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ORIGINAL RESEARCH

Incremental Prognostic Value of Echocardiography Measures of Right Ventricular Systolic Function in Patients With Chronic Heart Failure

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BACKGROUND: Tricuspid annular plane systolic excursion (TAPSE), Doppler tissue imaging–derived tricuspid lateral annular systolic wave velocity (S′), and right ventricular fractional area change (RV-FAC) are the most widely used echocardiographic measures of right ventricular systolic function. This study aimed to compare the prognostic value of TAPSE, S′, and RV-FAC in a large cohort of patients with chronic heart failure.

METHODS: Consecutive outpatients with heart failure and left ventricular ejection fraction <50% on guideline-recommended therapies undergoing echocardiography were followed up for the end point of cardiac and all-cause death.

RESULTS: Among 1590 patients (71±12 years, 77% men, left ventricular ejection fraction 34%±9%), 202 (13%) died from cardiac causes during a median follow-up of 28 (interquartile range, 14–40) months. According to the recommended cut points for TAPSE (<17 mm), S′ (<9.5 cm/s), or RV-FAC (<35%), right ventricular systolic dysfunction was found in 37%, 40%, and 35% of patients, respectively, with 21%, 31%, and 33% of discordant cases comparing TAPSE versus S′, TAPSE versus RV-FAC, and S′ versus RV-FAC. Both TAPSE <17 mm and RV-FAC <35% were more accurate than S′ <9.5 cm/s in predicting the risk of cardiac death (P<0.001), and their combination showed incremental prognostic power (P<0.001). Adding S′ to the combination of TAPSE and RV-FAC did not provide further incremental value (P=0.145). Similar findings were obtained when all-cause death was considered as the end point.

CONCLUSIONS: In patients with chronic heart failure and left ventricular ejection fraction <50%, TAPSE, and RV-FAC are more accurate than S′ in predicting the risk of cardiac and all-cause death. Considering both RV-FAC and TAPSE provides incremental prognostic value.

Key Words: echocardiography ■ heart failure ■ outcome ■ right ventricle ■ RV-FAC ■ S′ ■ TAPSE

The evaluation of right ventricular (RV) systolic function is essential in heart failure (HF), in both the acute and chronic settings, regardless of HF pathogenesis. Indeed, the presence and severity of RV systolic dysfunction correlate with worse clinical status, increased neurohormonal activation and are strong predictors of outcomes in HF.[1–3]

Transthoracic echocardiography is a key tool for studying RV systolic function. As recommended by the latest intersociety guidelines,[4] a thorough evaluation of

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CLINICAL PERSPECTIVE

What Is New?

- In patients with chronic heart failure and left ventricular ejection fraction <50%, right ventricular systolic dysfunction was discordant in up to 33% of cases considering tricuspid annulus plane systolic excursion, S′, or right ventricular fractional area change and tricuspid annulus plane systolic excursion and right ventricular fractional area change outperformed S′ in prognostic accuracy.

What Are the Clinical Implications?

- While reporting S′ may be redundant, tricuspid annulus plane systolic excursion and right ventricular fractional area change should be routinely reported to optimize risk stratification in patients with heart failure.

Nonstandard Abbreviations and Acronyms

RV-FAC	right ventricular fractional area change
S′	systolic wave velocity
TAPSE	tricuspid annulus plane systolic excursion

RV function should include both qualitative visualization and quantitative measures. Among these, tricuspid annulus plane systolic excursion (TAPSE),[5] tissue Doppler imaging of the RV basal free lateral wall (systolic wave velocity [S′]),[6] and RV fractional area change (RV-FAC) are the most commonly used parameters.[7] These RV function parameters provide distinct insights into RV contractility. TAPSE and S′ primarily assess longitudinal contraction, which may not capture regional contraction defects or conditions where decreased longitudinal function does not equate to overall impairment (eg, after pericardiotomy). TAPSE is more preload dependent, while S′ is angle dependent and less accurate under increased ventricular pressures.[5–7] In contrast, RV-FAC assesses both longitudinal and radial components, offering a comprehensive view of global RV function. However, it is more influenced by image quality and has higher interobserver variability.[5–7]

While the assessment of the RV free-wall strain represents an emerging tool with prognostic value,[8] its practical use is still limited, as confirmed by a recent international survey.[9] Similarly, although 3-dimensional echocardiography could enhance RV function assessment, its clinical application is restricted due to the need for advanced equipment and specialized training.[10,11] On the other hand, due to the complex morphology of the RV, cardiac magnetic resonance is currently considered the gold standard for evaluating RV contractility.[12] However, cardiac magnetic resonance is limited by its availability, high costs, and unsuitability for unstable patients. Therefore, echocardiography, with its greater accessibility, shorter test duration, and cost effectiveness, is the preferred choice in routine clinical practice, particularly for outpatient monitoring and bedside examinations.

Consequently, TAPSE, S′, and RV-FAC remain the most commonly used parameters for assessing RV systolic function in daily practice. Although numerous studies have demonstrated that TAPSE,[13,14] S′,[15] and RV-FAC[16] are predictive of outcomes in patients with HF, comparative studies are scarce, and the incremental value of these measures remains uncertain. Therefore, this study aims to evaluate and compare the prognostic significance of TAPSE, S′, and RV-FAC in a large cohort of patients with chronic HF and left ventricular (LV) systolic dysfunction.

METHODS

The data from this study are available upon reasonable request.

Subjects and Study Design

Consecutive outpatients referred to the echocardiographic laboratory of Fondazione Monasterio (Pisa, Italy) from April 2015 until April 2021 were evaluated. If a patient had undergone multiple exams, only the first evaluation was considered for this study. Given the potential bias in the retrospective selection of patients with HF and preserved LVEF (≥50%), whose diagnostic criteria have changed over time,[17–19] only patients with a clinical diagnosis of HF with either reduced (≤40%) or mildly reduced LVEF (41%–49%) were included. Only patients aged ≥18 years and able to provide consent were included. Considering the potential dynamic changes in RV function metrics, only stable outpatients (ie, those not requiring pharmacological/mechanical circulatory support or intravenous diuretics at the time of examination) were included. Other exclusion criteria included poor acoustic windows, uncorrected shunts, severe degenerative valve disease, or a history of tricuspid valve intervention, and any cardiac interventions (including percutaneous and surgical coronary revascularization, valve intervention, and device implantation) within 6 months before baseline examination.

Clinical features and laboratory parameters including N-terminal pro-B-type natriuretic peptidelevels, hemoglobin, and estimated glomerular filtration rate (calculated through the Chronic Kidney Disease

Epidemiology Collaboration formula) at the time of the examination were retrieved for each patient.

The protocol was approved by the Institutional Review Board of Fondazione Monasterio, and all patients permitted their anonymized data to be used for research purposes, in accordance with privacy regulations.

Transthoracic Echocardiography

Echocardiographic examinations included in this study were performed using commercially available ultrasound systems (iE33 or EPIQ7; Philips, Amsterdam, Netherlands). All procedures were conducted by experienced cardiologists (V.C. and A.G.) or certified sonographers (C.T. and E.P.), with subsequent review by expert cardiologists to ensure accuracy. Image acquisition and measurements adhered to a standardized protocol, following the recommendations of intersociety guidelines.[4] For this study, only measurements recorded during routine clinical evaluations were considered. Consequently, interobserver variability could not be assessed, since retrospective remeasurements were not performed.

Regarding RV function,[4,20] all measures were obtained from an optimized RV-focused 4-chamber view (Figure 1). TAPSE (mm) was measured as the RV lateral annular segment systolic displacement on the M-mode trace. S′ (cm/s) was measured as the peak systolic velocity of the RV lateral annular segment obtained using tissue Doppler imaging integrated with pulsed-wave Doppler. RV-FAC (%) was calculated through the formula 100×(RV end-diastolic area−RV end-systolic area)/RV end-diastolic area. As stated in the guidelines,[4] the RV area included moderator band, trabeculae, and papillary muscles.

The assessment of the tricuspid regurgitation jet at its maximum velocity was used to assess systolic pulmonary artery pressure through the modified Bernoulli's formula, by adding the estimated right atrial pressure, derived from inferior vena cava dimensions and collapsibility.[4]

Follow-Up and End Points

Patient follow-up was concluded in April 2023. Mortality data were confirmed through telephone interviews with patients, caregivers, or general practitioners and cross-referenced with computerized medical records. The end point of the study was cardiac death (ie, death attributed to myocardial infarction, sudden cardiac death, or HF progression). All-cause death was a secondary end point.

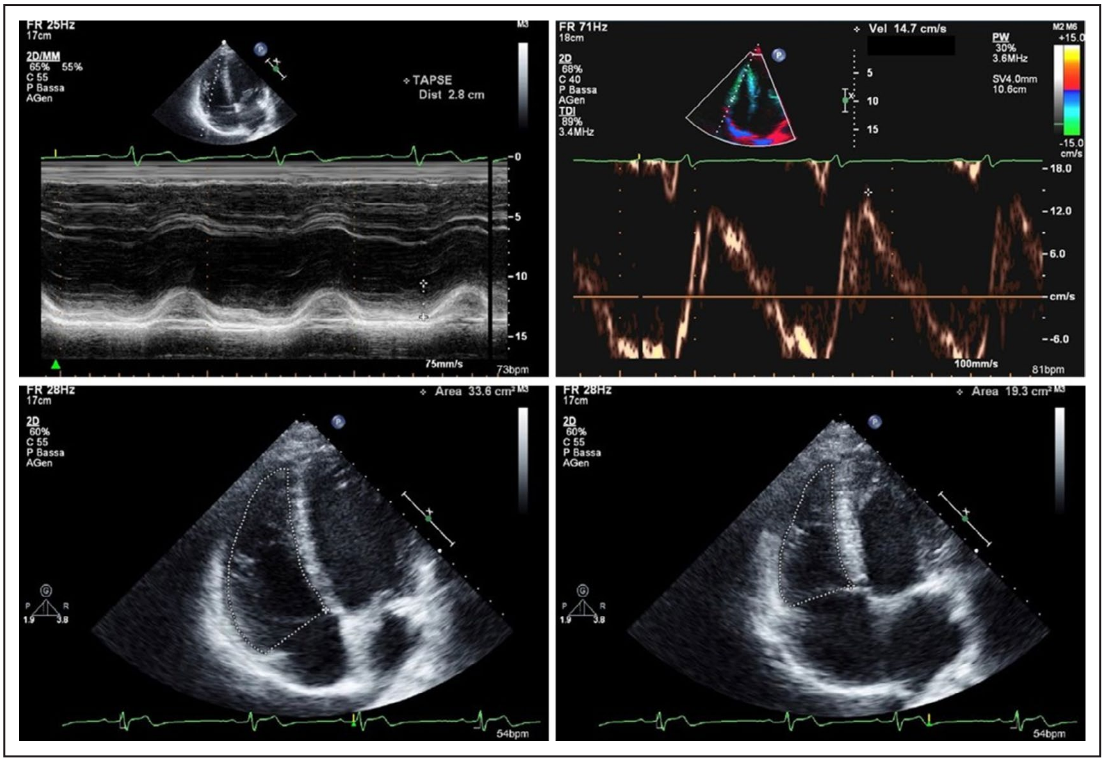

Figure 1. Echocardiography assessment of right ventricular systolic function.
Assessment of TAPSE (top left panel), S′ (top right panel), and RV-FAC (low panels) in a sample patient with chronic heart failure and reduced ejection fraction. RV-FAC indicates right ventricular fractional area change; S′, systolic wave velocity; and TAPSE, tricuspid annulus plane systolic excursion.

Statistical Analysis

For statistical analysis, R software version 3.4.0 (R Foundation for Statistical Computing, Vienna, Austria) and SPSS version 25.0 (IBM Statistics, Armonk, NY) were used. A significant 2-tailed *P* value was defined as ≤0.05.

Quantitative data were presented as mean±SD or median (interquartile range), depending on the distribution, while qualitative data were presented as numbers and percentages. The study population was divided into subgroups based on the occurrence of the primary end point (ie, cardiac death). Accordingly, baseline characteristics were compared using the χ^2 test for categorical variables and either Student's *t* test or the Mann–Whitney *U* test for continuous variables, as appropriate. Pearson's correlations between TAPSE, S′, and RV-FAC were calculated and graphically represented with scatter plots. The relation between TAPSE, S′, and RV-FAC and the risk of cardiac death was represented through the P-spline smoothing method and Kaplan–Meier curves. For each Kaplan–Meier curve, the χ^2 test statistic derived from the log-rank test was reported alongside the corresponding *P* value. This value, calculated by summing the individual χ^2 contributions at each event time, reflects the overall comparison of the survival distributions between groups. The Cox proportional hazards regression model was used to identify univariable and multivariable predictors of cardiac death. The proportional hazards assumption was verified for all the models using scaled Schoenfeld residuals. TAPSE, S′, and RV-FAC were included in separate models. Nonnormally distributed variables were log-transformed (natural logarithm) before regression, and only significant ($P\le0.05$) univariable predictors were included in multivariable models. Considering the potential influence of cardiac pacing or of a history of cardiac surgery on the measures of RV systolic function, a sensitivity analysis for the primary end point was performed in these subsets. While clinical and echocardiographic data were available for all patients, missing biohumoral data for 240 patients (14.8%) were imputed using the series mean imputation method before being entered into the regression models.

The predictive accuracy of each individual measure and their combinations was assessed by likelihood ratio tests to evaluate changes in χ^2 values. Initially, the χ^2 statistic was calculated for each individual predictor (eg, TAPSE, S′, or RV-FAC). Subsequently, the predictive performance of combinations of 2 predictors was evaluated, followed by the combination of all 3 variables. Changes in χ^2 values were compared across models to evaluate incremental improvement in risk prediction with additional variables.

RESULTS

The study population was composed of 1590 patients (aged 71±12 years, 77% men, 48% with ischemic pathogenesis). One third of patients had atrial fibrillation, and approximately one third had New York Heart Association functional class III/IV. Most patients were on optimal medical and device therapy, according to guidelines at the time of enrollment (Table 1). As per entry criteria, LVEF was reduced (34%±9%). Mean values of TAPSE, S′, and RV-FAC were, respectively, 18±5 mm, 10±3 cm/s, and 38%±8%.

Using the recommended cut points for TAPSE (<17 mm), S′ (<9.5 cm/s), and RV-FAC (<35%), RV systolic function was impaired in 37%, 40%, and 35% of patients, respectively. As shown in Figure 2, all measures were correlated with each other (all $P<0.001$). However, the definition of RV dysfunction was discordant in 21%, 31%, and 33% of the cases considering TAPSE versus S′, TAPSE versus RV-FAC, and S′ versus RV-FAC, respectively.

During the follow-up period, 333 patients died, 202 of cardiac causes. The patients meeting the end point of cardiac death were older and had higher New York Heart Association class, worse renal function, and higher N-terminal pro-B-type natriuretic peptide levels (Table 1). At echocardiography, they had more enlarged cardiac chambers, worse LV and RV systolic function, diastolic dysfunction, and severe mitral and tricuspid regurgitation (Table 2).

Per-unit reductions in TAPSE, S′, and RV-FAC were all associated with an increase in the risk of cardiac death (Figure 3). After dichotomization using standard cut points, the presence of a TAPSE <17 mm, S′ <9.5 cm/s, and RV-FAC <35% were again associated with a greater risk of cardiac death at Kaplan–Meier analysis (Figure 3).

The univariable predictors of cardiac and all-cause death are reported in Table S1. At multivariable regression analysis, adjusted for clinical, biohumoral, and echocardiographic confounders, TAPSE, S′, and RV-FAC were independent predictors of cardiac (Table 3) and all-cause death (Table S2). The independent prognostic value of TAPSE, S′, and RV-FAC remained significant in patients with spontaneous rhythm or biventricular pacing but not in those with RV pacing (Table S3). Additionally, a history of cardiac surgery (n=288) did not affect the independent prognostic value of TAPSE, S′, and RV-FAC (Table S4).

As reported in Figure 4, each of TAPSE <17 mm and RV-FAC <35% was more accurate than S′ <9.5 cm/s in predicting the risk of cardiac death (χ^2 Δ for TAPSE or RV-FAC versus S′=15, $P<0.001$). Notably, the combination of TAPSE and RV-FAC provided incremental prognostic power (χ^2 Δ for TAPSE+RV-FAC versus TAPSE

Table 1. Characteristics of the Study Population According to the End Point of Cardiac Death

Variables	All patients (n=1590)	No cardiac death at follow-up (n=1388, 87%)	Cardiac death at follow-up (n=202, 13%)	*P* value
Clinical features				
Age, y	71±12	70±12	76±11	<0.001*
Men, n (%)	1244 (77)	1089 (77)	155 (81)	0.164
Body mass index, kg/m^2	27±5	27±5	26±4	0.095
Ischemic pathogenesis, n (%)	776 (48)	665 (47)	111 (50)	0.5
New York Heart Association III–IV, n (%)	533 (33)	410 (29)	123 (59)	<0.001*
Atrial fibrillation, n (%)	533 (33)	452 (32)	81 (38)	0.1
Hypertension, n (%)	776 (48)	679 (48)	97 (47)	0.76
Diabetes, n (%)	436 (27)	368 (26)	68 (32)	0.087
COPD, n (%)	226 (14)	184 (13)	42 (18)	0.08
Biohumoral data				
Hemoglobin, g/dL	13±2	13±2	12±2	<0.001*
Estimated glomerular filtration rate, mL/min per 1.73 m^2	66 (47–84)	69 (51–86)	44 (32–63)	<0.001*
N-terminal pro-B-type natriuretic peptide, ng/L	1840 (714–4585)	1555 (626–3698)	5723 (2921–14 042)	<0.001*
Treatment				
β Blockers, n (%)	1438 (89)	1287 (91)	151 (79)	0.011*
ACEi/ARB, n (%)	1066 (66)	962 (68)	104 (52)	<0.001*
ARNI, n (%)	194 (12)	184 (13)	10 (5)	0.006*
MRA, n (%)	1050 (65)	933 (66)	117 (59)	0.582
Furosemide, n (%)	1083 (67)	919 (65)	164 (81)	<0.001*
ICD, n (%)	517 (32)	438 (31)	79 (38)	0.051
CRT, n (%)	404 (25)	339 (24)	65 (34)	0.001*

Values are mean±SD, median (interquartile range), or n (%). ACEi indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; ARNI, angiotensin receptor–neprilysin inhibitor; COPD, chronic obstructive pulmonary disease; CRT, cardiac resynchronization therapy; ICD, implantable cardioverter-defibrillator; and MRA, mineralocorticoid receptor antagonist.

*Statistically significant.

or RV-FAC=25, *P*<0.001), as confirmed with Kaplan–Meier curves (Figure 5). On the contrary, no further significant incremental value was observed by adding S′ to TAPSE and RV-FAC (χ^2 Δ 3, *P*=0.145). Similar findings were obtained when considering all-cause death as the end point (Figure S1).

DISCUSSION

In this study, the prognostic significance of the most commonly used echocardiography measures of RV systolic function (namely, TAPSE, S′, and RV-FAC) was compared in a large cohort of patients with chronic HF and LVEF <50% on guideline-recommended therapies. While these measures were correlated, the definition of RV systolic dysfunction was discordant in up to 33% of cases. Importantly, all 3 parameters independently predicted cardiac and all-cause death. Notably, TAPSE and RV-FAC outperformed S′ in prognostic accuracy, and their combination further enhanced risk prediction, whereas adding S′ to TAPSE and RV-FAC did not provide additional value.

While no prior studies have evaluated the incremental predictive value of these measures in patients with either HF with reduced ejection fraction or HF with mildly reduced ejection fraction, these findings have important practical implications: (1) Reporting S′ may be redundant when TAPSE and RV-FAC are available, due to its relatively lower prognostic value; and (2) TAPSE and RV-FAC should be routinely reported to optimize risk stratification in HF patients.

Although cardiac magnetic resonance is the gold standard for assessing RV systolic function, echocardiography remains the first-line tool due to its widespread availability, lower costs, and feasibility.[20] Emerging modalities, such as strain analysis and 3-dimensional imaging, offer promising advancements,[10,11,21] but their use is limited by the need for advanced instrumentations, specialized software, and dedicated training. Thus, TAPSE, S′, and RV-FAC remain the primary measures in routine clinical practice.[4] Among these, TAPSE

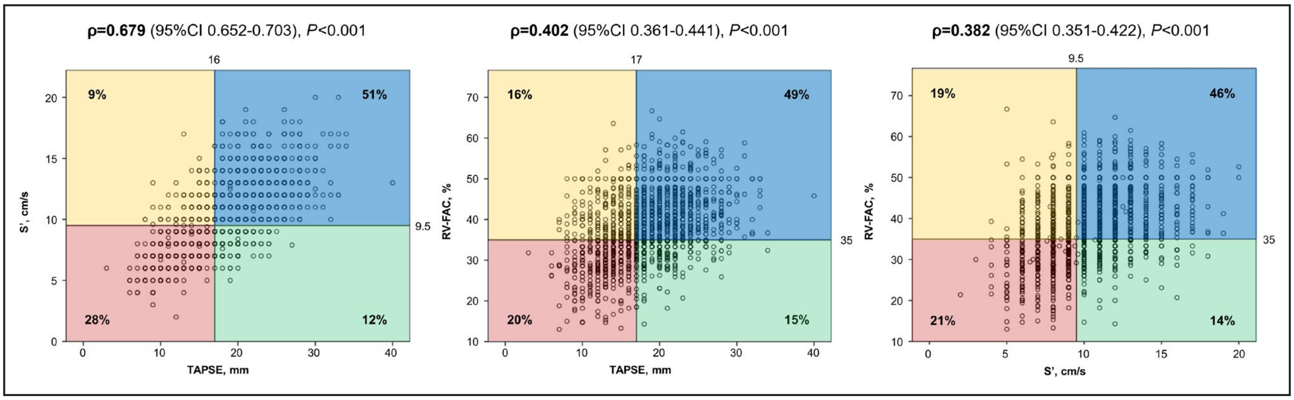

Figure 2. Correlation among the different measures of RV systolic function.
The different measures of RV systolic function were correlated with each other. However, discordance in classifying RV systolic dysfunction was observed in up to 33% of patients when using the recommended cut points: TAPSE (<17 mm), S′ (<9.5 cm/s), or RV-FAC (<35%). This discordance occurs when 1 measure classifies a patient as having RV dysfunction, while another measure classifies the same patient as normal. For example, a patient with a dilated RV may have preserved TAPSE (≥17 mm) but reduced RV-FAC (<35%). Conversely, a patient with a history of cardiac surgery may have reduced TAPSE (<17 mm) but preserved RV-FAC (≥35%). Red boxes indicate patients with "concordant" RV systolic dysfunction; blue boxes indicate patients with "concordant" normal RV systolic function; yellow and green boxes represent patients with "discordant" RV systolic function. RV indicates right ventricular; RV-FAC, right ventricular fractional area change; S′, systolic wave velocity; and TAPSE, tricuspid annulus plane systolic excursion.

and S′ are more reproducible than RV-FAC: among 40 individuals with varying degrees of RV function, the interobserver variabilities for TAPSE, S′, and RV-FAC were 11%, 8%, and 30%, respectively.[7] However, reflecting global rather than longitudinal RV contractility, RV-FAC correlates more strongly with cardiac magnetic resonance–derived RV ejection fraction.[22]

Given these premises, it is unsurprising that the diagnosis of RV systolic dysfunction may vary across patients when using these different measures. In our

Table 2. Echocardiographic Data of the Study Population According to the End Point of Cardiac Death

Variables	All patients (n=1590)	No cardiac death at follow-up (n=1388, 87%)	Cardiac death at follow-up (n=202, 13%)	*P* value
LAVi, mL/m²	44±15	43±14	51±20	<0.001*
Severe mitral regurgitation, n (%)	356 (22)	269 (19)	87 (43)	<0.001*
E wave, cm/s	92±36	90±36	104±40	<0.001*
E/e′ average	15±8	14±7	19±10	<0.001*
LVEDDi, mm/m²	31±5	31±5	32±5	0.408
LVESDi, mm/m²	26±5	26±5	27±6	0.048*
LVEDVi, mL/m²	96±28	95±27	99±36	0.49
LVESVi, mL/m²	65±26	64±24	70±32	0.02*
LVEF, %	34±9	35±8	31±9	<0.001*
RVOTd, mm	28 (26–31)	28 (26–30)	29 (27–32)	<0.001*
TAPSE, mm	18±5	19±5	16±5	<0.001*
S′, cm/s	10±3	10±3	9±3	<0.001*
RVDA, cm²	22 (18–25)	22 (18–25)	24 (20–28)	<0.001*
RVSA, cm²	13 (10–16)	13 (10–16)	15 (13–19)	<0.001*
RV-FAC, %	38±8	39±8	34±7	<0.001*
Severe tricuspid regurgitation, %	178 (11)	127 (9)	51 (23)	<0.001*
Systolic pulmonary artery pressure, mm Hg	41 (34–49)	40 (33–48)	48 (40–56)	<0.001*

Values are mean±SD, median (interquartile interval), or n (%). LAVi indicates left atrial volume/body surface area; LVEDDi, left ventricular end-diastolic diameter/body surface area; LVEDVi, left ventricular end-diastolic volume/body surface area; LVEF, left ventricular ejection fraction; LVESDi, left ventricular end-systolic diameter/body surface area; LVESVi, left ventricular end-systolic volume/body surface area; RV-FAC, right ventricular fractional area change; RVDA, right ventricular diastolic area; RVSA, right ventricular systolic area; RVOTd, right ventricular outflow tract diameter; S′, systolic wave velocity; and TAPSE, tricuspid annulus plane systolic excursion.

*Statistically significant.

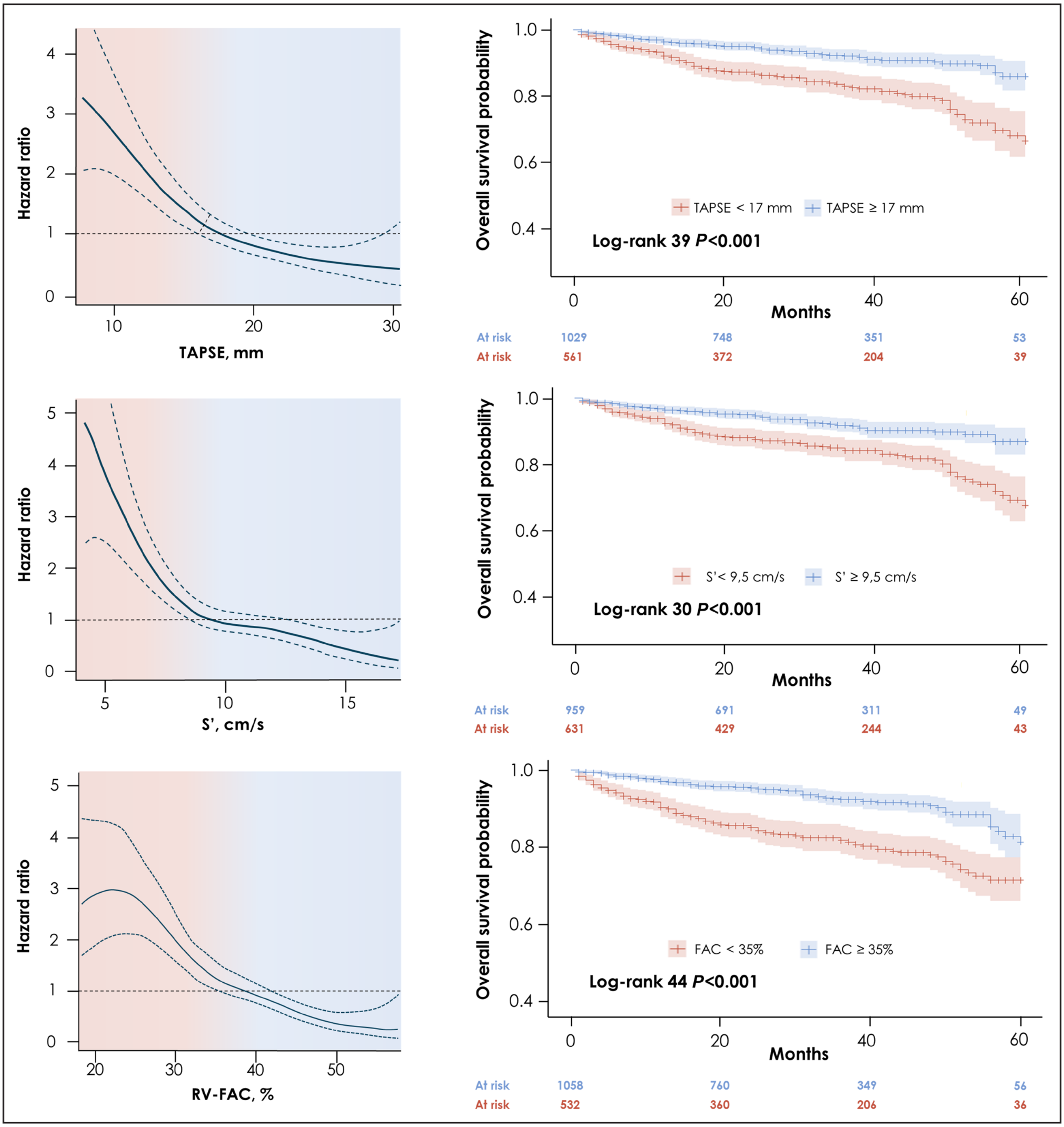

Figure 3. Right ventricular systolic function measures and risk of cardiac death.
Reduced TAPSE, S′, and RV-FAC were associated with a higher risk of cardiac death. The spline curves (left) show the event-risk change with the decrease of each measure, with the dashed lines representing the upper and lower limits of 95% confidence interval. The Kaplan–Meier curves (right) demonstrate the prognostic value of the cut points proposed by guidelines for each measure. Compared with patients with values above these cut points, the incidence of cardiac death was 13%, 11%, and 14% higher for patients with TAPSE <17 mm, S′ <9.5 cm/s, and RV-FAC <35%, respectively. RV-FAC indicates right ventricular fractional area change; S′, systolic wave velocity; and TAPSE, tricuspid annulus plane systolic excursion.

cohort, RV systolic dysfunction was identified in 37%, 40%, and 35% of patients using TAPSE, S′, and RV-FAC <35%, respectively, with inconsistency in up to 33% of cases. These discrepancies reflect the unique strengths and limitations of each parameter.[23] TAPSE and S′ are more reliable in patients with poor acoustic window,[7] but are more sensitive to conditions affecting longitudinal contraction, such as prior cardiac surgery[24]

Table 3. Multivariable Cox Regression Analysis for the End Point of Cardiac Death

Predictors	Multivariable model 1			Multivariable model 2			Multivariable model 3		
	HR	95% CI	*P* value	HR	95% CI	*P* value	HR	95% CI	*P* value
Age, y	1.04	1.02–1.05	<0.001*	1.03	1.02–1.05	<0.001*	1.04	1.02–1.05	<0.001*
Body mass index, kg/m^2	0.99	0.96–1.03	0.821	0.99	0.95–1.03	0.614	0.99	0.95–1.03	0.634
New York Heart Association class III–IV	1.51	1.09–2.10	0.013*	1.59	1.15–2.21	0.005*	1.93	1.35–2.76	<0.001*
Atrial fibrillation	0.89	0.64–1.25	0.613	1.01	0.73–1.41	0.938	0.97	0.68–1.39	0.887
Hemoglobin, g/dL	0.99	0.91–1.08	0.803	0.98	0.90–1.07	0.682	0.99	0.91–1.09	0.975
Ln (estimated glomerular filtration rate)	0.57	0.42–0.78	<0.001*	0.59	0.44–0.81	<0.001*	0.59	0.42–0.82	0.001*
Ln (N-terminal pro-B-type natriuretic peptide)	1.36	1.14–1.61	<0.001*	1.38	1.17–1.64	<0.001*	1.35	1.12–1.63	0.001*
LAVi, mL/m^2	1.01	1.01–1.02	0.002*	1.01	1.00–1.02	0.004*	1.01	0.99–1.02	0.131
Severe mitral regurgitation	1.22	0.87–1.70	0.247	1.20	0.86–1.68	0.274	1.52	1.07–2.17	0.019*
E/e′ average	1.01	0.99–1.03	0.237	1.02	0.99–1.03	0.108	1.01	0.99–1.03	0.099
LVEF, %	1.00	0.98–1.02	0.803	0.99	0.98–1.02	0.954	0.98	0.98–1.02	0.563
Severe tricuspid regurgitation	1.00	0.69–1.46	0.984	1.08	0.74–1.57	0.695	0.99	0.65–1.46	0.914
Systolic pulmonary artery pressure, mm Hg	1.00	0.99–1.02	0.944	0.99	0.98–1.02	0.904	0.96	0.97–1.00	0.129
TAPSE, mm	0.93	0.89–0.96	<0.001*	…	…	…	…	…	…
S′, cm/s	…	…	…	0.93	0.87–0.98	0.020*	…	…	…
RV-FAC, %	…	…	…	…	…	…	0.96	0.94–0.98	0.002*

Gray shades represent the 3 different measures of right ventricular systolic function (TAPSE, S′, and RV-FAC), each included in only 1 of the 3 different multivariable models. LAVi, left atrial volume/body surface area; LVEF, left ventricular ejection fraction; RV-FAC, right ventricular fractional area change; S′, systolic wave velocity; and TAPSE, tricuspid annular plane systolic excursion.

*Statistically significant.

or RV pacing.[25] Conversely, RV-FAC, although more comprehensive, is more sensitive to image quality and may underestimate RV performance at larger ventricular volumes.[25–27] These findings align with those of a previous study in 200 HF with reduced ejection fraction patients with preserved TAPSE (>16 mm), in which RV dysfunction was identified using RV-FAC, with a median value of 39% (28%–47%).[28]

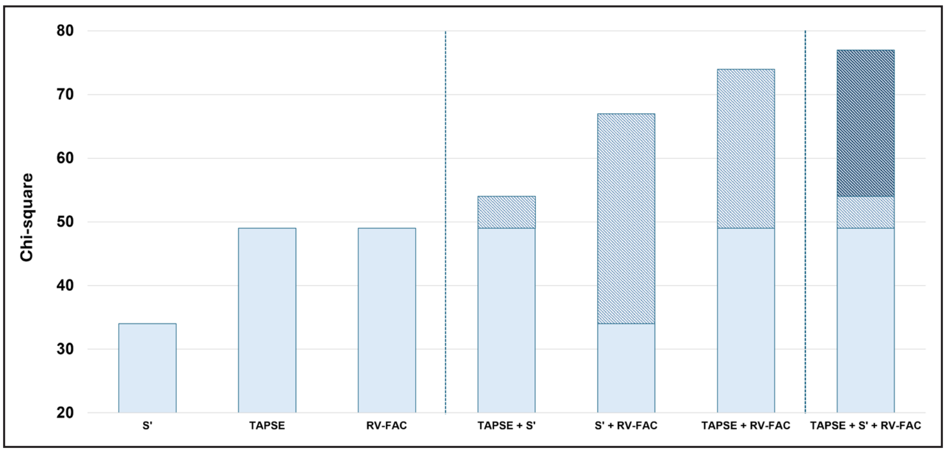

Figure 4. Accuracy in predicting the risk of cardiac death of TAPSE, S′, RV-FAC, and their combination.

While taken alone, TAPSE and RV-FAC were more accurate than S′ in predicting the risk of cardiac death (χ^2 Δ for TAPSE or RV-FAC vs S′=15, both *P*<0.001), their combination provided incremental prognostic power (χ^2 Δ for TAPSE+RV-FAC vs TAPSE or RV-FAC=25, both *P*<0.001). No further significant incremental value was observed by adding S′ to the combination of TAPSE and RV-FAC (χ^2 Δ 3, *P*=0.145). RV-FAC indicates right ventricular fractional area change; S′, systolic wave velocity; and TAPSE, tricuspid annulus plane systolic excursion.

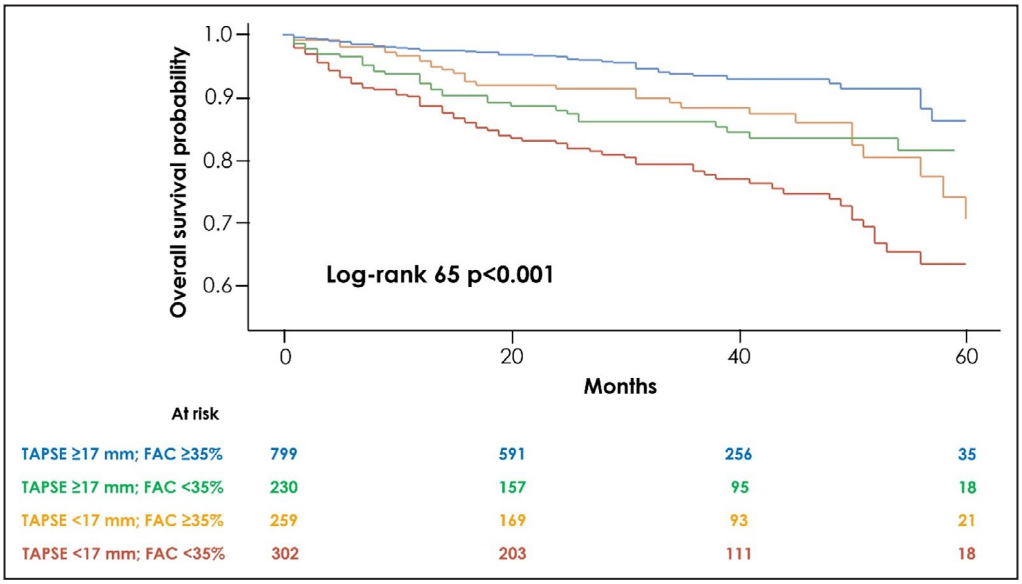

Figure 5. Incremental prognostic value of TAPSE and RV-FAC.
While either reduced TAPSE or RV-FAC was associated with lower event-free survival, the risk of cardiac death was greater when both measures were reduced. RV-FAC indicates right ventricular fractional area change; and TAPSE, tricuspid annulus plane systolic excursion.

The prognostic value of TAPSE, S′, and RV-FAC has been consistently demonstrated in various clinical contexts, including acute and chronic HF, ischemic and nonischemic cardiomyopathies, pulmonary embolism, and pulmonary hypertension.[25,29–31] Similarly, in our study, all 3 measures were strong predictors of cardiac and all-cause death independent of clinical, biohumoral, and echocardiographic variables.

Notably, each of RV-FAC and TAPSE was more accurate than S′ in predicting outcomes, and their combination yielded significant improvement in risk prediction. This incremental prognostic value may stem from the complementary information provided by TAPSE and RV-FAC.[24–28] Conversely, the relatively lower performance of S′ may be attributed to its reliance on single-point peak velocity measurements, which are less representative of overall RV contractility, particularly in cases of abnormal RV contraction mechanics.[32–34]

These results underscore the importance of tailored assessment strategies. Although echocardiography measures may be less accurate in patients with severe tricuspid regurgitation or a history of cardiac surgery,[24,35] the independent prognostic value of TAPSE, S′, and RV-FAC remained robust in this study. Conversely, their diminished prognostic value in patients with RV pacing highlights the need for advanced techniques to accurately assess RV function in this subset.[36]

Overall, all measures of RV systolic dysfunction demonstrated independent prognostic value in patients with chronic HF, consistent with prior literature. Importantly, this analysis provides new evidence that combining TAPSE and RV-FAC significantly enhances risk prediction accuracy. While the observational design limits direct clinical recommendations, our findings underscore the potential utility of identifying patients with both reduced TAPSE and RV-FAC as a particularly high-risk subgroup. For these patients, closer monitoring and proactive management strategies could be essential to preempt clinical deterioration. Future prospective research should focus on integrating these measures into risk stratification models and assessing their role in guiding advanced HF therapies, including device-based or pharmacological interventions.

Limitations

This study was conducted at a tertiary care center in Italy, which may limit generalizability to broader HF populations. Since most patients already had a diagnosis of HF, the clinical value of TAPSE, S′, and RV-FAC in newly diagnosed HF remains to be compared.

Excluding patients with HF with preserved ejection fraction is a limitation. However, including patients with LVEF ≥50% could have introduced bias, given the evolving definitions and heterogeneity of this population. HF with preserved ejection fraction encompasses a broad spectrum of conditions with distinct pathophysiological characteristics and treatments, which could affect the assessment of RV systolic function.[18] Future studies are warranted to evaluate TAPSE, S′, and RV-FAC in these specific populations. Similarly, since no patients with LV assist devices were included, the prognostic value of these measures remains to be explored in this subgroup.

The cross-sectional and retrospective design of this study limited the assessment of longitudinal changes in TAPSE, S′, and RV-FAC, which should be investigated in future prospective studies, particularly in response to pharmacological or interventional HF treatments. Moreover, detailed data on clinical signs of RV dysfunction (eg, ascites and peripheral edema) were unavailable in this retrospective cohort. Future research should investigate correlations between these clinical signs and echocardiographic measures of RV systolic function.

Finally, RV free-wall strain and 3-dimensional RV ejection fraction were not assessed due to limited availability. The incremental value of integrating these advanced measures with TAPSE, S′, and RV-FAC remains to be determined.

CONCLUSIONS

In a large cohort of patients with chronic HF and LVEF <50% on guideline-recommended therapies, RV systolic dysfunction was identified in 37%, 40%, and 35% of patients on the basis of TAPSE, S′, and RV-FAC, respectively. However, the diagnosis of RV systolic dysfunction was discordant in up to 33% of cases, emphasizing the need for a comprehensive approach. TAPSE and RV-FAC demonstrated superior prognostic accuracy compared with S′, and their combination significantly improved risk prediction. These findings highlight the clinical value of routine acquisition and reporting of both TAPSE and RV-FAC to refine risk stratification and identify high-risk subgroups. Patients with combined reductions in TAPSE and RV-FAC may benefit from closer monitoring and proactive management. Future prospective studies are needed to validate these findings and further explore their integration into clinical decision making for advanced HF therapies.

ARTICLE INFORMATION

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Supplemental Material

Tables S1–S4
Figure S1

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