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Original Research Article

Functional assessment of the right atrium in patients with heart failure with reduced ejection fraction and its association with six-month clinical outcomes: a prospective observational study

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ABSTRACT

Background: Right-sided cardiac remodeling has important prognostic implications in heart failure with reduced ejection fraction (HFrEF). Right atrial volume and myocardial deformation assessed using speckle-tracking echocardiography may identify patients at increased risk of adverse outcomes. The aim is to evaluate right atrial dimensions and function in patients with HFrEF and determine their association with six-month mortality and heart failure-related rehospitalization.

Methods: This prospective observational study included 93 hospitalized patients with HFrEF (LVEF ≤40%). Conventional echocardiographic parameters, right atrial dimensions, right atrial volume index (RAVI), and right atrial longitudinal strain (RALS) were assessed. Patients were followed for six months for death or rehospitalization. Receiver operating characteristic analysis determined predictive cut-offs.

Results: Thirty patients (32.3%) experienced adverse events; 17 (18.3%) were re-hospitalized and 13 (14.0%) died. Mean RAVI was significantly higher in patients with events than those without events (56.81 vs. 31.96 mL/m²; p<0.001), whereas RALS was lower (13.89% vs. 19.77%; p<0.001). RAVI ≥47.1 mL/m² predicted adverse events with 96.7% sensitivity and 96.8% specificity (AUC=0.996).

Conclusions: Increased RAVI and reduced RALS were significantly associated with adverse six-month outcomes in HFrEF.

Keywords: Heart failure, Right atrium, Right atrial volume index, Right atrial strain, Speckle-tracking echocardiography, Mortality, Re-hospitalization

INTRODUCTION

Heart failure is a complex clinical syndrome associated with substantial morbidity, recurrent hospitalization, impaired functional capacity, and mortality. Despite considerable advances in pharmacological and device-based therapy, patients with heart failure with reduced ejection fraction (HFrEF) remain at considerable risk of adverse cardiovascular events. Left ventricular ejection fraction (LVEF) continues to play a central role in the classification and management of HF; however, prognosis is influenced by abnormalities involving both ventricles

and the atria.[1] Right ventricular (RV) dysfunction is increasingly recognized as an important determinant of adverse outcome in chronic HF. Ghio et al demonstrated that RV systolic dysfunction and pulmonary artery pressure provide independent prognostic information in patients with chronic HF.[2] Progressive left-sided ventricular dysfunction may increase pulmonary vascular pressure and subsequently impose pressure and volume overload on the RV, contributing to tricuspid regurgitation, progressive right-sided chamber enlargement, and systemic venous congestion.[3]

The right atrium has traditionally received less attention than the ventricles in routine echocardiographic assessment. Nevertheless, the RA plays an integral role in cardiovascular performance through its reservoir, conduit, and contractile functions. During ventricular systole, the RA serves as a reservoir for systemic venous return; during early ventricular diastole, it functions as a passive conduit, while atrial contraction augments RV filling during late diastole. Alterations in these functions may occur as HF progresses and may reflect changes in RV compliance, right-sided filling pressures, and overall cardiovascular performance.[4-6]

RA enlargement may represent cumulative exposure to elevated right-sided filling pressures. Several studies have demonstrated a relationship between RA structural abnormalities and clinically relevant outcomes. Darsaklis et al reported that RA emptying fraction was associated with mortality in pulmonary hypertension, while Luijnenburg et al demonstrated an association between abnormal RA and RV diastolic function and impaired clinical status in patients with congenital heart disease.[4,5]

The right atrial volume index (RAVI), calculated by indexing RA volume to body surface area, provides a quantitative assessment of RA remodeling. Sallach et al reported that increasing RAVI was associated with worsening RV systolic dysfunction and predicted death, heart transplantation, and HF hospitalization in chronic systolic HF.[7] This finding has been supported by Darahim, who observed significantly greater RAVI among patients experiencing adverse outcomes and proposed a threshold for risk prediction in chronic systolic HF.[8] These observations suggest that RA volume may represent a clinically useful marker of right-sided hemodynamic burden.

Conventional measurements of cardiac chamber size and systolic function, however, may be influenced by preload, afterload, geometric assumptions, and inotropic conditions. Speckle-tracking echocardiography (STE) has emerged as a non-invasive technique for evaluating myocardial deformation and offers the potential to detect subtle functional abnormalities that may not be apparent with conventional measurements.[9,10]

Two-dimensional speckle-tracking echocardiography (2D-STE) allows quantitative evaluation of atrial deformation independently of the angle of insonation. The technique has demonstrated acceptable reproducibility for assessment of atrial and ventricular myocardial deformation.[11,12] Reference values for RA longitudinal strain have been described in healthy populations, providing a foundation for the application of strain imaging in various cardiovascular disorders.[13]

Evidence suggests that RA deformation is impaired in patients with HF. Haghighi et al demonstrated significantly reduced RA strain and strain-rate parameters in HF patients compared with healthy individuals and identified significant correlations between RA deformation and measures of cardiac performance.[9] Furthermore, RA strain abnormalities have been demonstrated in pulmonary hypertension, tricuspid regurgitation, and cardiomyopathy.[14-16]

The European Association of Cardiovascular Imaging (EACVI) and American Society of Echocardiography (ASE) have also provided recommendations for standardization of atrial and ventricular deformation imaging, emphasizing the increasing relevance of myocardial strain analysis in contemporary echocardiographic assessment.[17]

Although RAVI and RA strain appear promising, the prognostic implications of combining structural and functional RA measurements in hospitalized patients with HFrEF remain incompletely characterized. The present study was therefore conducted to evaluate RA dimensions and function using conventional and speckle-tracking echocardiography and to determine their association with functional status, mortality, and HF-related rehospitalization during six months of follow-up. The original thesis specifically evaluated RASAD, RALAD, RAVI, and RALS together with conventional LV and RV functional indices.

METHODS

Study design and population

This was a prospective observational study conducted among patients admitted to the Department of Cardiology, Institute of Post Graduate Medical Education and Research (IPGME&R) and S.S.K.M. Hospital, Kolkata.

The study was conducted from July 2018 to September 2019 and included 93 patients diagnosed with HFrEF, defined as a LVEF ≤40%. Patients aged >12 years admitted with HF and LVEF ≤40% were eligible for participation.

Exclusion criteria comprised age <12 years, valvular heart disease, congenital heart disease, restrictive cardiomyopathy, hypertrophic cardiomyopathy, severe mitral regurgitation (>grade 3), malignancy, and severe renal failure requiring dialysis. The study was conducted after approval from the Institutional Ethics Committee,

and informed consent was obtained from the participants according to institutional requirements.

Group allocation

Because the study was observational, no therapeutic intervention or randomized treatment allocation was performed. For assessment of clinical outcomes, patients were categorized according to their status during the six-month follow-up period. The no-event group included patients who survived without hospitalization for acute HF during follow-up. The event group comprised patients who either required rehospitalization for an acute HF episode or died during follow-up. For detailed outcome analysis, the patients were additionally considered in three categories: no event, re-hospitalization and death. Out of the 93 patients, 63 remained event-free, while 30 developed an adverse event. The event group consisted of 17 patients with rehospitalization and 13 patients who died.

Study procedure

At admission, demographic and clinical information was obtained using a standardized proforma. Recorded variables included age, sex, relevant cardiovascular risk factors, clinical diagnosis, duration of symptoms, and NYHA functional class. All patients underwent comprehensive transthoracic echocardiography.

Conventional echocardiographic evaluation included assessment of: left ventricular internal dimension in diastole (LVIDD); left ventricular internal dimension in systole (LVIDS); Interventricular septal thickness in diastole; left ventricular posterior wall thickness; LVEF; left atrial dimensions; and valvular abnormalities.

RV systolic function was evaluated using RV fractional area change (RV-FAC), tricuspid annular plane systolic excursion (TAPSE), and peak systolic tricuspid annular tissue velocity (tricuspid S′).

RA structural and functional parameters comprised: Right atrial short-axis dimension (RASAD) is an assessment of transverse RA dimension. Right atrial long-axis dimension (RALAD) is an assessment of longitudinal RA dimension. Right atrial volume index (RAVI): RA volume was calculated using Simpson's method from the apical four-chamber view at end-systole and subsequently indexed to body surface area. Right atrial longitudinal strain (RALS): RA myocardial deformation was assessed by 2D-STE.

Transthoracic echocardiography was performed using an EPIQ 7 echocardiography system (Philips Healthcare Systems).

For RA strain analysis, the RA endocardial border was manually traced at the septal, basal lateral, and apical borders at maximum atrial volume immediately before tricuspid valve opening in the apical four-chamber view. Following confirmation of satisfactory segmental tracking and optimization of the region of interest, longitudinal strain curves were generated for each segment. The software subsequently provided RALS values representing six RA segments.

Patients were followed for six months. Clinical status was determined through outpatient visits, hospital records, or telephone communication with patients or their family members. The predefined primary endpoints were: death during follow-up; re-hospitalization because of an acute HF episode requiring intravenous medication and supportive treatment.

Statistical analysis

Categorical variables were expressed as frequencies and percentages. Intergroup comparisons were performed using Pearson's chi-square test or Fisher's exact test, as appropriate. Continuous variables were summarized as mean, median, and standard deviation and compared using the Mann–Whitney U test or Kruskal–Wallis test according to the distribution and number of groups. Associations between continuous variables were evaluated using Spearman's rank correlation coefficient.

Receiver operating characteristic (ROC) curve analysis was performed to determine optimal cut-off values and evaluate the ability of relevant echocardiographic parameters to discriminate between patients with and without adverse outcomes. Predictive performance was quantified using the area under the ROC curve (AUC). Statistical analysis was performed using SPSS version 20. A $p<0.05$ was considered statistically significant.

RESULTS

A total of 93 patients with HFrEF were evaluated. The mean age of the study population was 56.76±11.58 years, with an age range of 32–78 years.

There were 59 males (63.4%) and 34 females (36.6%). The largest proportion of patients belonged to the 61–70-year age group (29.0%), followed by 51–60 years (26.9%) and 41–50 years (25.8%).

Regarding functional status, 52 patients (55.9%) were in NYHA class II, 25 (26.9%) were in NYHA class III, and 16 (17.2%) were in NYHA class IV. Thus, approximately 44% of the cohort had advanced symptoms corresponding to NYHA class III or IV (Table 1).

Baseline echocardiographic characteristics

Mean LVIDD was 55.33±9.53 mm and mean LVIDS was 47.55±9.90 mm. The mean LVEF was 28.95±8.34%. Regarding RV systolic indices, mean RV-FAC was 40.46±8.72%, mean TAPSE was 13.96±3.72 mm, and mean tricuspid S′ was 10.22±2.07 cm/s. Mean RALAD and RASAD were 39.40±9.04 mm and 33.10±8.66 mm,

respectively. Mean RAVI was 39.97±13.73 ml/m², whereas mean RALS was 17.88±7.05% (Table 2).

Six-month clinical outcomes

During six months of follow-up, 30 of 93 patients (32.3%) developed an adverse clinical outcome, while 63 patients (67.7%) remained free of events. Among the total population, 17 patients (18.3%) were re-hospitalized for acute HF, while 13 patients (14.0%) died.

All patients who developed events were in NYHA class III or IV. Of the event group, 46.7% belonged to NYHA class III and 53.3% belonged to NYHA class IV (Table 3).

Echocardiographic findings according to clinical outcome

Patients experiencing adverse events demonstrated significantly greater LV dimensions and poorer LV systolic function. Mean LVEF was 23.83±8.21% in the event group compared with 31.39±8.36% in the no-event group (p<0.001). Substantial differences were also observed in RV systolic function. Mean RV-FAC was 30.57±4.59% in patients with events compared with 45.16±5.76% in those without events (p<0.001).

Mean TAPSE was significantly reduced among patients with adverse events (10.52±1.59 mm) compared with event-free patients (15.60±3.31 mm; p<0.001). Similarly, mean tricuspid S′ was 8.04±1.43 cm/s in the event group versus 11.27±1.41 cm/s in the no-event group (p<0.001).

RA dimensions were significantly greater among patients developing adverse events. Mean RALAD was 44.74±4.45 mm among patients with events compared with 36.86±9.58 mm among those without events. Mean RASAD was 37.74±6.95 mm versus 30.90±8.57 mm, respectively (p<0.001 for both).

A particularly marked difference was observed for RAVI. Mean RAVI was 56.81±8.26 ml/m² in the event group compared with 31.96±6.71 ml/m² in the no-event group (p<0.001). Conversely, RA myocardial deformation was reduced among patients who developed adverse outcomes. Mean RALS was 13.89±6.36% in the event group compared with 19.77±6.59% in the no-event group (p<0.001) (Table 4).

When outcomes were analyzed separately, RAVI showed a progressive increase with worsening outcome. Mean RAVI values were 31.96 ml/m² in patients without events, 54.18 ml/m² in those who were re-hospitalized, and 60.25 ml/m² in patients who died.

In contrast, RALS progressively declined from 19.77% in the no-event group to 16.61% among re-hospitalized patients and 10.34% among patients who died. This pattern indicated increasing structural RA remodeling and worsening atrial myocardial deformation with increasing clinical severity (Table 5).

Receiver operating characteristic analysis

ROC analysis was performed for the major RV and RA echocardiographic parameters. An RV-FAC cut-off of 37.40% demonstrated a sensitivity of 93.7%, specificity of 96.7%, and AUC of 0.983. A TAPSE cut-off of 11.05 mm demonstrated 95.2% sensitivity and 73.3% specificity, with an AUC of 0.923. For tricuspid S′, a threshold of 10.25 cm/s provided 81.0% sensitivity and 100% specificity, with an AUC of 0.952. RAVI demonstrated the highest discriminatory ability.

A RAVI cut-off of 47.1 ml/m² provided 96.7% sensitivity and 96.8% specificity, with an AUC of 0.996 (95% CI: 0.989–1.000). A RALS threshold of 12.95% demonstrated 90.5% sensitivity and 56.7% specificity, with an AUC of 0.768 (95% CI: 0.660–0.876). All evaluated ROC parameters were statistically significant (p<0.001).

Table 1: Baseline demographic and clinical characteristics of the study population.

Variables	Value
Number of patients	93
Age (years)	56.76 ± 11.58
Male	59 (63.4%)
Female	34 (36.6%)
NYHA class II	52 (55.9%)
NYHA class III	25 (26.9%)
NYHA class IV	16 (17.2%)

Table 2: Baseline echocardiographic parameters.

Echocardiographic parameters	Mean±SD
LVIDD (mm)	55.33±9.53
LVIDS (mm)	47.55±9.90
LVEF (%)	28.95±8.34
RV-FAC (%)	40.46±8.72
TAPSE (mm)	13.96±3.72
Tricuspid S′ (cm/s)	10.22±2.07
RALAD (mm)	39.40±9.04
RASAD (mm)	33.10±8.66
RAVI (ml/m²)	39.97±13.73
RALS (%)	17.88±7.05

Table 3: Six-month clinical outcomes.

Outcomes	Number	Percentage
No event	63	67.7
Rehospitalization	17	18.3
Death	13	14.0
Any adverse event	30	32.3

Table 4: Comparison of major echocardiographic variables according to six-month outcome.

Parameters	No events (n=63)	Events (n=30)	P value
LVEF (%)	31.39±8.36	23.83±8.21	<0.001
RV-FAC (%)	45.16±5.76	30.57±4.59	<0.001
TAPSE (mm)	15.60±3.31	10.52±1.59	<0.001
Tricuspid S′ (cm/s)	11.27±1.41	8.04±1.43	<0.001
RALAD (mm)	36.86±9.58	44.74±4.45	<0.001
RASAD (mm)	30.90±8.57	37.74±6.95	<0.001
RAVI (ml/m²)	31.96±6.71	56.81±8.26	<0.001
RALS (%)	19.77±6.59	13.89±6.36	<0.001

Table 5: ROC-derived cut-off values for prediction of adverse events.

Parameters	Cut-off	Sensitivity (%)	Specificity (%)	AUC	P value
RV-FAC (%)	37.40	93.7	96.7	0.983	<0.001
TAPSE (mm)	11.05	95.2	73.3	0.923	<0.001
Tricuspid S′ (cm/s)	10.25	81.0	100.0	0.952	<0.001
RAVI (ml/m²)	47.10	96.7	96.8	0.996	<0.001
RALS (%)	12.95	90.5	56.7	0.768	<0.001

DISCUSSION

The present study evaluated RA structure and function in patients hospitalized with HFrEF and investigated the relationship of RA abnormalities with mortality and rehospitalization during six months of follow-up. The principal observation was that patients who developed adverse events demonstrated substantially greater RA enlargement and poorer RA myocardial deformation than those who remained event-free. RAVI and RALS were both significantly associated with clinical outcome, while conventional markers of RV systolic function were also markedly impaired among patients experiencing events. Approximately one-third of the study population experienced either HF-related rehospitalization or death during six months of follow-up. The event rate of 32.3% included 18.3% rehospitalization and 14.0% mortality. This comparatively high event rate may partly reflect the characteristics of the population, because all participants were hospitalized with HFrEF rather than recruited from a stable ambulatory HF population. Furthermore, approximately 44% had NYHA class III or IV symptoms at baseline. An important observation was the strong association between advanced NYHA functional class and adverse outcomes. All patients experiencing an event were in NYHA class III or IV. Functional status therefore remained an important clinical indicator of prognosis. These results emphasize that echocardiographic biomarkers should complement rather than replace comprehensive clinical assessment.

Right ventricular systolic function and outcome

RV dysfunction has long been associated with an adverse prognosis in HF. Ghio et al. demonstrated the independent and additive prognostic value of RV systolic performance and pulmonary artery pressure in chronic HF.[2] The pathophysiological progression from LV dysfunction to pulmonary hypertension, increased RV afterload, RV failure, functional tricuspid regurgitation, and right-sided congestion provides a mechanistic basis for this relationship.[3]

In the present study, RV-FAC, TAPSE, and tricuspid S′ were all significantly reduced among patients experiencing adverse events. Mean RV-FAC decreased from 45.16% in event-free individuals to 30.57% in patients experiencing an event. TAPSE decreased from 15.60 to 10.52 mm, and tricuspid S′ declined from 11.27 to 8.04 cm/s.

Puwanant et al similarly evaluated RV function in HF and reported that individuals with HFrEF had significantly lower RV-FAC, TAPSE, and tricuspid S′ compared with patients with preserved EF.[18] Their observations support the marked RV systolic impairment identified in the present cohort. The ROC findings additionally demonstrated strong discriminatory performance for RV-FAC, TAPSE, and tricuspid S′, with AUC values of 0.983, 0.923, and 0.952, respectively. Thus, systematic evaluation of RV systolic function appears essential when stratifying risk in patients with HFrEF.

Right atrial volume index and outcome

One of the most clinically relevant observations of the present study was the marked difference in RAVI according to clinical outcome. Mean RAVI was only 31.96 ml/m² among patients remaining event-free but increased to 56.81 ml/m² among patients who experienced an adverse event. A graded increase was also observed across

increasingly severe outcome categories, reaching 54.18 ml/m² among re-hospitalized patients and 60.25 ml/m² among patients who died. RA enlargement is likely to reflect the cumulative effects of increased RV filling pressures, impaired RV compliance, tricuspid regurgitation, and chronic volume and pressure overload. Unlike a single instantaneous pressure measurement, atrial remodeling may therefore represent the integrated hemodynamic burden experienced over time. Sallach et al evaluated 192 patients with chronic systolic HF and reported that RAVI increased progressively with worsening RV systolic function, LV systolic dysfunction, and LV diastolic dysfunction. Increasing RAVI was associated with death, transplantation and HF hospitalization, and remained independently associated with adverse events following multivariable adjustment.[7]

Darahim similarly reported significantly higher RAVI among patients experiencing an event than among those without an event and identified a RAVI threshold of approximately 29 ml/m² for prediction of adverse outcomes.[8] In comparison, the threshold identified in the present study was considerably higher at 47.1 ml/m². The difference may be related to the inclusion of a more severely ill hospitalized HFrEF population in the present study. The thesis itself proposed advanced HF severity as a potential explanation for this higher cut-off.

The particularly high AUC of 0.996 observed for RAVI indicates excellent discrimination within this study cohort. Nevertheless, despite its powerful univariate association and ROC performance, logistic regression in the original thesis did not establish RAVI as an independent predictor of outcome. Therefore, RAVI should be regarded as a potentially valuable component of multiparametric risk assessment rather than a standalone prognostic determinant. Patel et al demonstrated the potential utility of three-dimensional RA volume assessment in patients with acute decompensated HF, showing an association between 3D-RAVI and invasively measured RA pressure.[19] Such findings suggest that volumetric evaluation of the RA may provide important information regarding right-sided filling pressure and hemodynamic status.

Right atrial longitudinal strain and outcome

The assessment of RALS provided additional information regarding RA functional impairment. Mean RALS was significantly reduced in patients experiencing an event compared with patients remaining event-free. Moreover, RALS showed a progressive decline from 19.77% in event-free patients to 16.61% among re-hospitalized patients and 10.34% among those who died. The ability of strain imaging to assess myocardial deformation makes it particularly attractive in circumstances where conventional chamber dimensions are influenced by preload and geometric assumptions. Blessberger and Binder described the fundamental principles of 2D speckle-tracking echocardiography and highlighted its ability to provide angle-independent quantitative assessment of myocardial deformation.[11]

Padeletti et al established reference values for RA longitudinal strain using 2D-STE and reported substantially higher strain values in healthy individuals than those observed in this advanced HF population.[13] The markedly reduced RALS observed in the present study therefore appears consistent with significant RA myocardial dysfunction.

Haghighi et al demonstrated impaired RA strain and strain-rate parameters among patients with HF and reported meaningful correlations between RA deformation indices and cardiac output.[9] These findings support the concept that altered RA deformation is not merely a structural phenomenon but may be associated with impaired global cardiovascular performance. Padeletti et al also investigated RA speckle tracking in patients with chronic systolic HF and reported associations between RA deformation and pulmonary hemodynamics.[20] These findings provide a physiological rationale for the marked reduction in RALS among patients with severe HF and adverse clinical outcomes.

In the present study, a RALS cut-off of 12.95% predicted an adverse event with sensitivity of 90.5%. Specificity was comparatively modest at 56.7%, and the AUC of 0.768 was lower than that observed for RAVI or the major RV systolic parameters. Thus, although RALS was significantly associated with clinical outcome, its value appears more suitable as an adjunctive rather than solitary risk marker. The original multivariable analysis similarly did not establish RALS as an independent predictor of clinical events.

Relationship between right atrial and right ventricular abnormalities

RA and RV dysfunction are physiologically interdependent. Increased RV filling pressure and impaired RV systolic function increase atrial pressure and may eventually lead to atrial dilatation, reduced compliance, and impaired reservoir and contractile function. Joseph et al demonstrated an association between RA fractional area change and measures of right-heart function in patients with pulmonary arterial hypertension.[6] Similarly, Teixeira et al reported a relationship between severity of tricuspid regurgitation and RA mechanical dysfunction assessed using speckle-tracking echocardiography.[14]

D'Andrea et al evaluated RA deformation among patients with dilated cardiomyopathy undergoing cardiac resynchronization therapy and reported significant differences in RA strain between responders and non-responders, further demonstrating that atrial deformation may reflect the functional severity of myocardial disease.[16] The close association in the present study between elevated RAVI, reduced RALS, and impaired RV-FAC,

TAPSE, and tricuspid S′ supports this concept of integrated right-heart dysfunction.

Clinical implications

Routine echocardiographic assessment in HFrEF has traditionally focused predominantly on LV size and systolic function. However, the findings of the present study indicate that evaluation of the RA and RV may provide complementary prognostic information. RAVI is relatively straightforward to obtain during routine transthoracic echocardiography and demonstrated particularly strong discrimination between patients with and without adverse outcomes. RALS provides a quantitative measure of RA myocardial deformation and may reveal functional impairment that is not fully characterized by atrial size alone.

Accordingly, incorporation of RAVI and RALS alongside NYHA functional class, LVEF, TAPSE, RV-FAC, and tricuspid S′ may potentially improve identification of patients with advanced right-heart involvement who warrant closer clinical surveillance. Standardization remains important when atrial strain measurements are applied clinically. Badano et al. emphasized standardized acquisition, measurement, and terminology for atrial and ventricular deformation imaging. [17] Implementation of these recommendations and use of RA-specific software may enhance reproducibility and comparability among future studies.

Limitations

The findings should be interpreted in the context of several limitations. First, the sample size was relatively small and included predominantly hospitalized patients with comparatively advanced HF; therefore, the findings may not be generalizable to stable ambulatory HFrEF populations.

Second, RA volume was calculated using Simpson's method from a single apical four-chamber view. Because the RA is located in the far field in this view, reduced lateral resolution may affect accurate delineation of the endocardial border.

Third, established HF biomarkers such as B-type natriuretic peptide were not incorporated into the prognostic analysis. Fourth, only RA longitudinal strain was evaluated, and the software used for strain analysis was originally developed for LV myocardial analysis rather than specifically designed for the RA.

Finally, the study did not stratify patients according to the etiology of LV dysfunction. Larger prospective multicenter studies incorporating contemporary RA-specific deformation software, three-dimensional echocardiography, biomarkers, and comprehensive multivariable prognostic modelling are warranted.

CONCLUSION

The present study demonstrates that structural enlargement and functional impairment of the RA are closely associated with adverse six-month clinical outcomes among hospitalized patients with HFrEF.

Patients who experienced death or HF-related rehospitalization had significantly higher RAVI, greater RA dimensions, and substantially lower RALS compared with patients who remained event-free. A progressive increase in RAVI and decline in RALS were observed from the no-event group through rehospitalization to mortality, suggesting worsening RA remodeling and myocardial dysfunction with increasing disease severity. RAVI showed particularly strong discriminatory performance. A threshold of 47.1 ml/m² predicted adverse events with 96.7% sensitivity, 96.8% specificity, and an AUC of 0.996. Reduced RALS was also significantly associated with adverse outcomes, although its discriminatory performance was comparatively lower. Conventional RV systolic parameters, particularly RV-FAC, TAPSE, and tricuspid S′, were also strongly associated with outcomes. Although RAVI and RALS demonstrated significant prognostic value, neither was established as an independent predictor in the original multivariable analysis. Therefore, RA volume and strain may be most useful as complementary components of a comprehensive clinical and echocardiographic risk-assessment strategy in patients with HFrEF.

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