measured, and left ventricular ejection fraction (LVEF) was quantified using the biplane Simpson's method.[10] Left atrial maximum volume was measured at end-systole using the biplane method on the apical 4- and 2-chamber views.[10] Right-sided parameters were measured from a focused RV apical view, when available; in earlier examinations, reflecting a temporal trend in the adoption of RV-focused imaging, measurements were obtained from the best available RV-oriented apical image suitable for quantitative analysis. Integrative assessment of the TR severity was performed through a multiparametric approach including qualitative, semiquantitative, and quantitative parameters and was graded according to current ASE/EACVI (European Association of Cardiovascular Imaging) guidelines.[14,15] Systolic pulmonary artery pressure was estimated from the TR jet peak velocity applying the Bernoulli equation and adding right atrial pressure.

**TABLE 1 Proposed Echocardiographic Cutoffs for RV Dysfunction by the TVARC and the ASE**

| | TAPSE | RVFAC | RVGLS[a] | RVFWLS[a] |
|---|---|---|---|---|
| TVARC criteria | | | | |
| Normal | ≥17 mm | ≥37% | ≥21% | ≥23% |
| Mild dysfunction | 14-17 mm | 34%-37% | 18%-21% | 20%-23% |
| Moderate dysfunction | 10-14 mm | 30%-33% | 14%-17% | 15%-19% |
| Severe dysfunction | <10 mm | <30% | <14% | <15% |
| ASE criteria | | | | |
| Normal | >17 mm | >35% | >17% | >20% |
| Mild dysfunction | >13-≤17 mm | >29%-≤35% | >13%-≤17% | >15%-≤20% |
| Moderate dysfunction | >10-≤13 mm | >22%-≤29% | >9%-≤13% | >11%-≤15% |
| Severe dysfunction | ≤10 mm | ≤22% | ≤9% | ≤11% |

[a]RVGLS and RVFWLS are expressed in absolute values.

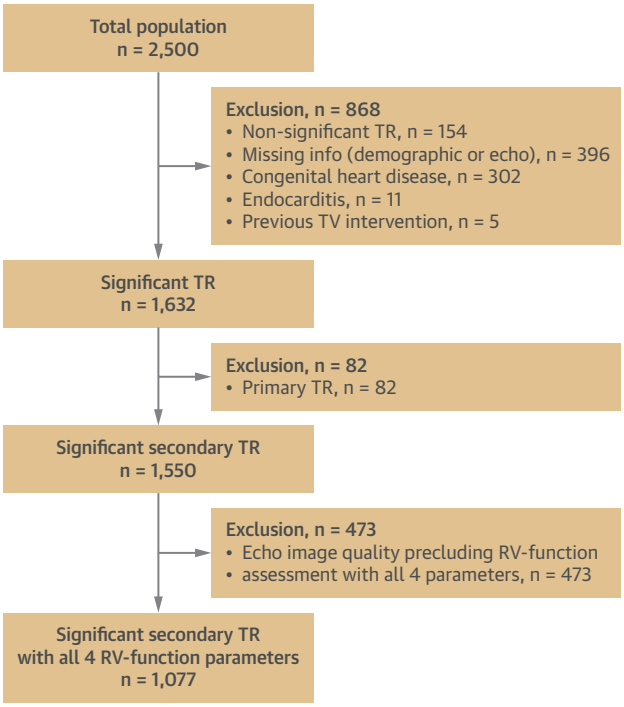
ASE = American Society of Echocardiography; FAC = fractional area change; FWLS = free wall longitudinal strain; GLS = global longitudinal strain; RV = right ventricular; TAPSE = tricuspid annular plane systolic excursion; TVARC = Tricuspid Valve Academic Research Consortium.

Right atrial pressure was estimated based on the inferior vena cava diameter and its collapsibility during breathing.[10] Furthermore, STR etiology was classified, using a stepwise approach, into the following 4 etiologies based on clinical and echocardiographic characteristics, as recently proposed[8,16-19]: 1) left-sided cardiac disease (either left-sided heart disease or left-sided valvular disease); 2) pulmonary hypertension; 3) RV dysfunction; and 4) atrial-STR. Etiologies 1 to 3 were grouped as ventricular-STR, whereas atrial-STR remained an independent group. The ratio of end-systolic right atrial to RV area was calculated and a value ≥1.5 is compatible with atrial-STR.

For comprehensive assessment of RV systolic function, RVFAC was calculated from end-diastolic and end-systolic RV areas, and TAPSE was measured using M-mode at the lateral tricuspid annulus. Speckle-tracking RVGLS and RVFWLS were measured from a 2-dimensional focused RV apical view, using commercially available software (Q-analysis package, EchoPac 202-204, GE Medical Systems). The RV was segmented into 6 regions: basal, mid, and apical for both the RV free wall and septum. The RVGLS was calculated as the average of all 6 segments, whereas RVFWLS was calculated as the average of the 3 free wall segments, excluding the septum.[20-22] Both strain parameters are reported as absolute (ie, positive) values. Tissue Doppler S′ and 3D volumetric data were not consistently acquired during the study period. Terminology (normal, mild, moderate, and severe) follows the graded categories proposed by TVARC and ASE; numeric thresholds are provided in Table 1.

**FOLLOW-UP AND OUTCOME DEFINITION.** The endpoint of the study was the composite of all-cause mortality and heart failure hospitalization. To ensure uniform RV function characterization, outcome analyses were performed in patients with complete availability of all 4 RV function parameters, from the time of diagnosis of significant TR until the study endpoint or last follow-up, censored in May 2022. Additionally, for all outcome analyses, patients were censored at the

**FIGURE 1 Flowchart for the Selection of the Study Groups**




RV = right ventricular; TR = tricuspid regurgitation; TV = tricuspid valve.

**TABLE 2 Baseline Clinical Characteristics of the Overall Study Groups**

| | Study Cohort (N = 1,550) | Validation Cohort (n = 198) | SMD |
|---|---|---|---|
| Demographic characteristic | | | |
| Age, y | 69 ± 13 | 74 ± 8.9 | 0.45 |
| Male | 770 (50) | 86 (51) | 0.02 |
| Body surface area, $m^2$ | 1.88 ± 0.22 | 1.77 ± 0.21 | 0.51 |
| Symptoms | | | |
| NYHA functional class III/IV | 684 (49) | 52 (31) | 0.37 |
| Cardiovascular risk factors | | | |
| Arterial hypertension | 1,153 (77) | 94 (55) | 0.48 |
| Diabetes mellitus | 298 (20) | 24 (14) | 0.16 |
| Dyslipidemia | 660 (46) | 59 (35) | 0.23 |
| (Ex-)smoker | 465 (33) | 46 (27) | 0.13 |
| Family history | 236 (16) | 19 (6) | 0.32 |
| Comorbidities | | | |
| COPD | 226 (15) | 22 (13) | 0.06 |
| Coronary artery disease | 616 (40) | 55 (33) | 0.15 |
| Atrial fibrillation | 780 (52) | 114 (71) | 0.40 |
| CIED | 507 (33) | 24 (14) | 0.46 |
| Previous cardiac surgery | 456 (29) | 11 (7) | 0.60 |
| Medication | | | |
| Beta-blocker | 858 (61) | 119 (74) | 0.28 |
| Loop diuretic agents | 892 (59) | 147 (90) | 0.76 |
| Laboratory values | | | |
| Hemoglobin, g/dL | 12.6 ± 2.1 | 12.6 ± 1.8 | <0.01 |
| Creatinine, μmol/L | 94 (74-124) | 94 (78-120) | <0.01 |

Values are mean ± SD, n (%), or median (Q1-Q3), unless otherwise indicated.
CIED = cardiac implantable electronic device; COPD = chronic obstructive pulmonary disease; SMD = standardized mean difference.

moment of TVI (including surgical repair or replacement and transcatheter edge-to-edge repair or transcatheter annuloplasty). Management decisions followed contemporaneous guidelines and heart team consensus.

**COMBINED GRADING AND VALIDATION COHORT.** A novel multiparametric approach was developed to optimally characterize RV function and detect subclinical dysfunction and remain practical for routine clinical use. Various combinations of echocardiographic parameters were systematically tested to identify the model with the strongest association with the study endpoint. External validation of the proposed grading scheme was performed in an independent cohort from the University Hospital of Rennes, France, using identical inclusion criteria and analytical methods.

**STATISTICAL ANALYSIS.** Continuous variables are presented as mean ± SD or median (Q1-Q3), and categorical variables as n (%). Normality was assessed using skewness/kurtosis, supported by Shapiro-Wilk and Kolmogorov-Smirnov testing. Concordance between the binary RV classifications was evaluated using Cohen's kappa (κ). Kaplan-Meier survival analysis was used to estimate the 5-year survival rate, censored for TVI, and differences between groups were analyzed using log-rank testing. The associations of clinical and echocardiographic parameters with the composite endpoint, censored for TVI, was evaluated using univariable and multivariable Cox proportional hazards regression models, adjusting for variables significant in the univariable analysis or known to have an impact on prognosis in patients with significant STR. The multivariable baseline model included age, sex, body surface area, coronary artery disease, NYHA functional class III/IV, presence of a cardiac implantable electronic device, previous cardiac surgery, hemoglobin, creatinine, left ventricular end-diastolic volume, LVEF, maximal left atrial volume, RV end-diastolic area, maximal right atrial area, maximal TR pressure gradient, right atrial pressure, and STR etiology (atrial-STR vs ventricular-STR). Correlation analysis excluded collinearity (correlation coefficient >0.60). The HRs and 95% CIs were calculated. All $P$ values were 2-sided, and a value of $P < 0.05$ was considered statistically significant. All data were analyzed using SPSS, v25.0 (IBM Corporation) and RStudio/2024.12.0 + 467 (R Foundation for Statistical Computing).

## RESULTS

**CLINICAL AND ECHOCARDIOGRAPHIC CHARACTERISTICS.** A total of 1,550 patients, diagnosed with significant STR, were included in the current analysis. Clinical characteristics of the overall study groups are presented in Table 2 and in patients with complete RV assessment (n = 1,077) in Supplemental Table 1. The mean age was 69 ± 13 years, with 770 being men (50%). Approximately half of the patients (49%) were symptomatic (NYHA functional class III/IV) and one-quarter (24%) presented with peripheral edema. Furthermore, a total of 780 patients (52%) had a history of atrial fibrillation and almost one-third (33%) of patients had a cardiac implantable electronic device in situ.

Echocardiographic characteristics of the overall study groups are presented in Table 3 (and in those with complete RV assessment in Supplemental Table 2). The mean LVEF was 44.1% ± 15.6% and approximately one-third of the patients had at least moderate left-sided valvular disease. Most patients

had a mildly dilated RV with a mean RV basal diameter of 46.1 ± 8.8 mm and median indexed RV end-diastolic area of 12.6 $cm^2/m^2$ (Q1-Q3: 10.2-15.6 $cm^2/m^2$). The right atrium was moderately to severely dilated in the overall study groups and pulmonary pressures were mildly elevated. The majority of patients (91%) presented with ventricular-STR as the underlying TR etiology, with 79%, 5%, and 8% diagnosed with left-sided cardiac disease, pulmonary hypertension, and RV dysfunction, respectively; only 9% of patients had atrial-STR as TR etiology.

**RV DYSFUNCTION DISTRIBUTION.** On average, RV function was reduced across all 4 parameters, including TAPSE, RVFAC, RVGLS, and RVFWLS (Table 3). However, application of the proposed TVARC and ASE cutoffs resulted in relatively discrepant classifications of RV dysfunction. Echocardiographic parameters, including TAPSE and RVFAC, classified more patients as having normal RV function (TAPSE: 37% and 27%; RVFAC: 44% and 50% according to the TVARC and ASE cutoffs, respectively) compared with speckle-tracking echocardiographic parameters. In contrast, only 9% and 25% of patients based on RVGLS, and 18% and 28% based on RVFWLS, were classified as normal RV function, using the respective TVARC and ASE thresholds (Figure 2). Accordingly, speckle-tracking echocardiography classified a significantly higher percentage of patients having reduced RV function, compared with conventional echocardiographic parameters. Cohen's κ analyses indicated poor-to-fair agreement for all parameters in classifying normal vs abnormal RV function or differentiating severe from mild-to-moderate dysfunction, whereas RVGLS and RVFWLS demonstrated moderate-to-substantial concordance (Supplemental Table 3).

**RV DYSFUNCTION AND ASSOCIATION WITH OUTCOMES.** During a median follow-up of 22 months (Q1-Q3: 3-63 months), 517 patients (48%) reached the composite endpoint of all-cause mortality and heart failure hospitalization, and 142 patients (13%) were censored for TVI. The event-free survival rates for the total study groups at 1-, 5-, and 10-year follow-up were 74%, 49%, and 35%, respectively. The Kaplan-Meier curves illustrating the 5-year composite endpoint (all-cause mortality or heart failure hospitalization), censored for TVI, according to each echocardiographic parameter assessing RV function (TAPSE, RVFAC, RVGLS, and RVFWLS) and stratified by the TVARC and the ASE cutoffs, are presented in Figure 3. The proposed echocardiographic cutoffs for RV function by the TVARC as well as the ASE showed a significant overall log-rank value of $P < 0.0001$ for each of the parameters. Additionally, all RV function parameters, as continuous variables as well as categorical variables according to the TVARC and ASE proposed cutoffs, had a value of $P < 0.001$ on the univariable Cox regression analysis (Supplemental Tables 4 and 5). However, when comparing the degrees of RV dysfunction on the Kaplan-Meier curves, differences were observed for each echocardiographic parameter (Figure 3; pairwise log-rank comparison, Supplemental Table 6), which were confirmed in the univariable Cox regression analysis (Supplemental Tables 4 and 5). In particular, patients with moderately and severely reduced TAPSE experienced significantly worse outcomes compared with those with normal or mildly reduced TAPSE (Figures 3A and 3E). In turn, only moderately to severely reduced RVFAC showed a significant difference in outcome compared with normal or mildly reduced RVFAC (Figures 3B and 3F). Speckle-tracking

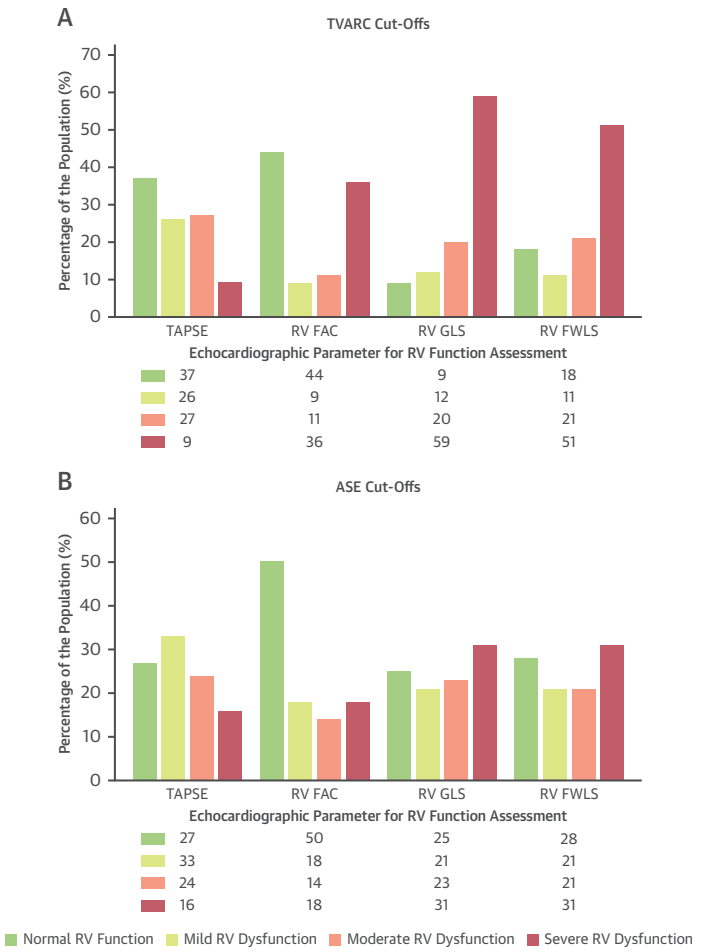
**TABLE 3 Echocardiographic Characteristics of the Overall Study Groups**

| | Study Cohort (N = 1,550) | Validation Cohort (n = 198) | SMD |
|---|---|---|---|
| Heart rate, beats/min | 80 ± 19 | 70 ± 14 | 0.60 |
| Left-sided parameters | | | |
| LVEF, % | 44.1 ± 15.6 | 55.3 ± 12.8 | 0.79 |
| Left atrial maximum volume-indexed, $mL/m^2$ | 49.6 (34.4-68.0) | 65.0 (48.0-84.8) | 0.59 |
| Significant aortic stenosis[a] | 211 (22) | 29 (15) | 0.18 |
| Significant mitral regurgitation[a] | 490 (32) | 49 (35) | 0.06 |
| Right-sided parameters | | | |
| Tricuspid valve annular diameter, mm | 41.9 ± 8.0 | 43.5 ± 6.7 | 0.22 |
| RV end-diastolic area-indexed, $cm^2/m^2$ | 12.6 (10.2-15.6) | 12.9 (10.3-16.2) | 0.07 |
| RV end-systolic area-indexed, $cm^2/m^2$ | 8.1 (6.2-10.6) | 7.4 (5.7-9.0) | 0.24 |
| RVFAC, % | 34.5 ± 13.2 | 43.3 ± 11.6 | 0.71 |
| RVGLS, %[b] | 12.6 ± 6.0 | 15.8 ± 4.7 | 0.59 |
| RVFWLS, %[b] | 15.5 ± 7.2 | 18.9 ± 5.7 | 0.52 |
| TAPSE, mm | 15.6 ± 5.1 | 18.7 ± 5.1 | 0.61 |
| RA maximum area-indexed, $cm^2/m^2$ | 14.0 (11.1-17.5) | 15.7 (13.0-21.1) | 0.31 |
| End-systolic RA to RV ratio ≥1.5 | | | |
| Value ≥1.5, concordant with atrial-STR | 306 (20) | 55 (32) | 0.28 |
| Systolic pulmonary artery pressure, mm Hg | 43.9 ± 16.2 | 43.2 ± 14.1 | 0.05 |
| TR severity | | | |
| Moderate-to-severe TR | 1,164 (75) | 37 (19) | 1.36 |
| Severe TR | 38 1 (25) | 161 (81) | |
| TR etiology | | | |
| Atrial STR | 144 (10) | 68 (34) | 0.63 |
| Ventricular STR | 1,369 (91) | 130 (66) | |

Values are mean ± SD, median (Q1-Q3), or n (%), unless otherwise indicated. [a]Significant aortic stenosis or mitral regurgitation is defined as at least moderate aortic stenosis or moderate mitral regurgitation, respectively. [b]RVGLS and RVFWLS are expressed in absolute values.

LVEF = left ventricular ejection fraction; RA = right atrium; RVFAC = right ventricular fractional area change; RVFWLS = right ventricular free wall longitudinal strain; RVGLS = right ventricular global longitudinal strain; STR = secondary tricuspid regurgitation; TAPSE = tricuspid annular plane systolic excursion; TR = tricuspid regurgitation; other abbreviations as in Tables 1 and 2.

**FIGURE 2 RV Function Distribution According to Each Echocardiographic Parameter Threshold**



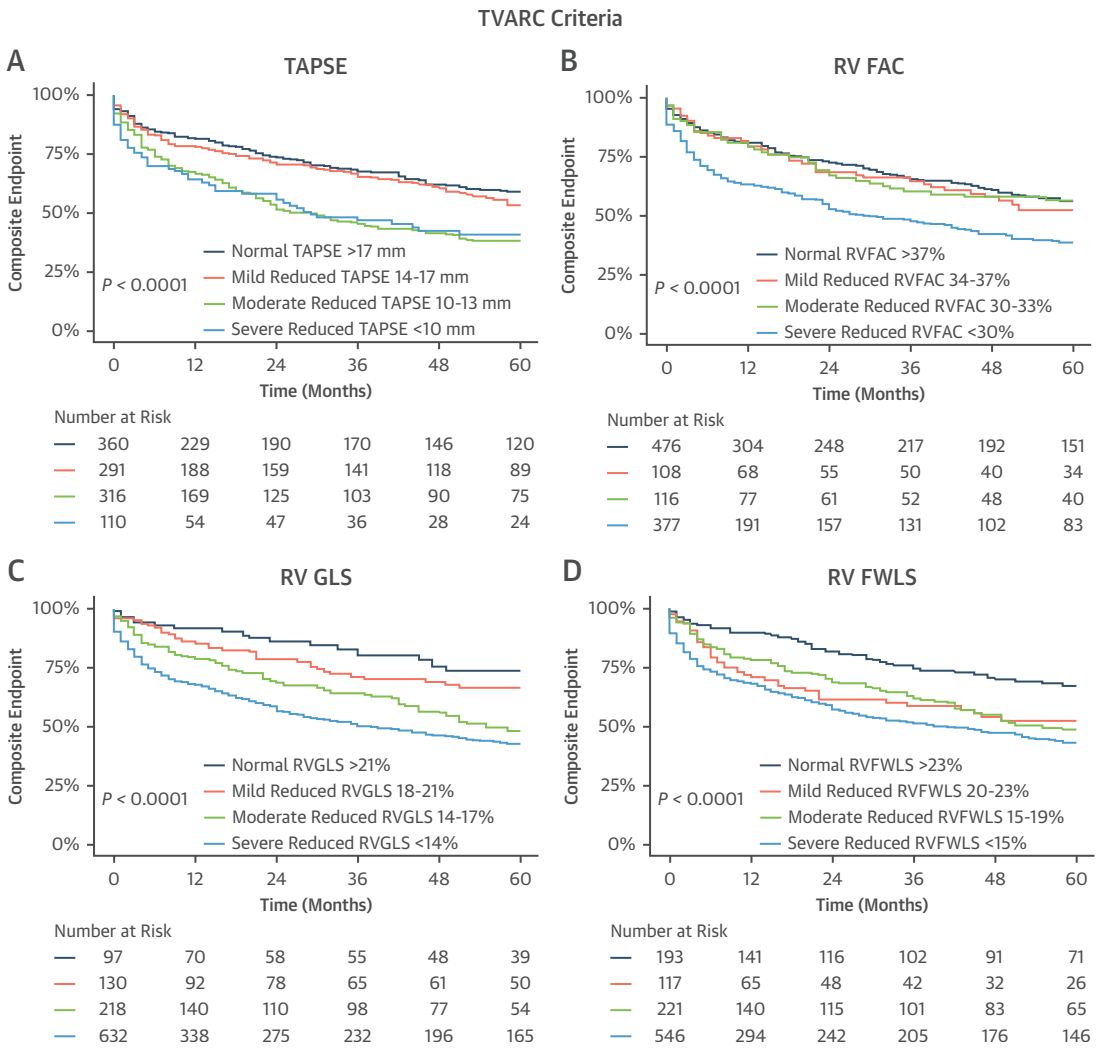

Distribution of patients with normal, mild, moderate, and severe RV dysfunction by TAPSE, RVFAC, RVGLS, and RVFWLS, according to TVARC (A) and ASE (B) criteria. ASE = American Society of Echocardiography; RVFAC = right ventricular fractional area change; RVFWLS = right ventricular free wall longitudinal strain; RVGLS = right ventricular global longitudinal strain; TAPSE = tricuspid annular plane systolic excursion; TVARC = Tricuspid Valve Academic Research Consortium; other abbreviation as in Figure 1.

parameters, both RVGLS (Figures 3C and 3G) and RVFWLS (Figures 3D and 3H), showed stronger associations with the composite endpoint than conventional indexes, discriminating across dysfunction grades. However, some comparisons between normal and mildly abnormal categories did not reach statistical significance for either TVARC or ASE criteria.

Multivariable Cox regression analyses were performed for each echocardiographic parameter of RV function, following adjustment for a comprehensive baseline model. RV function parameters, assessed as continuous variables, remained independently associated with the composite endpoint (Supplemental Table 7). When assessed as categorical variables (Table 4), the proposed TAPSE cutoffs did not remain independently associated with the composite endpoint, whereas RVFAC, RVGLS, and RVFWLS remained independently associated with the composite endpoint, although some subgroup analyses did not reach statistical significance.

**MULTIPARAMETRIC ASSESSMENT OF RV FUNCTION.** Given differences in refining risk stratification based on the specified cutoffs, we evaluated a novel grading system combining 2 complementary measures, including longitudinal and radial indexes, to distinguish normal from abnormal RV function and severe from nonsevere dysfunction (Supplemental Figure 1, Supplemental Tables 8 and 9). The strongest prognostic model combined the conventional parameter TAPSE with RVFWLS, which was therefore selected for the proposed grading system. Patients with normal TAPSE experienced similar event-free survival rates as compared to patients with normal RVFWLS (TAPSE: 62% and 64% and RVFWLS: 67% and 62% at 5 years, according to the TVARC and ASE criteria, respectively). Conversely, in patients with mildly reduced RVFWLS, event-free survival was significantly lower than in patients with normal RVFWLS and decreased already to 52% and 50% at 5 years, respectively, for the TVARC and the ASE cutoffs. We therefore further characterized patients with normal TAPSE according to normal or reduced RVFWLS. Using this approach, patients with normal TAPSE + normal RVFWLS experienced the highest event-free survival (71% and 69% at 5 years, based on TVARC and ASE thresholds, respectively), compared with that in patients reclassified with normal TAPSE + reduced RVFWLS, who had event-free survival rates comparable to patients with mildly reduced TAPSE (**Central Illustration A and B**). In addition, patients with moderately to severely reduced TAPSE were characterized by the worst prognosis with an event-free survival of only 39% for both TVARC and ASE cutoffs at 5-year follow-up. Moreover, using the same combined grading, patients with moderately to severely reduced TAPSE and nonseverely reduced RVFWLS had better 5-year survival than those with concomitantly severely reduced RVFWLS (TVARC 42% vs 37%; ASE 43% vs 33%; $P = 0.048$ and 0.005, respectively). On multivariable Cox regression analysis, the combined grading strategy was independently associated with the composite endpoint (overall value of $P < 0.001$ and $P < 0.005$, applying the TVARC and ASE cutoffs,

**FIGURE 3** Kaplan-Meier Curves for the Composite Endpoint by RV Dysfunction Grade



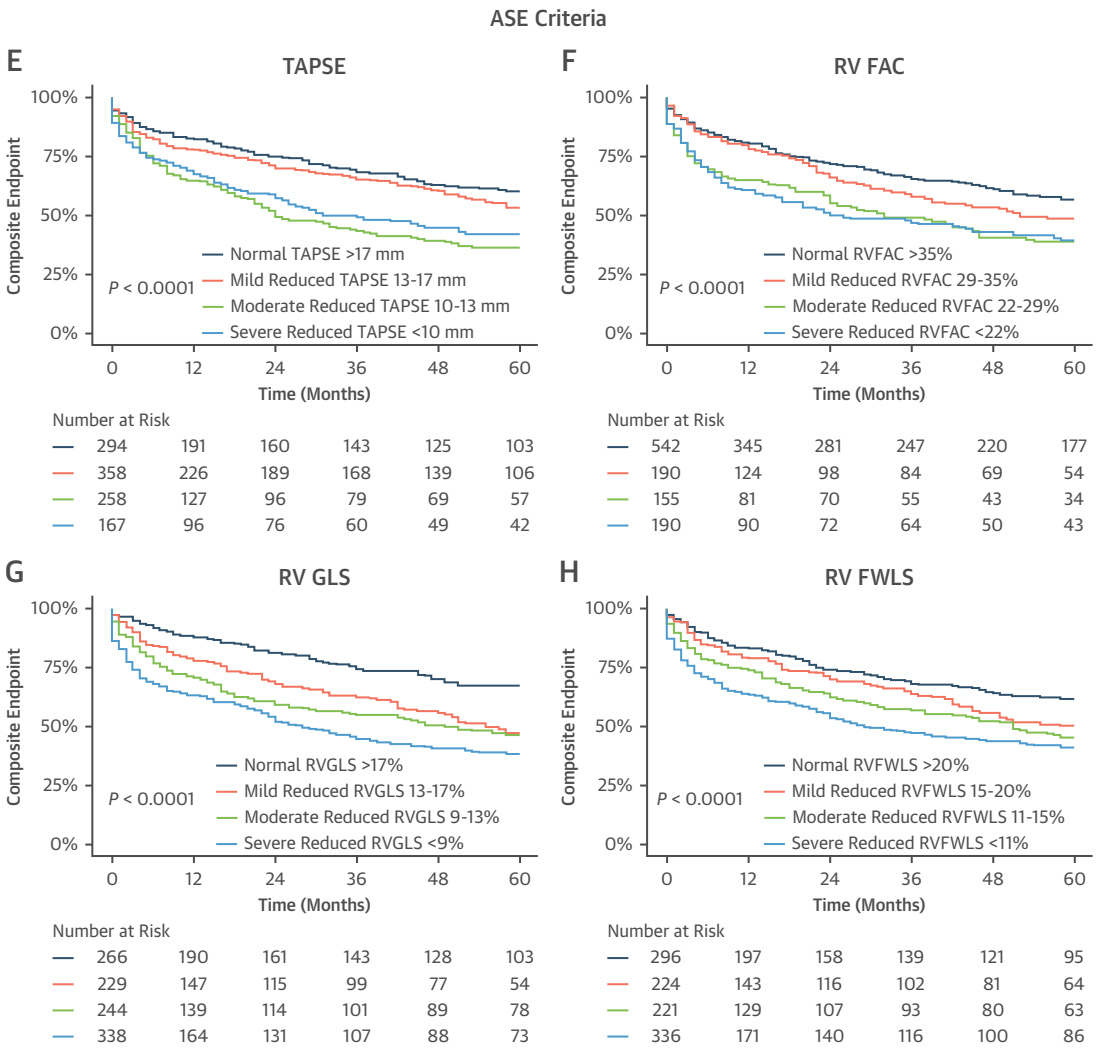

Kaplan-Meier curves for the composite endpoint, censored for tricuspid valve intervention, by TAPSE, RVFAC, RVGLS, and RVFWLS, according to TVARC (A to D) and ASE (E to H) criteria. Abbreviations as in Figures 1 and 2.

*Continued on the next page*

respectively), and also across the different grades of RV dysfunction (**Table 4**).

Results for the combined grading were validated in an independent cohort, including 198 patients with significant STR (Supplemental Figure 2). A description of the baseline clinical and echocardiographic characteristics is provided in **Tables 2 and 3**. Although moderate standardized mean differences were observed between cohorts, this may be regarded as a strength, as the proposed grading concept was evaluated in a distinct cohort of patients with significant STR. Of these patients, 145 had all RV function measures available and were included for outcome analyses. During a median follow-up of 20 months (Q1-Q3: 6-32 months), 68 patients (47%) reached the composite endpoint, and 24 patients (17%) were censored for TVI. Kaplan-Meier survival curves confirmed significantly worse outcomes at 5-year follow-up in patients with normal TAPSE and reduced RVFWLS, compared with outcomes in patients with normal values for both parameters, with similar findings using the TVARC and ASE thresholds (**Figure 4**). Additionally, in the univariable Cox regression analysis, the combined grading was

**FIGURE 3 Continued**




associated with the composite endpoint (Table 5) and remained independently associated with the composite endpoint after adjusting for age, sex, creatinine, NYHA functional class, LVEF, and STR etiology (Supplemental Table 10), for both TVARC and ASE thresholds, respectively.

## DISCUSSION

This main findings of this study were: 1) in conservatively treated patients with significant STR, the TVARC and ASE thresholds yielded relatively different RV dysfunction classification; 2) although each of the RV function parameters was significantly associated with the combined endpoint, the magnitude and consistency varied across dysfunction grades; 3) TAPSE performed well to identify patients at very high risk, with moderate-severely reduced TAPSE characterized by the lowest event-free survival rates, whereas impaired RVFWLS (even mildly reduced) showed the best sensitivity to identify patients at higher risk even when conventional parameters were still normal; and 4) combining TAPSE with RVFWLS improved risk stratification by identifying patients with normal TAPSE but impaired RVFWLS and those with severe dysfunction by both measures, who had the poorest outcome.

**RV SYSTOLIC FUNCTION ASSESSMENT.** RV function relies on a complex interplay of systemic venous return (preload), myocardial diastolic and systolic function, pulmonary vasculature afterload, and

**TABLE 4 Multivariable Cox Proportional Hazards Models for the Composite Endpoint, Censored for TV Intervention, for the Study Cohort**

| | TVARC Criteria (n = 1,077) | | ASE Criteria (n = 1,077) | |
|---|---|---|---|---|
| | HR (95% CI) | *P* Value | HR (95% CI) | *P* Value |
| Baseline model + TAPSE (category) | | 0.119 | | 0.057 |
| Normal | Ref. | Ref. | Ref. | Ref. |
| Mild | 1.016 (0.758-1.362) | 0.913 | 1.090 (0.815-1.458) | 0.561 |
| Moderate | 1.314 (0.995-1.736) | 0.055 | 1.487 (1.096-2.016) | **0.011** |
| Severe | 1.360 (0.937-1.972) | 0.105 | 1.247 (0.891-1.747) | 0.199 |
| Baseline model + RVFAC (category) | | **0.043** | | **0.013** |
| Normal | Ref. | Ref. | Ref. | Ref. |
| Mild | 0.836 (0.572-1.223) | 0.356 | 1.051 (0.776-1.423) | 0.748 |
| Moderate | 1.015 (0.694-1.485) | 0.937 | 1.324 (0.972-1.802) | 0.075 |
| Severe | 1.312 (1.025-1.678) | **0.031** | 1.561 (1.171-2.081) | **0.002** |
| Baseline model + RVGLS[a] (category) | | **0.009** | | **0.001** |
| Normal | Ref. | Ref. | Ref. | Ref. |
| Mild | 1.369 (0.793-2.363) | 0.259 | 1.303 (0.911-1.862) | 0.147 |
| Moderate | 1.469 (0.880-2.452) | 0.141 | 1.572 (1.111-2.225) | **0.011** |
| Severe | 1.962 (1.225-3.144) | **0.005** | 1.844 (1.341-2.535) | **<0.001** |
| Baseline model + RVFWLS[a] (category) | | **0.001** | | **0.009** |
| Normal | Ref. | Ref. | Ref. | Ref. |
| Mild | 1.711 (1.095-2.675) | **0.018** | 1.169 (0.832-1.642) | 0.369 |
| Moderate | 1.352 (0.910-2.008) | 0.135 | 1.417 (1.022-1.965) | **0.036** |
| Severe | 1.869 (1.329-2.629) | **<0.001** | 1.631 (1.206-2.207) | **0.002** |
| Baseline model + Combined grading | | **<0.001** | | **0.005** |
| Normal TAPSE + normal RVFWLS | Ref. | Ref. | Ref. | Ref. |
| Normal TAPSE + reduced RVFWLS | 2.243 (1.397-3.600) | **<0.001** | 1.755 (1.119-2.753) | **0.014** |
| Mildly reduced TAPSE | 1.816 (1.136-2.902) | **0.013** | 1.505 (1.003-2.259) | **0.048** |
| Moderate/severe reduced TAPSE + nonsevere reduced RVFWLS | 1.913 (1.149-3.186) | **0.013** | 1.677 (1.099-2.558) | **0.017** |
| Moderate/severe reduced TAPSE + severe reduced RVFWLS | 2.620 (1.643-4.179) | **<0.001** | 2.241 (1.459-3.443) | **<0.001** |

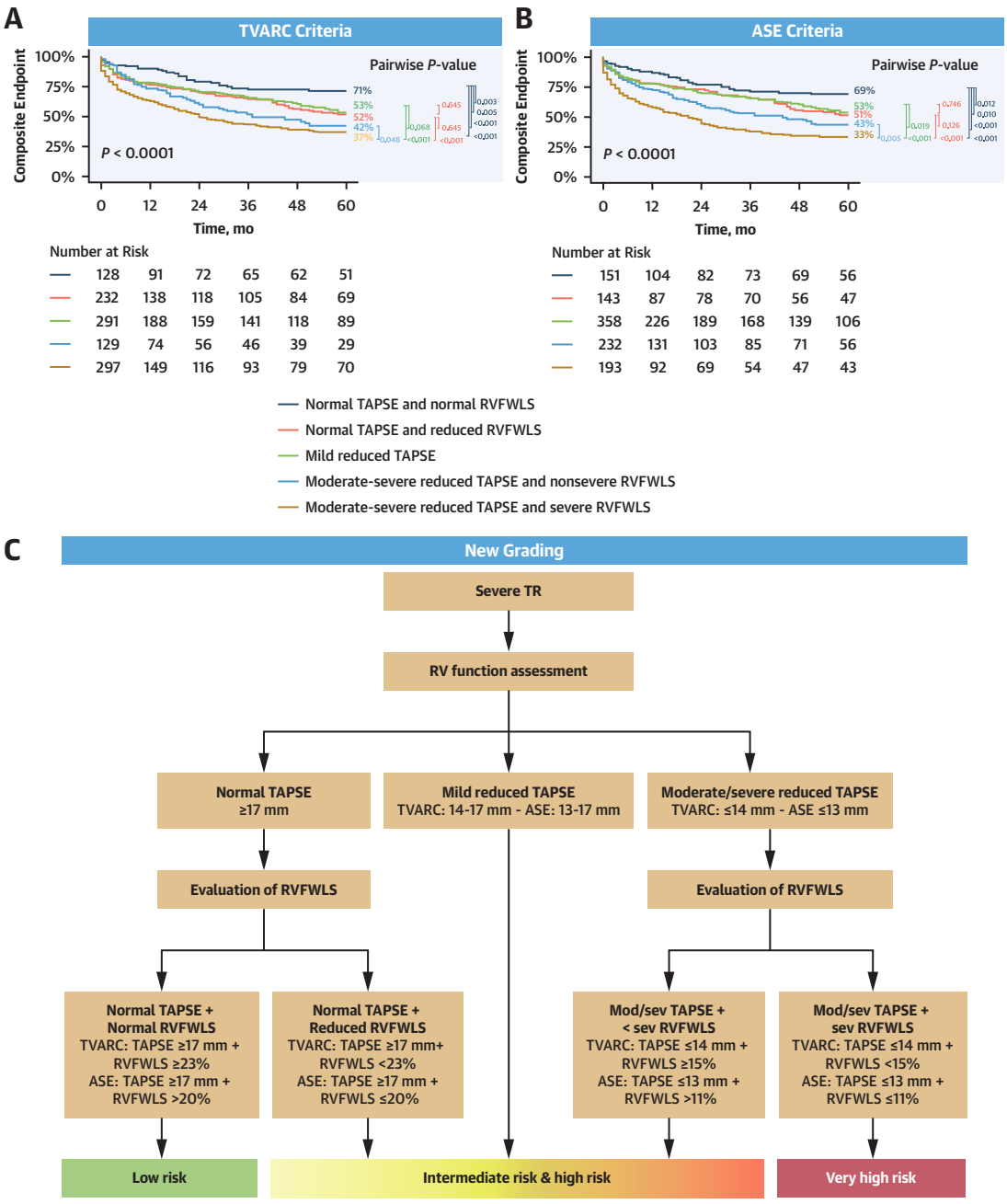
Baseline model: age, sex, body surface area (kg/m$^2$), presence of coronary artery disease, NYHA functional class III/IV, presence of a cardiac implantable electronic device, previous cardiac surgery, hemoglobin (g/dL), creatinine (μmol/L), left ventricular end-diastolic volume-indexed for BSA (mL/m$^2$), LVEF, left atrial maximum volume-indexed for BSA (mL/m$^2$), right ventricular end-diastolic area—indexed for BSA (cm$^2$/m$^2$), right atrial maximum area-indexed for BSA (cm$^2$/m$^2$), maximal TR pressure gradient (mm Hg), right atrial pressure, and STR etiology (atrial-STR vs ventricular-STR)[b]. **Bold** indicates statistically significant values of $P < 0.05$. [a]RVGLS and RVFWLS are expressed in absolute values. [b]Replacing the STR etiology classification (as described by Galloo et al[16]) by the end-systolic RA to RV ratio in baseline model of the multivariable Cox regression analysis, the combined grading of RV function remained independently associated with the composite endpoint.

BSA = body surface area; Ref. = Reference; TV = tricuspid valve; other abbreviations as in Tables 1 and 3.

pericardial distensibility.[10,11] Under physiological conditions, RV stroke volume is predominantly defined by its longitudinal contraction.[11] Therefore, TAPSE and S′, which both quantify longitudinal shortening and are simple and reproducible, are assumed to be some of the most reliable correlates of RV function. Longitudinal shortening measures, however, do not fully characterize RV function. In particular conditions (eg, post open-heart surgery), radial shortening compensates for reduced longitudinal motion (thus increasing RVFAC) with preservation of cardiac output.[23] Advanced echocardiographic parameters (RVGLS, RVFWLS, and 3D echocardiography-derived RVEF) may perform better than conventional measures in the assessment of RV function. However, 3D echocardiography-derived RVEF in particular remains underutilized in clinical practice, available and performed routinely in only 12% of European centers,[24] suggesting the need and preference for most echocardiogram laboratories to rely on conventional and strain parameters.

In patients with significant STR, RV function assessment is particularly challenging and may overestimate contractile performance because of regurgitant flow into a low-resistance chamber. Nevertheless, in patients with significant STR, TAPSE <17 mm was shown to be independently associated with all-cause mortality, regardless of the presence of RV dilatation.[25] Furthermore, Prihadi et al[26] showed in a large cohort of STR patients that TAPSE <17 mm and RVFAC <35% were associated with increased mortality, but RVFWLS <−23%

## CENTRAL ILLUSTRATION Proposed RV Function Grading in Significant STR




**Galloo X, et al. JACC Cardiovasc Imaging. 2026;19(11):1297-1310.**

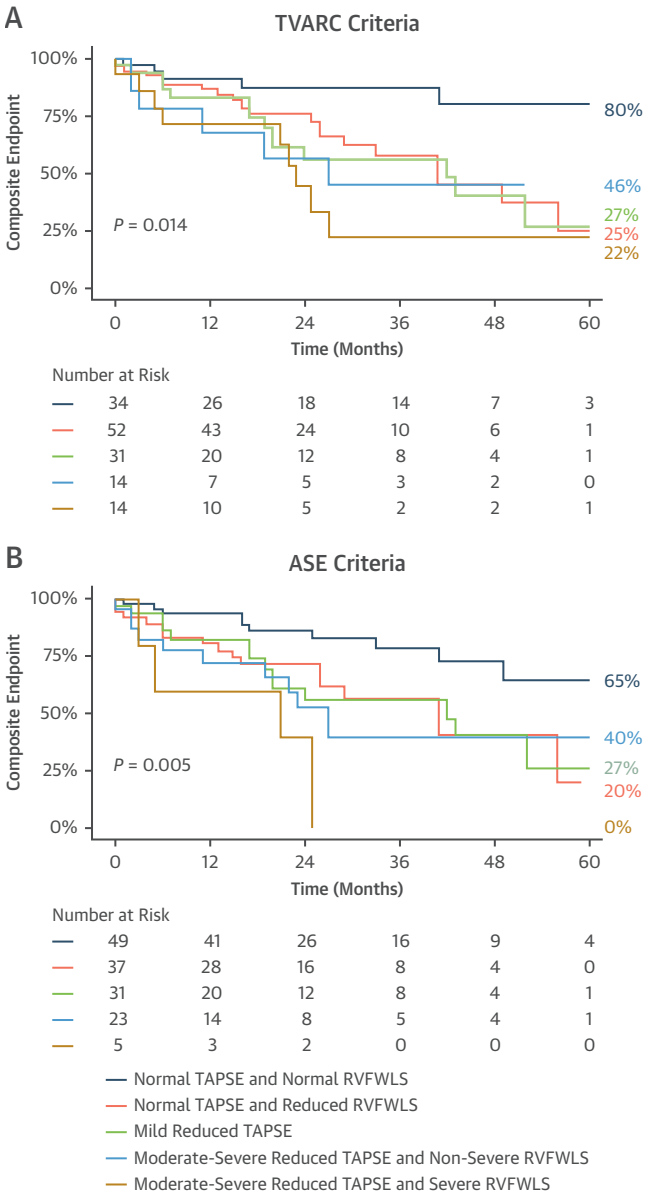
Kaplan-Meier analyses stratified by TVARC (Tricuspid Valve Academic Research Consortium) (A) and ASE (American Society of Echocardiography) (B) criteria showed lower event-free survival in patients with preserved tricuspid annular plane systolic excursion (TAPSE) but reduced right ventricular free wall longitudinal strain (RVFWLS), and the poorest outcomes in those with moderate-severely reduced TAPSE and severely reduced RVFWLS. These findings support the complementary role of TAPSE and RVFWLS in RV systolic assessment (C). RV = right ventricular; STR = secondary tricuspid regurgitation.

outperformed the predictive value of TAPSE and RVFAC. In another study, Ogawa et al[27] defined, with the use of receiver-operating characteristic curve analysis, the optimal cutoffs associated with all-cause death for RVFWLS and RVFAC as −18% and 35%, respectively. More recently, Zornitzki et al[28] showed that patients with significant TR experienced excess mortality at lower levels compared with patients without significant TR (TAPSE <18 mm vs <21.5 mm and S′ <10.0 cm/s vs <10.9 cm/s, respectively). The exact prognostic thresholds to be used for each of these echocardiographic parameters, therefore, remain unclear. Considering the only fair agreement between parameters observed (Supplemental Table 3), the findings of our study support a graded, multiparametric approach rather than reliance on a single cutoff for risk stratification. The 2025 ESC (European Society of Cardiology) guidelines on valvular heart disease are the first to introduce specific thresholds for defining RV dysfunction, suggesting that early RV decline should trigger an indication for intervention, whereas severe RV dysfunction may indicate limited benefit;[6,7] however, these cutoffs remain unvalidated and lack outcome-based evidence.[6] In addition, recent risk scores such as the TRI-SCORE, which has been specially developed to assess outcomes in patients undergoing isolated TVI, do not provide a clear indication of which parameters or cutoffs should be used to assess RV dysfunction, even though moderate/severe RV dysfunction is one of the criteria used to calculate the overall score.[29]

The recent TVARC and ASE recommendations have provided updated normative values for the echocardiographic assessment of RV function in patients with significant TR, and are the first to propose thresholds for different grades (mild, moderate, and severe, respectively) of RV dysfunction, to be used in future clinical trials (**Table 1**).[11,12] However, these proposed cutoffs are mainly based on multinational reports of normative data, and still require prognostic validation.[10] The TVARC and ASE thresholds are not identical, as the former were developed with an emphasis on patients with TR, whereas the latter are derived from a comprehensive review of large epidemiologic cohorts involving patients with pulmonary hypertension.[11,12] Because Zornitzki et al[28] showed that different cutoffs apply for patients with and without significant TR, these data may advocate for different normative data and severity grading thresholds for patients with different phenotypes. A personalized approach incorporating phenotype-specific thresholds may be appropriate; however, validation through future multicenter studies is required.

A key finding of the current study is that, although RV function parameters were overall associated with outcome in a large, real-world cohort of patients with significant STR, several of the currently

**FIGURE 4 Kaplan-Meier Curves for the Composite Endpoint for the Validation Cohort, Following TVARC and ASE Thresholds**




Kaplan-Meier curves for the composite endpoint, censored for tricuspid valve intervention, in the validation cohort using the TVARC (A) and ASE (B) criteria. Abbreviations as in **Figure 2**.

**TABLE 5 Univariable Cox Proportional Hazards Models for the Composite Endpoint, Censored for TV Intervention, for the Validation Cohort**

| | TVARC Criteria (n = 145) | | ASE Criteria (n = 145) | |
|---|---|---|---|---|
| | HR (95% CI) | *P* Value | HR (95% CI) | *P* Value |
| Combined grading | | **0.029** | | **0.011** |
| Normal TAPSE + normal RVFWLS | Ref. | Ref. | Ref. | Ref. |
| Normal TAPSE + reduced RVFWLS | 3.340 (1.255-8.889) | **0.016** | 2.591 (1.173-5.721) | **0.019** |
| Mildly reduced TAPSE | 3.859 (1.388-10.731) | **0.010** | 2.694 (1.195-6.071) | **0.017** |
| Moderate/severe reduced TAPSE + nonsevere reduced RVFWLS | 4.312 (1.309-14.200) | **0.016** | 3.064 (1.299-7.226) | **0.011** |
| Moderate/severe reduced TAPSE + severe reduced RVFWLS | 5.951 (1.987-17.820) | **0.001** | 7.072 (2.179-22.951) | **0.001** |

**Bold** indicates statistically significant values of $P < 0.05$.
Abbreviations as in Tables 1, 3, and 4.

recommended cutoffs showed limited ability to discriminate risk across the full spectrum of RV dysfunction severity. In particular, adjacent categories (mild vs moderate vs severe) were not consistently separated, with overlapping survival curves and nonsignificant pairwise comparisons for some parameters. This likely reflects the complex heterogeneity of STR phenotypes. Collectively, these results suggest that categorical grading based solely on single-parameter cutoffs may be insufficient for refined risk stratification and support a multiparametric approach to RV assessment in this setting.

**CLINICAL IMPLICATIONS OF THE MULTIPARAMETRIC GRADING STRATEGY.** Based on current study results, TAPSE may serve as a practical first-line screening parameter for identifying patients at high risk, considering that it is the most commonly used quantitative measurement for the evaluation of RV function according to a survey by the EACVI (91% of centers).[24] However, RVFWLS appears to provide complementary information beyond TAPSE and may support further differentiation of very-low-risk from low-risk patients, as well as high-risk from very-high-risk patients, within the proposed grading framework. Accordingly, we proposed a new combined grading strategy for routine clinical practice (**Central Illustration**), based on distinct and statistically significant 5-year Kaplan-Meier survival strata and their concordance with TRI-SCORE stratified 2-year outcomes (2-year survival decreased stepwise across risk strata and was similar between the TRI-SCORE cohort [83%, 74%, and 59% for low-/intermediate-/high-risk, respectively] and our cohort using TVARC criteria [79%, 70%, 60%, and 49% for low-/intermediate-/high-risk/very-high-risk, respectively] and ASE criteria [77%, 70%-73%, 59%, and 45% for low-/intermediate-/high-risk/very-high-risk, respectively]).[29] The combined grading classifies patients with normal TAPSE and normal RVFWLS as "low-risk," whereas patients with normal TAPSE and reduced RVFWLS represent an "intermediate-risk" group, similar to those with mildly reduced TAPSE. The former may suggest a watchful waiting strategy, whereas the latter reflects the presence of subclinical RV dysfunction for which a TVI could be beneficial at an earlier stage. This strategy may avoid that patients are referred too late to gain any meaningful benefit from TVI. The current study illustrates that patients with moderately to severely reduced TAPSE were already at a "high risk," with a comparable risk to the high-risk TRI-SCORE.[29] However, patients with moderately-severely reduced TAPSE and concomitantly severely reduced RVFWLS presented with an even worse prognosis and may be considered as "very high risk." Accordingly, TAPSE may serve as a practical screening marker for RV dysfunction, but is best interpreted within a multiparametric RV assessment that incorporates RVFWLS. This complements the recent ESC guidelines,[6] which, for the first time, propose thresholds for severe RV dysfunction to flag potentially nonbeneficial intervention. These proposed thresholds, however, require validation in cohorts undergoing surgical or transcatheter TVI.

**STUDY LIMITATIONS.** Limitations include the single-center retrospective design and potential selection bias. Some patients were excluded because image quality precluded comprehensive RV assessment, reflecting real-world challenges in significant TR. The TAPSE-RVFWLS grading may be influenced by the inherent limitations of TAPSE and by the dependence of RVFWLS on image quality, tracking feasibility, loading conditions, and temporal changes in acquisition protocols with less systematic RV-focused views in earlier studies. Furthermore, tissue Doppler

imaging and 3D echocardiography data were not systematically available; however, these parameters merit further investigation in future clinical trials. Additionally, strain values are potentially vendor-dependent, and RVFWLS remains load-sensitive. Although external validation strengthened the study, limited sample size and event rate constrained subgroup comparisons and multivariable modeling.

## CONCLUSIONS

In patients with significant STR, TVARC, and ASE RV dysfunction grades were associated with all-cause mortality or hospitalization for heart failure, although risk discrimination was inconsistent across grades. Particularly, combining TAPSE and RVFWLS may offer an exploratory, pragmatic approach to refine risk stratification of these patients with potential implications for timely decision-making for intervention.

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## PERSPECTIVES

**COMPETENCY IN MEDICAL KNOWLEDGE:** Accurate RV function assessment is essential in the management of significant STR. Because echocardiographic parameters show limited concordance, current guidelines recommend a multiparametric approach to assess RV function. Combining TAPSE with RVFWLS may help earlier detection of subclinical RV dysfunction, improve risk stratification, may guide timely referral for emerging TVI, and may also enable a more refined prognostic assessment among patients with moderate-to-severe RV dysfunction.

**TRANSLATIONAL OUTLOOK:** Prospective studies should validate TAPSE-RVFWLS grading, with attention to optimal image quality of the RV free wall, and assess how standardized RV strain acquisition can improve clinical decision-making.

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**KEY WORDS** ASE, right ventricular function, secondary tricuspid regurgitation, survival, tricuspid valve, TVARC

**APPENDIX** For supplemental tables and figures, please see the online version of this paper.