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Original Article

Evaluation of Right Ventricular Dysfunction Using Echocardiography as a Diagnostic Tool to Rule Out Pulmonary Hypertension

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ABSTRACT

Background: Pulmonary hypertension increases right ventricular afterload and may lead to progressive right ventricular dysfunction. Echocardiography provides a non-invasive means of evaluating right ventricular structure, systolic function, and pressure-related abnormalities. Objective: To evaluate right ventricular dysfunction using echocardiography and examine the associations and discriminatory performance of selected echocardiographic parameters in patients assessed for pulmonary hypertension. Methods: This cross-sectional observational study included 62 patients evaluated at Bajwa Hospital, Lahore. Tricuspid annular plane systolic excursion, tricuspid valve pressure gradient, right ventricular systolic tissue Doppler velocity, right ventricular dilation, inferior vena cava collapsibility, and tricuspid regurgitation grade were assessed. Continuous variables were compared using Welch's independent-samples t-test, while categorical associations were evaluated using chi-square tests. Receiver operating characteristic analysis was performed with clinically appropriate test directions. Results: Pulmonary hypertension was identified echocardiographically in 38 participants (61.3%). Compared with participants without pulmonary hypertension, affected participants had lower TAPSE (14.79 ± 4.22 vs 19.54 ± 2.60 mm; mean difference −4.75 mm, $p < 0.001$), higher TVPG (49.79 ± 7.95 vs 28.63 ± 5.98 mmHg; mean difference 21.16 mmHg, $p < 0.001$), and lower RV S′ TDI (9.00 ± 2.90 vs 11.58 ± 2.41 cm/s; $p < 0.001$). Right ventricular dilation was strongly associated with pulmonary hypertension (OR 28.33, 95% CI 6.51–123.40). TVPG showed the highest discriminatory performance (AUC 0.969). Conclusion: A multiparametric echocardiographic assessment identified substantial right ventricular structural and functional differences associated with pulmonary hypertension. Echocardiography is useful for initial evaluation but should not replace confirmatory hemodynamic assessment. Keywords: Pulmonary Hypertension; Echocardiography; Right Ventricular Dysfunction; Tricuspid Annular Plane Systolic Excursion; Tricuspid Valve Pressure Gradient.

INTRODUCTION

Pulmonary hypertension is a progressive cardiopulmonary condition characterized by an abnormal elevation in pulmonary arterial pressure and is associated with substantial morbidity and mortality. Hemodynamically, pulmonary hypertension is currently defined by a mean pulmonary arterial pressure greater than 20 mmHg at rest, as measured by right-heart catheterization. Pulmonary arterial hypertension represents a specific precapillary subtype of pulmonary hypertension and should therefore be distinguished from pulmonary hypertension caused by left-sided heart disease, lung disease, chronic thromboembolic disease, or other multifactorial conditions (1,2). Although right-heart catheterization

remains the reference standard for confirming and classifying pulmonary hypertension, its invasive nature limits its use as an initial assessment method in all clinically suspected cases (2,3).

The right ventricle is particularly vulnerable to the progressive increase in pulmonary vascular resistance associated with pulmonary hypertension. During the early stages of pressure overload, the right ventricle may compensate through increased contractility and myocardial hypertrophy. Persistent elevation of afterload, however, can lead to progressive right ventricular dilation, impaired systolic function, functional tricuspid regurgitation, interventricular septal displacement, reduced left ventricular filling, systemic venous congestion, and ultimately right-sided heart failure (3–5). Right ventricular function is therefore a major determinant of symptoms, functional status, disease progression, and prognosis in patients with pulmonary hypertension.

Transthoracic echocardiography is widely used as the initial non-invasive imaging modality for patients with symptoms or clinical findings suggestive of pulmonary hypertension. It allows simultaneous evaluation of cardiac structure, right ventricular performance, tricuspid regurgitation, right atrial pressure, and estimated pulmonary arterial pressure. Although echocardiography cannot independently confirm the hemodynamic diagnosis or fully classify the underlying type of pulmonary hypertension, it can identify features associated with an increased echocardiographic probability of the disease and help determine the need for further clinical and invasive assessment (3,4).

Several echocardiographic indices are used to evaluate right ventricular structure and systolic function. Tricuspid annular plane systolic excursion measures longitudinal displacement of the tricuspid annulus and provides a practical estimate of right ventricular systolic performance. Tissue Doppler-derived right ventricular systolic velocity provides an additional assessment of longitudinal myocardial contraction, whereas right ventricular chamber dimensions identify structural remodeling. Tricuspid regurgitation velocity and the derived tricuspid valve pressure gradient are commonly used to estimate pulmonary artery systolic pressure when an adequate Doppler signal is available. Inferior vena cava diameter and inspiratory collapsibility provide indirect information regarding right atrial pressure, while the severity of tricuspid regurgitation may reflect right ventricular and tricuspid annular remodeling under sustained pressure overload (4,6).

Despite their clinical utility, individual echocardiographic measurements have important limitations. Tricuspid annular plane systolic excursion and tissue Doppler systolic velocity assess only selected components of right ventricular contraction and may be influenced by loading conditions, cardiac translation, image quality, and operator technique. Estimates derived from tricuspid regurgitation velocity may also be affected by inadequate Doppler alignment, poor signal quality, or inaccurate estimation of right atrial pressure. Consequently, contemporary assessment of suspected pulmonary hypertension relies on a multiparametric echocardiographic approach rather than interpretation of a single measurement in isolation (3,6,7).

Evidence regarding the relative contribution of routinely available echocardiographic parameters remains limited in many resource-constrained clinical settings, where access to right-heart catheterization and advanced cardiac imaging may be restricted. Evaluation of the relationships between right ventricular function, tricuspid valve pressure gradients, inferior vena cava findings, tricuspid regurgitation severity, right ventricular dilation, and echocardiographic pulmonary hypertension status may improve the interpretation of routine echocardiograms in patients undergoing assessment for suspected disease. Therefore, this study aimed to evaluate right ventricular dysfunction using transthoracic echocardiography and to examine the associations and discriminatory performance of selected echocardiographic parameters in patients assessed for pulmonary hypertension.

MATERIALS AND METHODS

A hospital-based cross-sectional observational study was conducted at Bajwa Hospital, Lahore, Pakistan. The study population comprised adult male and female patients referred for echocardiographic evaluation because of confirmed or clinically suspected pulmonary hypertension. Patients were eligible when they were between 18 and 70 years of age and agreed to undergo transthoracic echocardiography. Patients with congenital heart disease, acute pulmonary embolism, or severe pulmonary disease that could substantially compromise echocardiographic image acquisition or interpretation were excluded.

The required sample size was estimated using the single-population proportion formula, (n = Z^2p(1-p)/E^2), with a 95% confidence level and an anticipated proportion of 5%. A total of 62 participants were included in the final analysis. Participants were selected using a random sampling approach from patients meeting the eligibility criteria during the study period.

Each participant underwent clinical evaluation followed by transthoracic echocardiography. Demographic and clinical information included age, sex, and principal presenting symptom. The symptoms recorded in the study dataset were chest pain, fatigue, dyspnea, and syncope. Echocardiographic assessment included right ventricular size, tricuspid annular plane systolic excursion, tricuspid valve pressure gradient, right ventricular systolic tissue Doppler velocity, tricuspid regurgitation velocity and severity, estimated pulmonary artery systolic pressure, and inferior vena cava diameter and collapsibility. The presence or absence of echocardiographic pulmonary hypertension was recorded as the principal study outcome.

Right ventricular structural remodeling was assessed by documenting whether the right ventricle was dilated. Right ventricular longitudinal systolic function was evaluated using tricuspid annular plane systolic excursion and tissue Doppler-derived right ventricular systolic velocity. Tricuspid valve pressure gradient was obtained from the peak tricuspid regurgitation velocity using the simplified Bernoulli relationship, and pulmonary artery systolic pressure was estimated by incorporating the echocardiographic estimate of right atrial pressure where an adequate tricuspid regurgitation signal was available. Inferior vena cava collapsibility was evaluated during respiration and recorded categorically. Tricuspid regurgitation was classified as mild, moderate, or severe according to the echocardiographic assessment. The individual parameters were interpreted collectively because no single echocardiographic measurement is sufficient to confirm or exclude pulmonary hypertension independently (3,4,6).

Data were analysed using IBM SPSS Statistics version 26.0. Continuous variables were summarized as mean, standard deviation, minimum, and maximum, whereas categorical variables were presented as frequencies and percentages. Continuous echocardiographic measurements were compared between participants with and without echocardiographic pulmonary hypertension using independent-samples t-tests. Equality of variances was assessed before selecting the conventional or Welch-adjusted test result. Mean differences were interpreted together with their corresponding 95% confidence intervals.

Associations between pulmonary hypertension status and categorical echocardiographic findings, including right ventricular dilation, inferior vena cava collapsibility, and tricuspid regurgitation grade, were assessed using the Pearson chi-square test or Fisher's exact test when expected cell frequencies were insufficient. Categorical variables were not treated as continuous measurements for independent-samples t-testing. All statistical tests were two-sided, and a p-value below 0.05 was considered statistically significant.

Receiver operating characteristic curve analysis was used to examine the discriminatory performance of continuous echocardiographic parameters for identifying participants classified as having echocardiographic pulmonary hypertension. The direction of each test variable was specified according to its clinical interpretation: higher tricuspid valve pressure gradients indicated a greater probability of

pulmonary hypertension, whereas lower tricuspid annular plane systolic excursion and lower right ventricular systolic tissue Doppler velocity indicated poorer right ventricular systolic function. Areas under the curve were interpreted with their 95% confidence intervals. Where the available data permitted, clinically relevant cut-off values were evaluated using sensitivity and specificity rather than relying on the area under the curve alone.

A conventional multivariable logistic regression model containing multiple correlated echocardiographic variables was not considered suitable for definitive coefficient interpretation when complete or near-complete separation prevented stable model convergence. Inferential conclusions were therefore based primarily on appropriately selected continuous-variable comparisons, categorical association tests, and directionally specified receiver operating characteristic analyses. All analyses used the 62 participants with available outcome data, and denominators were checked against the source dataset before final reporting.

RESULTS

A total of 62 participants were included in the analysis. Their mean age was 50.90 ± 13.25 years, with a reported range of 26–80 years. Chest pain was recorded as the principal presenting symptom in 17 participants (27.4%), followed by fatigue in 16 (25.8%), dyspnea in 15 (24.2%), and syncope in 14 (22.6%).

The mean tricuspid annular plane systolic excursion was 16.63 ± 4.34 mm, the mean tricuspid valve pressure gradient was 41.60 ± 12.64 mmHg, and the mean right ventricular systolic tissue Doppler velocity was 10.02 ± 3.01 cm/s. Right ventricular dilation was present in 42 participants (67.7%), while absent inferior vena cava collapsibility was recorded in 40 (64.5%). Echocardiographic pulmonary hypertension was identified in 38 participants (61.3%). Tricuspid regurgitation was mild in 25 participants (40.3%), moderate in 23 (37.1%), and severe in 14 (22.6%).

Participants classified as having pulmonary hypertension demonstrated significantly poorer right ventricular systolic function than those without pulmonary hypertension. Mean TAPSE was 14.79 ± 4.22 mm in the pulmonary hypertension group compared with 19.54 ± 2.60 mm in the group without pulmonary hypertension. The adjusted mean difference was −4.75 mm (95% CI, −6.48 to −3.02; $p < 0.001$), corresponding to a large standardized effect size of Hedges' $g = -1.27$.

The mean tricuspid valve pressure gradient was substantially higher among participants with pulmonary hypertension than among those without pulmonary hypertension, at 49.79 ± 7.95 versus 28.63 ± 5.98 mmHg. The mean difference was 21.16 mmHg (95% CI, 17.61–24.71; $p < 0.001$), with a very large standardized effect size of Hedges' $g = 2.88$. Right ventricular systolic tissue Doppler velocity was also lower in the pulmonary hypertension group, with mean values of 9.00 ± 2.90 versus 11.58 ± 2.41 cm/s. The corresponding mean difference was −2.58 cm/s (95% CI, −3.95 to −1.21; $p < 0.001$; Hedges' $g = -0.93$).

Right ventricular dilation was strongly associated with pulmonary hypertension. Among participants with pulmonary hypertension, 35 of 38 (92.1%) had right ventricular dilation, compared with 7 of 24 (29.2%) participants without pulmonary hypertension. Participants with right ventricular dilation had approximately 28 times greater odds of being classified as having pulmonary hypertension than those without dilation (odds ratio, 28.33; 95% CI, 6.51–123.40; $p < 0.001$).

Table 1. Demographic and Clinical Characteristics of Participants

Variable	Category or Summary	n (%) or Mean ± SD
Age, years	—	50.90 ± 13.25
Age range, years	—	26–80
Presenting symptom	Chest pain	17 (27.4)
	Fatigue	16 (25.8)
	Dyspnea	15 (24.2)
	Syncope	14 (22.6)

Values are presented as mean ± standard deviation or n (%). The presenting-symptom categories represent the principal symptom recorded for each participant. Total N = 62.

Table 2. Echocardiographic Characteristics of the Study Population

Parameter	Category or Summary	n (%) or Mean ± SD
TAPSE, mm	—	16.63 ± 4.34
TAPSE range, mm	—	1–30
TVPG, mmHg	—	41.60 ± 12.64
TVPG range, mmHg	—	19–68
RV S′ TDI, cm/s	—	10.02 ± 3.01
RV S′ TDI range, cm/s	—	4–16
Right ventricular dilation	Present	42 (67.7)
	Absent	20 (32.3)
IVC collapsibility	Present	22 (35.5)
	Absent	40 (64.5)
Echocardiographic pulmonary hypertension	Present	38 (61.3)
	Absent	24 (38.7)
Tricuspid regurgitation grade	Mild	25 (40.3)
	Moderate	23 (37.1)
	Severe	14 (22.6)

TAPSE, tricuspid annular plane systolic excursion; TVPG, tricuspid valve pressure gradient; RV S′ TDI, right ventricular systolic tissue Doppler velocity; IVC, inferior vena cava. Total N = 62.

Table 3. Comparison of Continuous Echocardiographic Parameters According to Pulmonary Hypertension Status

Parameter	PH Present, n = 38 Mean ± SD	PH Absent, n = 24 Mean ± SD	Mean Difference (95% CI)	Welch t	df	p-value	Hedges' g
TAPSE, mm	14.79 ± 4.22	19.54 ± 2.60	−4.75 (−6.48 to −3.02)	−5.48	59.99	<0.001	−1.27
TVPG, mmHg	49.79 ± 7.95	28.63 ± 5.98	21.16 (17.61 to 24.71)	11.92	58.06	<0.001	2.88
RV S′ TDI, cm/s	9.00 ± 2.90	11.58 ± 2.41	−2.58 (−3.95 to −1.21)	−3.79	55.48	<0.001	−0.93

Mean differences were calculated as PH present minus PH absent. Welch's independent-samples t-test was used because it does not require equal group variances. Negative effect estimates for TAPSE and RV S′ TDI indicate lower values among participants with pulmonary hypertension. CI, confidence interval; PH, pulmonary hypertension.

Table 4. Association Between Right Ventricular Dilation and Pulmonary Hypertension

Right Ventricular Dilation	PH Present, n = 38	PH Absent, n = 24	Total	Odds Ratio (95% CI)	p-value
Present	35 (92.1)	7 (29.2)	42	28.33 (6.51–123.40)	<0.001
Absent	3 (7.9)	17 (70.8)	20	Reference	—

Values are n (% within pulmonary hypertension group). Pearson $\chi^2 = 26.665$, df = 1. The odds ratio represents the odds of pulmonary hypertension among participants with right ventricular dilation compared with those without dilation.

Table 5. Association Between Tricuspid Regurgitation Grade and Pulmonary Hypertension

Tricuspid Regurgitation Grade	PH Present, n = 38	PH Absent, n = 24	Total
Mild	1 (2.6)	24 (100.0)	25
Moderate	23 (60.5)	0 (0.0)	23
Severe	14 (36.8)	0 (0.0)	14
Total	38 (100.0)	24 (100.0)	62

Values are n (% within pulmonary hypertension group). Pearson $\chi^2 = 57.954$, df = 2, $p < 0.001$. Because zero cell frequencies were present, conventional odds ratios were not estimated.

Table 6. Discriminatory Performance of Continuous Echocardiographic Parameters for Pulmonary Hypertension

Parameter	Original AUC	Clinically Oriented AUC	Direction Associated With PH	Interpretation
TAPSE	0.106	0.894	Lower values	Good discrimination
TVPG	0.969	0.969	Higher values	Excellent discrimination
RV S′ TDI	0.155	0.845	Lower values	Good discrimination
IVC collapsibility coding	0.924	0.924	According to reported coding	Excellent discrimination

The clinically oriented AUC for TAPSE and RV S′ TDI was obtained by reversing the test direction because lower values indicate greater right ventricular dysfunction. AUC, area under the receiver operating characteristic curve; PH, pulmonary hypertension.

Tricuspid regurgitation grade also differed markedly according to pulmonary hypertension status. All 24 participants without pulmonary hypertension had mild tricuspid regurgitation. In contrast, 23 of 38 participants with pulmonary hypertension (60.5%) had moderate tricuspid regurgitation and 14 (36.8%) had severe tricuspid regurgitation. The association between tricuspid regurgitation grade and pulmonary hypertension was statistically significant ($\chi^2 = 57.954$, df = 2, $p < 0.001$).

Receiver operating characteristic analysis demonstrated excellent discrimination for tricuspid valve pressure gradient, with an area under the curve of 0.969. Inferior vena cava collapsibility coding also showed a high reported area under the curve of 0.924. The initially reported areas under the curve for TAPSE and right ventricular systolic tissue Doppler velocity were 0.106 and 0.155, respectively. Because lower values of these parameters indicate poorer right ventricular function, reversal of the test direction produced clinically oriented areas under the curve of 0.894 for TAPSE and 0.845 for right ventricular systolic tissue Doppler velocity, indicating good rather than poor discriminatory performance.

The originally reported multivariable logistic regression model reached complete or near-complete separation and did not converge, as reflected by a −2 log likelihood of zero, a Nagelkerke R^2 of 1.000, extremely large standard errors, and unstable coefficient estimates. The individual regression coefficients were therefore not interpreted as reliable measures of association. The principal inferential findings were instead based on continuous-variable comparisons, categorical association tests, odds ratios, and directionally corrected receiver operating characteristic analyses.

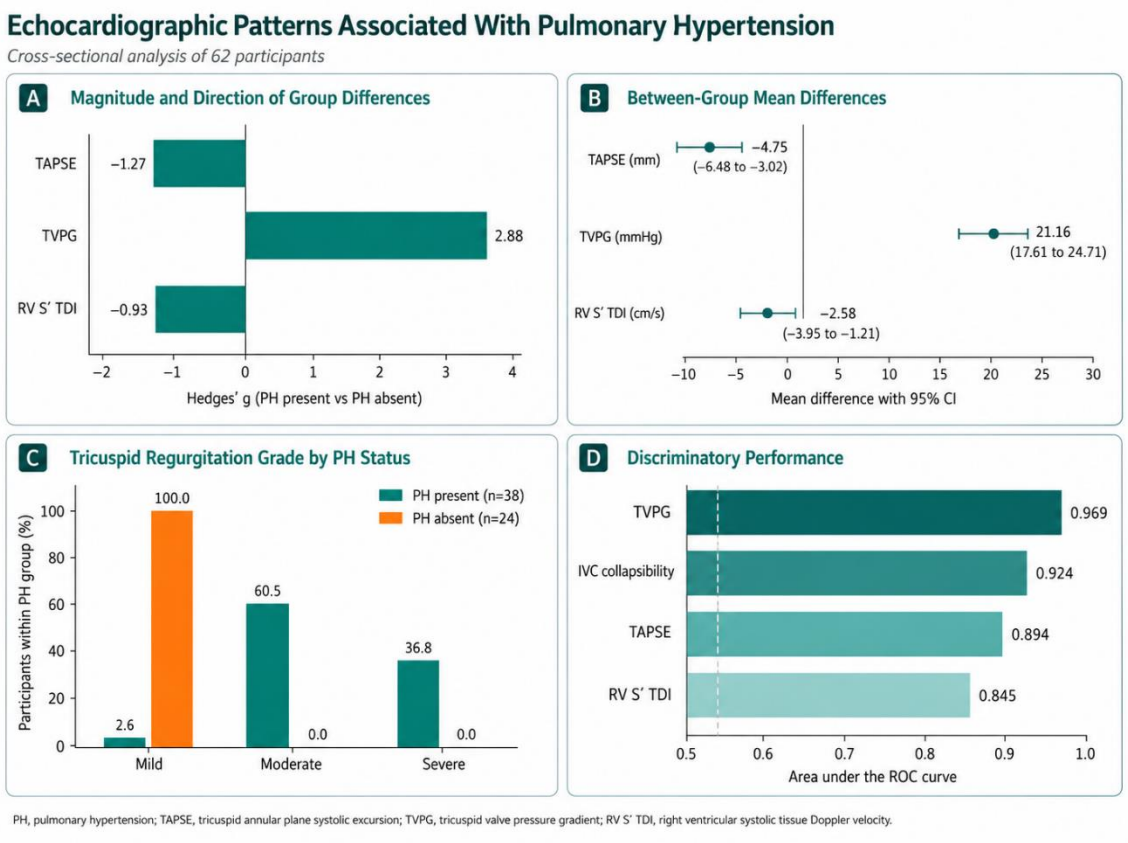

Figure 1. Echocardiographic patterns associated with pulmonary hypertension. Panel A shows large standardized differences between participants with and without pulmonary hypertension for TAPSE (Hedges' g = −1.27), TVPG (g = 2.88), and RV S′ TDI (g = −0.93). Panel B presents the corresponding mean differences with 95% confidence intervals: −4.75 mm for TAPSE, 21.16 mmHg for TVPG, and −2.58 cm/s for RV S′ TDI. Panel C demonstrates that moderate or severe tricuspid regurgitation occurred almost exclusively among PH-positive participants, whereas all PH-negative participants had mild regurgitation. Panel D shows

excellent discrimination for TVPG (AUC = 0.969) and IVC collapsibility (AUC = 0.924), with good discrimination for directionally corrected TAPSE (AUC = 0.894) and RV S' TDI (AUC = 0.845).

DISCUSSION

This study evaluated right ventricular function and related echocardiographic findings among 62 patients assessed for pulmonary hypertension. Participants classified as having echocardiographic pulmonary hypertension had significantly lower tricuspid annular plane systolic excursion and right ventricular systolic tissue Doppler velocity, together with substantially higher tricuspid valve pressure gradients. Right ventricular dilation and moderate-to-severe tricuspid regurgitation were also strongly associated with pulmonary hypertension status. Among the continuous parameters, tricuspid valve pressure gradient demonstrated the highest discriminatory performance, while directionally corrected analyses indicated that tricuspid annular plane systolic excursion and right ventricular systolic tissue Doppler velocity also had good discriminatory ability.

The higher tricuspid valve pressure gradient observed among participants with pulmonary hypertension is consistent with the established role of Doppler echocardiography in estimating pressure differences across the tricuspid valve and assessing the probability of elevated pulmonary arterial pressure. Tricuspid regurgitation velocity and its derived pressure gradient are commonly incorporated into the initial echocardiographic assessment of suspected pulmonary hypertension, although these estimates remain dependent on signal quality, Doppler alignment, and right atrial pressure estimation (3,4). In the present study, the large mean difference in tricuspid valve pressure gradient between participants with and without pulmonary hypertension suggests that this parameter provided substantial separation between the two groups. However, because the pulmonary hypertension classification may itself have incorporated pressure-gradient information, the observed discriminatory performance should be interpreted as internal agreement within the echocardiographic assessment rather than validation against an independent diagnostic reference standard.

Tricuspid annular plane systolic excursion was significantly lower among participants with pulmonary hypertension. This finding reflects impaired longitudinal shortening of the right ventricle under sustained pressure overload. Tricuspid annular plane systolic excursion is widely used because it is rapid, reproducible, and clinically interpretable, although it evaluates only one component of right ventricular contraction and is influenced by loading conditions and overall cardiac motion (4,6). The directionally corrected area under the receiver operating characteristic curve indicated good discrimination, supporting its clinical value as part of a broader right ventricular assessment rather than as an isolated diagnostic test.

Right ventricular systolic tissue Doppler velocity was also lower in the pulmonary hypertension group. Tissue Doppler-derived systolic velocity provides information regarding longitudinal right ventricular myocardial motion and may identify impaired systolic performance when interpreted alongside structural and hemodynamic measurements. Previous research has demonstrated that quantitative echocardiographic assessment of right ventricular function provides clinically meaningful prognostic and functional information in patients evaluated for pulmonary hypertension (6,7). The present findings similarly indicate that reduced right ventricular systolic velocity is associated with echocardiographic pulmonary hypertension, although its performance was lower than that of the tricuspid valve pressure gradient.

Right ventricular dilation was present in 92.1% of participants with pulmonary hypertension compared with 29.2% of those without pulmonary hypertension. The corresponding odds ratio indicated a strong association between right ventricular enlargement and pulmonary hypertension status. Progressive elevation in pulmonary vascular resistance increases right ventricular afterload, initially producing compensatory hypertrophy and increased contractility. With sustained pressure overload, the right ventricle may dilate, wall stress may increase, and systolic function may deteriorate (3,5,9). The high

prevalence of right ventricular dilation in the pulmonary hypertension group is therefore physiologically plausible and consistent with advanced structural adaptation to increased afterload.

Tricuspid regurgitation severity also differed markedly between the groups. All participants without pulmonary hypertension had mild tricuspid regurgitation, whereas nearly all participants with pulmonary hypertension had moderate or severe regurgitation. Increased right ventricular pressure and progressive chamber enlargement may cause tricuspid annular dilation and leaflet tethering, leading to functional tricuspid regurgitation. Worsening regurgitation can further increase right-sided volume overload and contribute to systemic venous congestion (3,5). Nevertheless, the near-complete separation observed between tricuspid regurgitation categories and pulmonary hypertension status raises the possibility that tricuspid regurgitation severity contributed directly to the classification of pulmonary hypertension or that the sample included a restricted clinical spectrum. This finding should therefore be confirmed in a larger sample using an independent reference standard.

Inferior vena cava collapsibility showed a high reported area under the receiver operating characteristic curve. Reduced respiratory collapse of the inferior vena cava may reflect increased right atrial pressure and systemic venous congestion. However, its interpretation depends on the measurement protocol, respiratory effort, volume status, and categorical coding method. Because the manuscript recorded inferior vena cava collapsibility as a categorical variable but originally analysed it using numerical coding, its diagnostic performance requires confirmation after the coding scheme and operational definition have been verified.

The corrected receiver operating characteristic analysis is an important aspect of the revised interpretation. The originally reported areas under the curve for tricuspid annular plane systolic excursion and right ventricular systolic tissue Doppler velocity were below 0.50 because lower, rather than higher, values indicated greater right ventricular dysfunction. Reversing the direction of these variables produced areas under the curve of 0.894 and 0.845, respectively. These values suggest that both parameters were informative, but neither should be interpreted independently of the broader clinical and echocardiographic assessment. A multiparametric approach is preferable because right ventricular structure, systolic performance, pressure estimation, tricuspid regurgitation, and right atrial pressure provide complementary information (4,6).

The originally reported multivariable logistic regression model achieved apparent complete classification but failed to converge and produced extremely large standard errors. These findings are characteristic of complete or near-complete separation and do not provide reliable evidence of perfect diagnostic performance. The problem was likely intensified by the small sample, the inclusion of several highly correlated echocardiographic variables, and the possibility that some predictors were involved in defining pulmonary hypertension status. The individual regression coefficients and odds ratios from that model should therefore not be interpreted. Future analyses should use a smaller set of clinically distinct predictors, prespecified model development procedures, and penalized regression methods where separation persists.

The study has several strengths. It examined multiple routinely available echocardiographic indicators, compared structural and functional findings, and demonstrated internally consistent differences in right ventricular performance between the study groups. The large observed differences in tricuspid valve pressure gradient, tricuspid annular plane systolic excursion, right ventricular systolic tissue Doppler velocity, right ventricular dilation, and tricuspid regurgitation grade support the clinical relevance of comprehensive right-heart assessment in patients undergoing evaluation for suspected pulmonary hypertension.

Several limitations must also be considered. The study was conducted at a single hospital and included only 62 participants, which limits precision and generalizability. The cross-sectional design does not establish temporal or causal relationships and cannot determine whether the echocardiographic findings

predict disease progression or clinical outcomes. The pulmonary hypertension classification was not validated against simultaneous right-heart catheterization, and the exact classification algorithm was not fully documented. Incorporation bias may therefore have inflated the associations and receiver operating characteristic results, particularly for tricuspid valve pressure gradient and tricuspid regurgitation severity. The reported age range included an individual older than the stated eligibility limit, and the gender frequencies were internally inconsistent and therefore could not be reliably reported. Echocardiographic measurements are also dependent on image quality and operator technique, while interobserver and intraobserver reliability were not evaluated. Finally, receiver operating characteristic confidence intervals, diagnostic cut-offs, sensitivity, specificity, and predictive values were unavailable and should be reported in future studies.

Overall, the findings support the clinical usefulness of a structured, multiparametric echocardiographic assessment of the right ventricle in patients evaluated for pulmonary hypertension. The results should not, however, be interpreted as demonstrating that echocardiography can definitively confirm or rule out pulmonary hypertension. Further prospective research using standardized echocardiographic protocols, independent right-heart catheterization findings, larger multicentre samples, and externally validated diagnostic thresholds is required.

CONCLUSION

Patients classified as having echocardiographic pulmonary hypertension demonstrated lower tricuspid annular plane systolic excursion and right ventricular systolic tissue Doppler velocity, higher tricuspid valve pressure gradients, more frequent right ventricular dilation, and greater tricuspid regurgitation severity than those without pulmonary hypertension. Tricuspid valve pressure gradient showed the highest discriminatory performance, while tricuspid annular plane systolic excursion and right ventricular systolic tissue Doppler velocity also provided clinically relevant information after correction of the receiver operating characteristic direction. These findings support the use of a multiparametric echocardiographic approach for the initial evaluation of suspected pulmonary hypertension, but confirmatory classification should not rely on echocardiographic findings alone.

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