ORIGINAL RESEARCH

Right ventricular systolic function in hypertensive heart failure

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Background: Heart failure (HF) is a major cause of cardiovascular admissions and hypertensive heart failure (HHF) is the most common cause of HF admissions in sub-Saharan Africa, Nigeria inclusive. Right ventricular (RV) dysfunction is being increasingly recognized in HF and found to be an independent predictor of adverse outcomes in HF. This study aimed to determine the prevalence of RV systolic dysfunction in HHF by several echocardiographic parameters.

Methodology: One hundred subjects with HHF were recruited consecutively into the study along with 50 age and sex-matched controls. All study participants gave written informed consent, and had a full physical examination, blood investigations, 12-lead electrocardiogram, and transthoracic echocardiography. RV systolic function was assessed in all subjects using different methods based on the American Society of Echocardiography guidelines for echocardiographic assessment of the right heart in adults. This included tricuspid annular plane systolic excursion (TAPSE), RV myocardial performance index (MPI), and RV systolic excursion velocity by tissue Doppler (S′).

Results: RV systolic dysfunction was found in 53% of subjects with HHF by TAPSE, 56% by RV MPI, and 48% by tissue Doppler systolic excursion S′. RV systolic dysfunction increased with reducing left ventricular ejection fraction (LVEF) in subjects with HHF.

Conclusion: A high proportion of subjects with HHF were found to have RV systolic functional abnormalities using TAPSE, RV MPI, and RV S′. Prevalence of RV systolic dysfunction increased with reducing LVEF.

Keywords: right ventricle, systolic function, TAPSE, RV MPI, RV S′, hypertensive heart failure

Introduction

Heart failure (HF) is a major public health problem with increasing worldwide prevalence and is singled out as an emerging epidemic.[1] The aging of the population and increasing survival of subjects with cardiac disease due to availability of new treatment methods may account for some of the increase in the prevalence of HF. HF accounts for 3%–7% of hospital admissions in Africa, including Nigeria.[2]

Hypertensive heart disease is the commonest echocardiographic diagnosis and the commonest cause of HF in Nigeria[3] compared to ischemic heart disease in the western world.

The function of the right ventricle is being increasingly recognized as a major determinant of adverse outcomes in subjects with cardiac diseases. Studies have shown that right ventricular (RV) function correlates more closely to exercise capacity in HF than the left ventricular (LV) function.[4]

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The advent of reliable and reproducible echocardiographic measures of RV function such as tricuspid annular plane systolic excursion (TAPSE), RV myocardial performance index (MPI), and tissue Doppler-derived tricuspid lateral annular velocities (S′, E′, A′, E′/A′)[5] has made the assessment of RV function in cardiac diseases easier and helped identify the important role of RV in HF subjects. We undertook this study to determine the prevalence of RV systolic dysfunction in subjects with hypertensive heart failure (HHF) using several echocardiographic parameters and to determine if RV systolic dysfunction was associated with other markers of prognosis in HF.

Materials and methods

This study was a cross-sectional study carried out at the Cardiac Care Unit of the Department of Medicine, Obafemi Awolowo University Teaching Hospitals' Complex, Ife, Osun State. Ethical clearance for the study was obtained from the Ethics and Research Committee of the Obafemi Awolowo University Teaching Hospital. One hundred newly and previously diagnosed subjects with hypertensive HF attending the Cardiology Outpatient Clinics were studied. Fifty apparently healthy subjects were recruited to serve as controls. All subjects with HF were recruited while on HF medications. Age criterion was ≥18 years with no upper age limit. All participants included in the study provided written informed consent prior to enrollment in the study.

The inclusion criterion was subjects who had a clinical diagnosis of hypertensive HF.[6] Hypertension was defined as average of three blood pressure measurements ≥140/90 mmHg, according to the Joint National Committee VII guidelines[7] and subjects had features of longstanding hypertension including thickened arterial wall, locomotor brachialis, and at least grade 2 hypertensive retinopathy. All subjects met the Framingham criteria[8] for congestive HF and were classified based on the New York Heart Association (NYHA) functional classification.[9]

Subjects with suspected HF from causes other than hypertensive HF based on history, physical examination, and echocardiographic features were excluded from the study. Subjects with chest pain, electrocardiogram (ECG) and echocardiographic features suggestive of ischemic heart disease, elevated troponins, and previous cardiac catheterizations diagnostic of ischemic heart disease were excluded from the study. Cardiac catheterization was not done in all subjects. Other subjects with comorbid diseases such as uncontrolled asthma, chronic obstructive pulmonary disease, stages 3–5

chronic kidney disease, and diabetes mellitus were also excluded from the study. Subjects who had suboptimal echocardiographic windows were also excluded from the study.

Procedure

Data were obtained using a questionnaire that included demographic data and other relevant history details. Complete physical examination was carried out on each study participant. The blood pressure was measured on the right arm in supine and standing positions with an Accoson's mercury sphygmomanometer. Korotkoff sounds I and V were used for systolic and diastolic blood pressure, respectively. Three consecutive measurements were taken at 5 minute intervals and the average values were recorded.

Investigations

Routine laboratory investigations were done to further assess clinical state of the subjects and rule out comorbidities. These included full blood count (anemia defined as packed cell volume <33%), electrolytes, urea and creatinine, and random blood glucose tests.

Resting 12-lead ECG

The resting 12-lead ECG was obtained using a 3-channel electrocardiograph (Cardiofax YD-907D; Nihon Kohden, Tokyo, Japan). The machine was set at a paper speed of 25 mm/s and amplitude 10 mm/mv. Lead II was used for recording a long rhythm strip. The ECG was specifically analyzed for heart rate and rhythm, QRS axis, PR interval, QRS duration, QT intervals, QTc duration, P wave morphology, pathological Q waves, ST segment and T wave changes, presence of LV or RV hypertrophy, and arrhythmias according to the recommendation of the American Heart Association.[10]

Transthoracic echocardiography

Two-dimensional (2D), M-mode, and Doppler studies were performed on all subjects using vivid 7 dimension ultrasound imaging system (GE Healthcare Bio-sciences Corp, Piscataway, NJ, USA) with P5s MHz transducer with subjects in the left lateral position. Measurements were taken in accordance with the recommendations of the American Society of Echocardiography by noting the leading edge to leading edge recordings.[11] Echocardiographic studies were analyzed for pericardial abnormalities, wall dimensions, chamber size, wall motion abnormalities, intramural thrombi, valve morphology, LV systolic and diastolic function, septal defects, and other congenital heart defects, and estimated intracardiac and vascular pressures.

LV wall and chamber dimensions were measured using 2D-guided M-mode echocardiography with simultaneous electrocardiographic monitoring of the cardiac cycle. The M-mode cursor cut perpendicularly across the interventricular septum, LV chamber, and posterior wall at the level of the mitral valve tips as the cardiac anatomy was visualized with the 2D echo from the parasternal long axis view. Measurements were made with leading edge to leading edge recordings taken at end-diastole and end-systole. End-diastole was recognized as the beginning of the electrocardiographic qRs complex while end-systole was recognized as the peak downward deflection of the interventricular septum and the peak upward deflection of the LV posterior wall.[11]

LV systolic function

This was assessed using M-mode echocardiography taken from the parasternal long axis view to determine LV wall dimensions, ejection fraction (EF), and fractional shortening (FS). The Teichholz formula[12] programmed by the automated facilities in the echocardiography machine was used for determining the LV volumes in end-diastole and end-systole:

$$\frac{7}{(LVID + 2.4)} \times (LVID)^3$$

where LVID is the LV internal dimension.

EF was then determined by the formula

$$EF = \frac{LVEDV - LVESV}{LVEDV} \times 100\%$$

where LVEDV is the LV end-diastolic volume and LVESV is the LV end-systolic volume.

FS was determined by the formula

$$FS = \frac{LVIDd - LVIDs}{LVIDd} \times 100\%$$

where LVIDd and LVIDs are the LV internal diameters in the diastole and systole, respectively.

The above formulae were programmed by the automated facilities in the echocardiography machine. A similar study[13] employed the use of the Teichholz formula in determining LV systolic function.

The RV study included RV dimension (RVD), systolic function using TAPSE, and tissue Doppler MPI and RV S′ and diastolic function using pulsed and tissue Doppler velocities of the tricuspid annulus (E, A, E/A, E′, A′ E/E′) according to

the American Society of Echocardiography guidelines for the echocardiographic assessments of the right heart in adults.[5]

RVD

RVD was measured in the apical four-chamber view with focus on the RV. It was recorded as the RV basal diameter taken as the maximal short axis dimension in the basal one third of the RV cavity at end-diastole. Values >4.2 cm were considered abnormal indicating RV dilatation. The relative size of the RV was also compared visually with that of the LV to help determine RV dilatation.

TAPSE

This was acquired in the apical four-chamber RV-focused view by placing the M-mode cursor through the tricuspid annulus and measuring the amount of longitudinal motion of the annulus at peak systole. Values ≤1.6 cm indicated impaired RV systolic function (Figure 1).

RV tissue Doppler MPI

This is an index of global RV function and was obtained in the apical four-chamber view and in tissue Doppler mode. Pulsed Doppler sample volume was then placed on the tricuspid annulus (Figure 2). The RV tissue Doppler MPI was calculated as follows

$$MPI = \frac{\left(\begin{array}{l} tricuspid\ valve\ closure\text{-}opening \\ time - ejection\ time \end{array}\right)}{ejection\ time}$$

The tricuspid valve closure–opening time (TCO) encompasses isovolumic contraction time, ejection time (RVET),
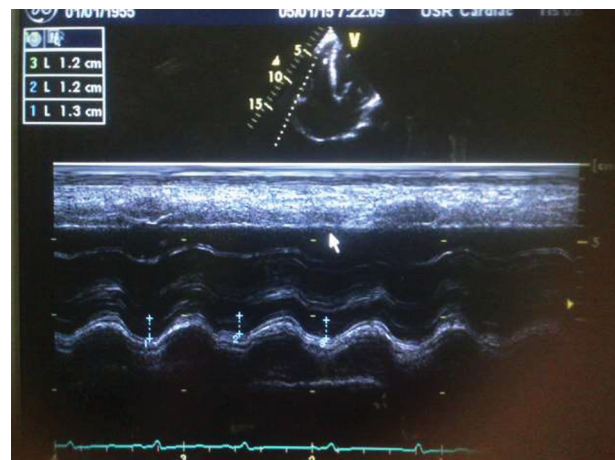

Figure 1 Abnormal TAPSE, 1.2cm (average value of 1,2 and 3 in Figure 1) in subjects with HF.
Abbreviations: HHF, hypertensive heart failure; TAPSE, tricuspid annular plane systolic excursion.

and isovolumic relaxation time. RV MPI values >0.55 implied RV dysfunction (Figure 2).

Tissue Doppler systolic velocity of the tricuspid annulus, S′

This was obtained using the same pulsed tissue Doppler image with sample volume on the tricuspid annulus as for RV MPI. RV S′ was recorded as the highest systolic velocity and values ≤10 cm/s indicated impaired RV systolic function (Figure 3).

Data analysis

Data were analyzed using the statistical package for social sciences (IBM Corporation, Armonk, NY, USA), version 20.0 software. Data summary and presentation techniques such as arithmetic means, standard deviation, and frequency distribution tables and charts were used where appropriate. Categorical variables were represented in numbers and
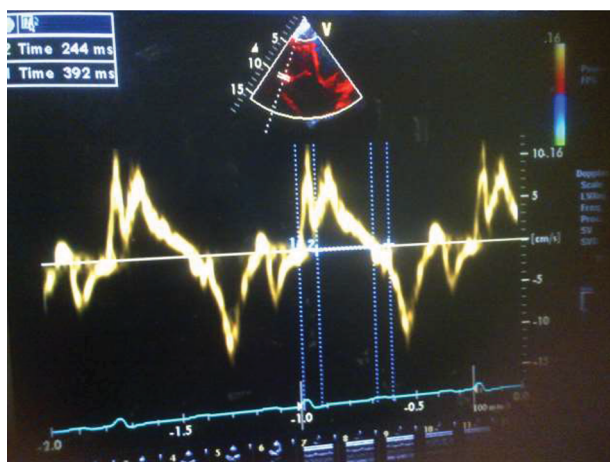
Figure 2 Abnormal RV MPI, 0.60 (1: TCO; 2:RVET) in subjects with HF.
Abbreviations: HF, heart failure; MPI, myocardial performance index; RV, right ventricular; TCO, tricuspid valve closure-opening time; RVET, RV ejection time.
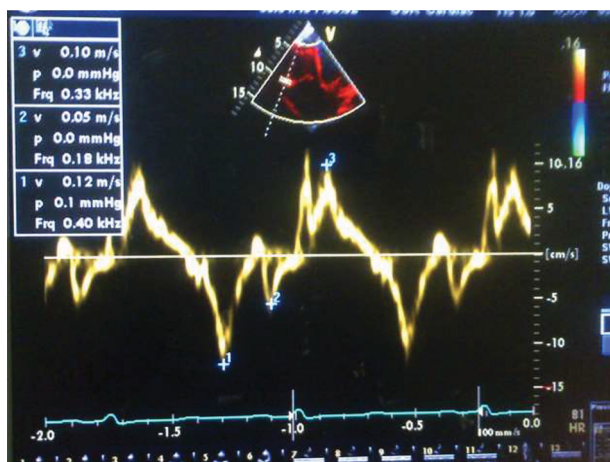
Figure 3 Abnormal RV S′, 0.10m/s in subjects with HF.
Abbreviations: HF, heart failure; RV, right ventricular; S′, systolic excursion velocity by tissue Doppler.

percentages and charted where appropriate. Chi-square analysis was used to describe differences between categorical variables. Statistical 2 sample *t*-test and *t*-test in regression output were used to assess significant differences between group means of quantitative variables. Analysis of variance was used to compare means of variables with more than two categories. Pearson's correlation analysis was used where necessary. Statistical significance was defined as *p*-values <0.05.

Results

One hundred subjects with HF and 50 apparently healthy subjects were studied.

Clinical parameters of study subjects

Table 1 shows the clinical parameters of the study subjects. The HF subjects were matched for age and sex with healthy controls in a ratio of 2:1. The mean ages of both groups were similar (64.56±11.85 vs 63.74±10.76 years; *p*=0.200). Body mass index was significantly lower in HF subjects compared

Table 1 Demographic and clinical characteristics of the study population

Parameters	HF subjects N (%)	Controls
Male	52 (52)	26 (52)
NYHA I	5 (5)	
NYHA II	41 (41)	
NYHA III	54 (54)	
Anemia (PCV <33%)	22 (22)	
LVH (ECG)	62 (62)	
LAE (ECG)	43 (43)	
AF	6 (6)	
ACEI	100 (100)	
Loop diuretics	96 (96)	
Spironolactone	98 (98)	
Digoxin	75 (75)	
Beta blocker	9 (9)	

	Mean ± SD	Mean ± SD	*p*-value
Age (years)	64.56±11.85	63.74±10.76	0.200
PCV (%)	35.37±2.31	37.56±3.20	0.115
Weight (kg)	72.87±13.46	77.44±13.54	<0.0001
Height (m)	1.62±0.07	1.64±0.07	<0.0001
BMI (kg/m²)	27.48±5.07	28.57±5.39	<0.0001
HR (bpm)	86.48±1.20	71.38±1.30	0.050
SBP (mmHg)	129.50±20.41	120.22±11.20	<0.0001
DBP (mmHg)	80.00±12.70	71.16±8.49	0.201
Serum sodium (mmol/L)	133.06±2.43	136.10±2.67	0.620
Serum potassium	3.54±0.60	3.65±0.82	0.841

Note: *p*-value is significant at <0.05.
Abbreviations: NYHA, New York Heart Association; PCV, packed cell volume; LVH, left ventricular hypertrophy; LAE, left atrial abnormality; AF, atrial fibrillation; ACEI, angiotensin converting enzyme inhibitor; BMI, body mass index; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; HF, heart failure; ECG, electrocardiogram; SD, standard deviation.

to controls. HF subjects had significantly higher baseline systolic blood pressures than controls (129.50±20.41 vs 120.22±11.20 mmHg, *p*<0.001).

Fifty-two percent of subjects satisfied Framingham's major criteria for HF. All subjects with HF were in NYHA stages I–III, with subjects in NYHA II and III accounting for 41% and 54% of HF subjects, respectively.

Echocardiographic parameters of study subjects

Table 2 shows the echocardiographic parameters in study subjects. All echocardiographic variables were significantly different between subjects and controls. LV ejection fraction

Table 2 Echocardiographic variables in the study population

Parameters	HF Subjects Mean ± SD	Controls Mean ± SD	*p*-value
LVEF (%)	38.34±10.34	64.50±6.72	<0.001*
FS (%)	19.56±5.34	34.96±5.19	0.007*
LVEDD (cm)	6.02±0.91	4.48±0.48	<0.001*
LVPWD (cm)	1.21±0.16	1.04±0.12	0.046*
IVSD (cm)	1.36±0.90	1.12±0.16	0.028*
LAD (cm)	4.23±0.55	2.97±0.38	0.036*
RVD (cm)	3.90±0.74	3.32±0.47	0.020*
RV systolic function			
TAPSE (cm)	1.66±0.47	2.76±0.39	<0.001*
RV MPI	0.61±0.30	0.35±0.11	<0.001*
RV S′ (cm/s)	10.57±2.40	14.32±1.89	0.010*

Note: **p*-value significant at <0.05.
Abbreviations: HF, heart failure; LVEF, left ventricular ejection fraction; FS, fractional shortening; LVEDD, left ventricular end-diastolic diameter; LVPWD, left ventricular posterior wall diameter; IVSD, interventricular septal wall diameter; LAD, left atrial diameter; RVD, right ventricular diameter; RV, right ventricle; TAPSE, tricuspid annular plane systolic excursion; RV MPI, right ventricular myocardial performance index; RV S′, right ventricular systolic excursion velocity by tissue Doppler; SD, standard deviation.

(LVEF) and FS mean values were significantly lower in subjects with HF than controls, while LV end-diastolic diameter (LVEDD) and left atrial diameter were significantly higher in HF subjects than controls. TAPSE and RV S′ were significantly lower in HF subjects than in controls while RV MPI was significantly higher in HF subjects than in controls. Eighty-four percent of HF subjects had reduced LVEF (LVEF <50%).

RV systolic dysfunction in HF subjects

Figure 4 shows the prevalence of RV systolic dysfunction in HF subjects by TAPSE, RV MPI, and S′. Prevalence of RV systolic dysfunction in HF subjects with preserved EF (LVEF >50%) was 1.89% by TAPSE and 5.36% by RV MPI. The prevalence of RV systolic dysfunction was highest in HF subjects with LVEF between 30% and 39% (41.51% by TAPSE, 39.29% by RV MPI, and 41.67% by RV S′) and subjects with LVEF <30% (33.96% by TAPSE, 28.57% by RV MPI, and 39.58% by RV S′).

Correlation of RV echocardiographic variables with clinical and other echocardiographic variables in HF subjects

Bivariate correlation analysis showed that TAPSE and RV S′ correlated positively and significantly with LVEF (*r*=0.578, *p*<0.001; *r*=0.664, *p*=0.002) while RV MPI showed a significant negative correlation with LVEF (*r*=−0.307, *p*<0.001). TAPSE, RV MPI, and RV S′ also significantly correlated with FS (*p*<0.001) and LVEDD (*p*<0.05). RV S′ had a significant positive correlation with SBP (*r*=0.263, *p*=0.008) as shown in Table 3.
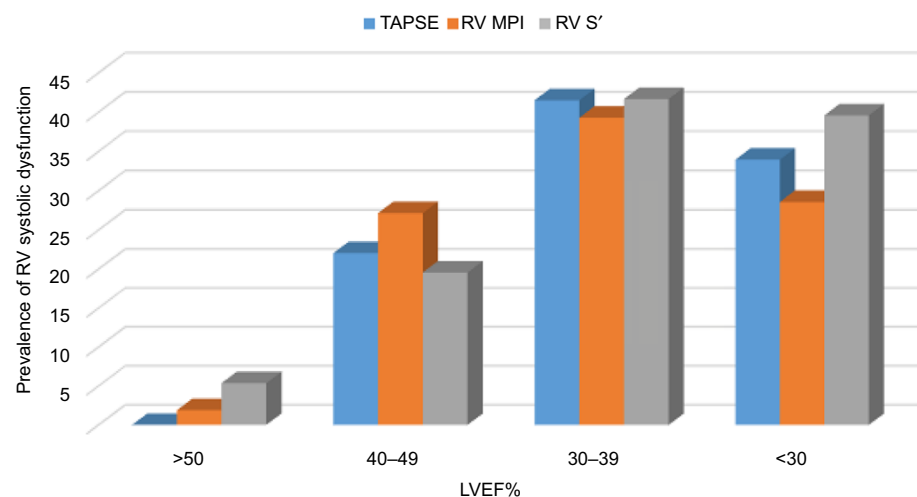

Figure 4 Prevalence of RV systolic dysfunction in HF subjects stratified by LVEF.
Abbreviations: RV, right ventricular; HF, heart failure; LVEF, left ventricular ejection fraction; TAPSE, tricuspid annular plane systolic excursion; MPI, myocardial performance index; RV S′, right ventricular systolic excursion velocity by tissue Doppler.

Table 3 Correlation of echocardiographic variables RV systolic function with clinical and other echocardiographic variables in HF subjects

Parameter	TAPSE		RV MPI		RV S′	
	r	p-value	r	p-value	R	p-value
Age	−0.049	0.626	0.179	0.076	0.040	0.685
SBP	0.194	0.053	−0.080	0.429	0.263	0.008*
DBP	0.094	0.352	0.013	0.901	0.066	0.517
LVEF	0.578	0.000*	−0.307	0.002*	0.664	0.000*
FS	0.572	0.000*	−0.473	0.000*	0.739	0.000*
LVEDD	−0.337	0.001*	0.290	0.003*	−0.394	0.000*
LAD	−0.047	0.646	0.334	0.000*	−0.464	0.000*
LVPWD	−0.008	0.939	0.218	0.007*	−0.302	0.000*
IVSD	0.053	0.600	0.039	0.634	−0.066	0.419

Note: *p-value significant at <0.05.
Abbreviations: r, Pearson's correlation coefficient; TAPSE, tricuspid annular plane systolic excursion; RV MPI, right ventricular myocardial performance index; RV S′, right ventricular systolic excursion velocity by tissue Doppler; LVEF, left ventricular ejection fraction; FS, fractional shortening; LVEDD, left ventricular end-diastolic diameter; LVPWD, left ventricular posterior wall diameter; IVSD, interventricular septal diameter; LAD, left atrial diameter; HF, heart failure; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Discussion

This study shows that RV systolic dysfunction is common in subjects with HF and goes further to investigate RV systolic function using alternative echocardiographic parameters other than TAPSE which is mostly routinely used to assess RV function in echocardiographic studies. It also shows that RV MPI and RV S′ can also be reliably used to assess RV systolic function in HF subjects.

We found statistically significant differences in the prevalence of RV systolic dysfunction between subjects with HHF and control subjects using all three echocardiographic parameters. A high prevalence of RV systolic dysfunction was found using all three echocardiographic parameters – 53% by TAPSE, 56% by RV MPI, and 48% by RV S′. Ojji et al[13] also found a high prevalence of RV systolic dysfunction in subjects with HHF in Nigeria using TAPSE (44.5%). TAPSE is simple and easily reproducible and has been found to correlate with the radionuclide angiographic estimate of RV global systolic function.[14] However, TAPSE assumes that the longitudinal displacement of a single segment represents the function of a three-dimensional (3D) structure and is found to be angle and load dependent.[5] Kjaergaard et al[15] studied RV function in HF subjects using TAPSE and found that although TAPSE is reduced with LV dysfunction in HF the absolute reduction is small and seemed to be of minor importance in the clinical utilization of TAPSE as a measure of RV systolic function or as a prognostic factor. The fact that there are limitations to the use of a single method of assessing function necessitates the validation of other methods to serve as alternatives or further validate results obtained using one method.

Right sided MPI

The right sided MPI also known as the Tei index is a global estimate of both systolic and diastolic function of the right ventricle. We found the RV systolic dysfunction in HHF subjects in this study to be 56% using the RV MPI.

MPI was shown by Karnati et al[16] to correlate with radionuclide-derived RV EF. Tei et al[17] found that RV MPI was a strong predictor of clinical status and survival in subjects with pulmonary hypertension. The LV Tei index has been well studied in subjects with HF[18,19] however, there are less studies on the clinical value of the RV Tei index. Thus, we decided to also assess RV function in subjects with HHF using MPI.

Tissue Doppler-derived tricuspid lateral annular systolic velocity (RV S′)

This was also used to assess RV systolic function in this study. RV S′ velocity <10 cm/s indicates RV systolic dysfunction[5] and was found in up to 48% of subjects with HHF in this study. Damy et al[20] compared four RV systolic echocardiographic parameters (TAPSE, RV S′ aka peak systolic velocity [PSV] tdi, RV fractional area, and 3-integral of the systolic wave) to predict adverse outcomes in chronic HF and concluded that RV S′ (PSV tdi) <9.5 cm/s was the best predictor of the combined endpoint (death, urgent heart transplantation, urgent ventricle assist device implantation, or acute HF episode). RV S′ has population-based validation studies and mean values for normal populations are available[21] which makes this echocardiographic parameter even more useful.

Clinical and echocardiographic correlates of RV systolic dysfunction

Echocardiographic measures of RV systolic function have been previously found to be independent of age and gender in the healthy population.[15,22] This study also found the same to be true in subjects with HHF. Kjaergaard[22] et al reported that TAPSE does not correlate with age or gender in HF subjects. Ojji in Nigeria[23] also reported that TAPSE did not correlate with gender in HHF. It is not known why echocardiographic measures of RV function do not correlate with age or gender; however, some studies showed that RV end-diastolic volume and 3D echocardiographic imaging of the RV demonstrate significant differences with gender and age.[15] The lack of a relation of TAPSE with gender makes it possible for the same reference values to be used for both sexes.

This study found significant correlation between echocardiographic variables of RV systolic function and several indices of LV function. TAPSE and RV S′ correlated positively and significantly with LVEF (r=0.578, p<0.001; r=0.664,

p=0.002) while RV MPI showed a significant negative correlation with LVEF (r=−0.307, $p<0.001$). TAPSE, RV MPI, and RV S′ also significantly correlated with FS ($p<0.001$) and LVEDD ($p<0.05$). RV S′ had a positive correlation with SBP. Prevalence of RV dysfunction increased with decreasing LVEF in this study. Several studies[24,25] have reported positive correlations between echocardiographic variables of RV systolic function and LVEF and LV chamber dimensions. Guglin et al[25] noted that RV systolic dysfunction correlated positively with LVEDD in HF subjects. Karaye et al[26] also reported that LVEF was the best correlate of TAPSE and RV S′; however, this was in a cohort of hypertensive subjects without features of HF. In this study, subjects with reduced EF had the highest prevalence of RV systolic dysfunction (61.9% and 63% by TAPSE and RV MPI, respectively). This observation was also reported in studies by de Groote et al[4] (52%) and by Puwanant et al[27] (63%–76%).

RV function worsens with increasing severity of LV dysfunction and this may result from the concept of ventricular interdependence.[28] HF subjects with reduced EF but normal RV function have better prognosis compared to those with impaired RV systolic function.[29] Subjects with HF with preserved EF may also have RV dysfunction and this has been found to be associated with clinical and echocardiographic evidence of more advanced HF and is predictive of poorer outcomes.[29]

Limitations of the study

Ischemic heart disease was excluded in subjects by history, physical eaxmination, electrocardiography, and wall motion abnormalities on echocardiography. Cardiac catheterization or myocardial perfusion imaging was not performed; so subjects with subclinical features of ischemic heart disease may have been missed.

Conclusion

RV systolic dysfunction is common in subjects with hypertensive HF and was found in >50% of such subjects using TAPSE and RV MPI and in 48% with RV S′. All three echocardiographic parameters of RV systolic function correlated with LVEF and FS.

Disclosure

The authors report no conflicts of interest in this work. OA Oketona and OT Oketona are a married couple.

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