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Original Research Article

EVALUATION OF RIGHT VENTRICULAR DYSFUNCTION WITH 2D ECHO AND ITS ASSOCIATION WITH MULTIDIMENSIONAL SCORING SYSTEM (BODE INDEX) IN COPD PATIENTS

Aditi Singh[1], Ram Mohan Rao Bongu[2], Mohd. Raheem Hussain[3], K. Ramesh Kumar[4], Chukkala Mounika[5]

[1]*Post Graduate, Department of Respiratory Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.*
[2]*Assistant Professor, Department of General Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.*
[3]*Professor, Department of Respiratory Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.*
[4]*HOD & Professor, Department of Respiratory Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.*
[5]*Post Graduate, Department of Respiratory Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.*

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Corresponding Author:
Dr. K. Ramesh Kumar,
HOD & Professor, Department of Respiratory Medicine, Bhaskar Medical College and Hospital, Moinabad, Telangana, India.

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ABSTRACT

Background: Chronic obstructive pulmonary disease (COPD) is associated with airflow limitation and cardiovascular complications, including pulmonary hypertension and right ventricular dysfunction. The BODE index provides multidimensional assessment of COPD severity. This study evaluated the relationship between BODE staging and echocardiographic parameters of right ventricular function and pulmonary hypertension.

Materials and Methods: Sixty patients with COPD were evaluated using GOLD and BODE staging. Echocardiographic assessment included tricuspid regurgitation (TR) velocity, right ventricular systolic pressure (RVSP), and tricuspid annular plane systolic excursion (TAPSE). Associations between BODE stage and echocardiographic variables were assessed, along with correlation and logistic regression analyses.

Results: The mean age was 60.81 ± 9.37 years, with males comprising 66.7% of participants. BODE stage 3 was most frequent (31.7%), followed by stage 4 (26.7%). Smoking status was associated with BODE stage ($p<0.001$), whereas pollution exposure and illness duration were not. GOLD and BODE staging showed a positive correlation ($r=0.993$, $p<0.001$). TR velocity and RVSP increased with advancing BODE stage, while TAPSE decreased ($p<0.001$ for all). Pulmonary hypertension was associated with BODE stage ($p<0.001$) and was absent in stages 1 and 2. BODE score correlated positively with TR velocity ($r=0.753$), RVSP ($r=0.963$), and pulmonary hypertension ($r=0.484$), and negatively with TAPSE ($r=-0.813$; $p<0.001$ for all). On logistic regression, TR velocity was the only independent predictor of pulmonary hypertension (OR=17.153, $p=0.007$).

Conclusion: Increasing BODE severity is associated with worsening right ventricular function and pulmonary vascular involvement in COPD. Integrating BODE assessment with echocardiography, particularly TR velocity, may facilitate recognition of cardiovascular complications and improve prognostic assessment.

Keywords: Chronic obstructive pulmonary disease; BODE index; BODE staging; Pulmonary hypertension; Right ventricular dysfunction; Echocardiography; Tricuspid regurgitation velocity; Right ventricular systolic pressure; TAPSE; COPD severity.

INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) has emerged as one of the leading global health challenges, currently ranking among the top three causes of mortality worldwide. A significant burden of COPD related deaths occurs in low- and middle-income countries, where exposure to environmental pollutants, tobacco smoke, and biomass fuel combustion remains high. Given the progressive nature and systemic manifestations of COPD, early identification of prognostic markers is essential to reduce morbidity, prevent complications, and improve survival outcomes.[1]

COPD is characterized by persistent respiratory symptoms and irreversible airflow limitation resulting from chronic inflammation of the airways and lung parenchyma. Patients typically present with dyspnea, chronic cough, and sputum production, which progressively worsen as airflow obstruction advances. According to the GOLD criteria, spirometry particularly the post-bronchodilator FEV1 remains the cornerstone for diagnosing and grading the severity of COPD. However, FEV1 alone does not adequately reflect the full clinical spectrum or predict long-term outcomes, as it correlates only modestly with symptoms such as dyspnea, exercise limitation, and overall functional status.[2]

The systemic consequences of COPD extend beyond the lungs and impose a substantial impact on cardiovascular function. Chronic hypoxemia, pulmonary vasoconstriction, and vascular remodeling increase pulmonary arterial pressures, gradually leading to right ventricular (RV) hypertrophy, dilation, and eventual RV failure collectively termed cor pulmonale. RV dysfunction often develops insidiously and is associated with poor prognosis once clinically evident. Early identification of RV structural and functional impairment is therefore vital for timely intervention. Echocardiography, a widely accessible non-invasive tool, permits detailed assessment of RV morphology, systolic performance, and estimation of pulmonary pressures using parameters such as tricuspid regurgitation velocity (TRV) and tricuspid annular plane systolic excursion (TAPSE).[3,4]

Although echocardiography helps detect cardiovascular complications, COPD prognosis is influenced by multiple interdependent factors. To address this complexity, the BODE Index a multidimensional scoring system incorporating Body Mass Index (BMI), Airflow Obstruction (FEV1), Dyspnea severity, and Exercise capacity (6-minute walk test) was developed as a superior predictor of mortality compared to spirometry alone. The BODE index integrates pulmonary and extrapulmonary components of COPD, thus reflecting both disease severity and systemic involvement. Patients with higher BODE scores are known to have increased hospitalization rates, reduced quality of life, and poorer survival.

Cardiovascular-related mortality is the second most common cause of death in COPD patients after lung cancer. Several studies highlight a strong relationship between RV dysfunction and adverse outcomes, yet the interplay between RV impairment and multidimensional indices such as BODE has not been extensively explored. A better understanding of this relationship can enhance prognostic assessment and guide individualized therapeutic strategies. Despite growing evidence that both RV dysfunction and BODE index independently predict morbidity in COPD, limited data exist regarding their direct association, particularly in the Indian population where risk factors and disease patterns may differ.[5]

Given these gaps, the present study aims to investigate the prevalence and severity of right ventricular dysfunction in COPD patients using 2D echocardiography and to evaluate how these findings correlate with BODE index stages. Establishing such an association may strengthen the role of echocardiography as a complementary prognostic tool and aid clinicians in identifying high-risk individuals at earlier stages of disease progression. Ultimately, integrating cardiac evaluation into COPD management may contribute to improved patient outcomes, better resource allocation, and more holistic care for individuals affected by this increasingly prevalent condition.

MATERIALS AND METHODS

Study Design: This research is designed as a prospective, observational, hospital-based study conducted over a defined period of 18 months. The study focuses on evaluating right ventricular dysfunction in patients with clinically and spirometrically confirmed Chronic Obstructive Pulmonary Disease (COPD). As an observational design, no experimental intervention or drug administration is involved; instead, natural disease characteristics and associated cardiac changes are assessed systematically.

Study Setting: The study will be carried out in the Department of Pulmonary Medicine, Bhaskar Medical College & Bhaskar General Hospital, Hyderabad, Telangana. All evaluations including clinical assessment, spirometry, and echo cardiography will be performed within the institution's diagnostic facilities under standard protocols.

Study Population

Inclusion Criteria

- Patients diagnosed with COPD based on GOLD criteria, confirmed by spirometry.
- Adults willing to participate and providing written informed consent.

Exclusion Criteria

To ensure accurate assessment of right ventricular changes specifically attributable to COPD, the following patients will be excluded:

Those experiencing acute exacerbation of COPD.

- Patients with pre-existing left-sided heart failure, ischemic heart disease, or rheumatic heart disease.
- Individuals with congenital heart disease.
- Patients undergoing anti-tubercular therapy (ATT) for pulmonary tuberculosis.

Selection and Enrollment of Participants

Consecutive patients meeting inclusion criteria during the study period will be enrolled after obtaining informed written consent. On the day of enrollment, each patient will undergo a comprehensive assessment including detailed history, physical examination, spirometry, functional evaluation, and echocardiography.

Data Collection Procedures

1. Clinical History and Examination

A structured format will be used to document:

- Smoking history (pack-years), environmental exposures, occupational hazards.
- Past medical history including respiratory and cardiovascular illnesses.
- Family history and relevant personal habits.
- Physical examination focusing on anthropometric measurements (height, weight, BMI), vital signs, respiratory findings, cardiovascular assessment, and oxygen saturation.

2. Assessment of BODE Index Components

The BODE Index is composed of four parameters Body Mass Index (B), Airflow Obstruction (O), Dyspnea (D), and Exercise Capacity (E). Each parameter will be evaluated as follows:

A. Body Mass Index (BMI)

BMI will be calculated using the standard formula:
BMI = Weight (kg) / Height (m2)
Patients will be categorized according to BODE scoring criteria:

- 0 points: BMI > 21 kg/m2
- 1 point: BMI ≤ 21 kg/m2

B. Airflow Obstruction

Spirometry will be conducted adhering to American Thoracic Society (ATS) standards. Each patient will perform the test before and 20 minutes after inhalation of salbutamol nebulization.

- Forced Expiratory Volume in 1 second (FEV1) predicted % values will determine the obstruction score:

0 points: ≥ 65% predicted
1 point: 50–64% predicted
2 points: 36–49% predicted
3 points: ≤ 35% predicted

Spirometric classification helps quantify airflow limitation and correlates with disease severity.

C. Dyspnea Assessment

Dyspnea severity will be quantified using the Modified Medical Research Council (mMRC) Scale, which includes:

- Grade 0: Breathlessness only with strenuous exercise
- Grade 1: Shortness of breath when hurrying or walking up a slight incline
- Grade 2: Walks slower than people of same age or stops due to breathlessness
- Grade 3: Stops for breath after walking 100 meters or a few minutes
- Grade 4: Too breathless to leave the house or breathless during daily activities Scores are assigned from 0 to 3 based on BODE index scoring.

D. Exercise Tolerance – 6-Minute Walk Test (6MWT): A standardized 25-meter walking track will be used. Each patient will perform two tests, spaced at least 30 minutes apart, and the longer distance will be recorded.

Scoring according to walked distance:

- 0 points: >350 meters
- 1 point: 250–349 meters
- 2 points: 150–249 meters
- 3 points: <150 meters

This test evaluates functional capacity and correlates strongly with COPD severity and overall prognosis.

3. Calculation of the BODE Index

Each of the four components—BMI, FEV1, mMRC dyspnea scale, and 6MWT distance— will be scored, and the total (ranging from 0 to 10) will be used to categorize COPD severity into BODE stages:
Stage 1: Score 0–2
Stage 2: Score 3–4
Stage 3: Score 5–6
Stage 4: Score 7–10

4. Echocardiographic Evaluation (2D Echo)

All participants will undergo transthoracic 2D echocardiography in the left lateral decubitus position. Measurements will be obtained following the recommendations of the American Society of Echocardiography (ASE).

Parameters Recorded

- Right atrial (RA) dilation
- Right ventricular (RV) wall thickness and hypertrophy
- Right ventricular internal diameter
- Inferior vena cava (IVC) diameter
- Tricuspid regurgitation velocity (TRV)
- ≤ 2.8 m/s: normal
- 2.8 m/s: suggests pulmonary hypertension
- Tricuspid Annular Plane Systolic Excursion (TAPSE)
- Normal: ≥ 17 mm (mean referenced as 23.3 ± 3.6 mm in uploaded file) Echocardiography will help evaluate RV structure, systolic function, and estimate pulmonary artery pressures.

5. Correlational Analysis

The collected data will be used to evaluate:

- Prevalence of RV dysfunction in COPD patients.
- Relationship between RV dysfunction parameters and BODE index score.
- Trends in cardiac involvement across BODE stages.

This correlation aims to establish whether right ventricular impairment worsens with increasing COPD severity.

Statistical Analysis: All data will be entered into a secure database. Appropriate statistical tests (ANOVA, chi- square tests, correlation coefficients, etc.) will be used depending on variable type and

distribution. A p-value of <0.05 will be considered statistically significant.

Ethical Considerations: Ethical approval has been obtained from the Institutional Ethical Committee (IEC). Written informed consent will be collected from every participant. Data confidentiality and patient safety will be strictly maintained. No financial burden or experimental therapy will be imposed on participants.

RESULTS

Table 1: Mean comparison of age according to BODE stage

BODE Staging	n	Mean	SD	Test value	P value
Stage 1	11	58.7273	11.03713	0.793	0.503
Stage 2	14	64.0714	7.77040		
Stage 3	19	60.0526	9.75519		
Stage 4	16	60.3125	9.16311		

ANOVA test; p≤0.05 considered statistically significant: No statistically significant difference in mean age was observed across BODE stages (p=0.503). Mean age was 58.73 ± 11.04 years in stage 1 and 64.07 ± 7.77 years in stage 2. Mean ages in stages 3 and 4 were 60.05 ± 9.76 and 60.31 ± 9.16 years, respectively.

Table 2: Comparison of gender according to BODE staging

BODE Staging	Males n	Males %	Females n	Females %	Chi-Square value	P value
Stage 1	6	15	5	25	2.220	0.528
Stage 2	8	20	6	30		
Stage 3	14	35	5	25		
Stage 4	12	30	4	20		

Chi-Square test; p≤0.05 considered statistically significant: Gender distribution did not differ significantly across BODE stages (p=0.528). Males constituted 15%, 20%, 35%, and 30% of the respective BODE stages. Females represented 25%, 30%, 25%, and 20%, respectively. Thus, gender was not significantly associated with BODE staging.

Table 3: Comparison of smoking status according to BODE staging

BODE Staging	Never n	Never %	Former n	Former %	Current n	Current %	Chi-Square value	P value
Stage 1	11	36.7	0	0	0	0	43.866	<0.001*
Stage 2	14	46.7	0	0	0	0		
Stage 3	4	13.3	9	47.4	6	54.5		
Stage 4	1	3.3	10	52.6	5	45.5		

Chi-Square test; p≤0.05 considered statistically significant

Smoking status was significantly associated with BODE stage (p<0.001). All subjects in BODE stages 1 and 2 were never smokers. Stages 3 and 4 showed a predominance of former and current smokers. The findings demonstrate a strong association between smoking status and increasing BODE severity.

Table 4: Comparison of pollution exposure according to BODE staging

BODE Staging	Low n	Low %	Moderate n	Moderate %	High n	High %	Chi-Square value	P value
Stage 1	5	45.5	5	20.8	1	4	10.517	0.105
Stage 2	2	18.2	6	25.0	6	24		
Stage 3	1	9.1	7	29.2	11	44		
Stage 4	3	27.3	6	25.0	7	28		

Chi-Square test; p≤0.05 considered statistically significant

No significant association was found between pollution exposure and BODE stage (p=0.105). Low, moderate, and high exposure levels were distributed variably across the BODE stages. Although high pollution exposure was more frequent in stage 3, the overall association did not reach statistical significance.

Table 5: Mean comparison of duration of illness according to BODE stage

BODE Staging	n	Mean	SD	Test value	P value
Stage 1	11	18.0000	6.19677	1.746	0.168
Stage 2	14	14.5714	7.53162		
Stage 3	19	14.9474	6.29350		
Stage 4	16	12.0625	6.57742		

Kruskal-Wallis test; p≤0.05 considered statistically significant

No statistically significant difference in illness duration was observed across BODE stages (p=0.168). Mean duration was highest in stage 1 (18.00 ± 6.20 years) and lowest in stage 4 (12.06 ± 6.58 years). The differences in duration across BODE stages were not statistically significant.

Table 6: Comparison and correlation of GOLD staging with BODE stage

BODE Staging	GOLD Stage 1 n	%	GOLD Stage 2 n	%	GOLD Stage 3 n	%	GOLD Stage 4 n	%
Stage 1	11	100	0	0	0	0	0	0
Stage 2	0	0	14	100	0	0	0	0
Stage 3	0	0	0	0	19	95	0	0
Stage 4	0	0	0	0	1	5	15	100

Statistical parameter	Value
Chi-Square value	173.438
Correlation value	0.993
P value	<0.001*

Chi-Square test; p≤0.05 considered statistically significant

GOLD staging showed an extremely strong positive correlation with BODE stage (r=0.993, p<0.001). All subjects in BODE stage 1 were GOLD stage 1, and all subjects in BODE stage 2 were GOLD stage 2. Similarly, 95% of BODE stage 3 subjects were GOLD stage 3, while all BODE stage 4 subjects were GOLD stage 4.

Table 7: Mean comparison of ECG parameters according to BODE staging

Parameters	BODE	n	Mean	SD	Test value	P value
TR Velocity	Stage 1	11	1.9818	0.31880	43.232	<0.001*
	Stage 2	14	2.0071	0.31492		
	Stage 3	19	3.4421	0.27349		
	Stage 4	16	3.3938	0.26700		
RVSP	Stage 1	11	16.9091	1.97254	54.042	<0.001*
	Stage 2	14	24.8571	1.99450		
	Stage 3	19	34.9474	2.04053		
	Stage 4	16	48.9375	4.20268		
TAPSE	Stage 1	11	22.1818	2.27236	41.074	<0.001*
	Stage 2	14	20.1429	1.74784		
	Stage 3	19	16.6316	1.60591		
	Stage 4	16	15.2500	1.73205		

Kruskal-Wallis test; p≤0.05 considered statistically significant

All three echocardiographic parameters differed significantly across BODE stages (p<0.001). TR velocity and RVSP increased progressively with advancing BODE stage. In contrast, TAPSE decreased from 22.18 ± 2.27 mm in stage 1 to 15.25 ± 1.73 mm in stage 4. These findings indicate worsening pulmonary vascular involvement and right ventricular function with increasing BODE severity.

Table 7: Pairwise comparison – post hoc analysis

Comparison between	TR Velocity P value	RVSP P value	TAPSE P value
Stage 1 – Stage 2	1.000	0.450	1.000
Stage 1 – Stage 3	<0.001*	<0.001*	<0.001*
Stage 1 – Stage 4	<0.001*	<0.001*	<0.001*
Stage 2 – Stage 3	<0.001*	0.033*	0.004*
Stage 2 – Stage 4	<0.001*	<0.001*	<0.001*
Stage 3 – Stage 4	1.000	0.034*	0.965

Post-hoc analysis demonstrated significant differences predominantly between lower and higher BODE stages. TR velocity and TAPSE showed no significant differences between stages 1 and 2 or between stages 3 and 4. RVSP showed significant differences between several stages, including stage 3 versus stage 4 (p=0.034). Overall, the findings support progressive echocardiographic deterioration with increasing BODE stage.

Table 8: Categorization of subjects according to the ECG parameter cut-off scores

Parameters	Category	n	%
TR Velocity	Normal (≤3.4 m/s)	43	71.7
	High (>3.4 m/s)	17	28.3
RVSP	Normal (≤50 mmHg)	54	90
	High (>50 mmHg)	6	10
TAPSE	Normal (≥17mm)	36	60
	High (<17mm)	24	40

Most subjects had normal TR velocity (71.7%) and normal RVSP (90%). Normal TAPSE was observed in 60% of subjects, while 40% had values below the specified cut-off. High values were observed in 28.3% for TR velocity and 10% for RVSP.

Table 9: Comparison of ECG categories according to BODE staging

ECG	Category	Stage 1 n	Stage 1 %	Stage 2 n	Stage 2 %	Stage 3 n	Stage 3 %	Stage 4 n	Stage 4 %
TR Velocity	Normal	11	25.6	14	32.6	10	23.3	8	18.6
	High	0	0	0	0	9	52.9	8	47.1
	Value							16.973	
	P value							0.001*	
RVSP	Normal	11	20.4	14	25.9	19	35.2	10	18.5
	High	0	0	0	0	0	0	6	100
	Value							18.333	
	P value							<0.001*	
TAPSE	Normal	11	30.6	14	38.9	9	25	2	5.6
	High	0	0	0	0	10	41.7	14	58.3
	Value							32.971	
	P value							<0.001*	

The distribution of echocardiographic categories differed significantly across BODE stages for TR velocity, RVSP, and TAPSE. High TR velocity was observed only in BODE stages 3 and 4. All high RVSP values occurred in stage 4, while reduced TAPSE was observed only in stages 3 and 4. These findings demonstrate a significant association between increasing BODE stage and abnormal echocardiographic parameters.

Table 10: Comparison of pulmonary hypertension according to BODE staging

BODE Staging	No n	No %	Yes n	Yes %	Chi-Square value	P value
Stage 1	11	26.8	0	0	20.111	<0.001*
Stage 2	14	34.1	0	0		
Stage 3	8	19.5	11	57.9		
Stage 4	8	19.5	8	42.1		

Chi-Square test; p≤0.05 considered statistically significant

Pulmonary hypertension was significantly associated with BODE stage (p<0.001). No cases of pulmonary hypertension were observed in BODE stages 1 and 2. Pulmonary hypertension was present in 57.9% of stage 3 and 42.1% of stage 4 subjects. Thus, pulmonary hypertension was predominantly observed in advanced BODE stages.

Table 11: Mean comparison of ECG parameters according to pulmonary hypertension

Parameters	P. HTN	n	Mean	SD	Test value	P value
TR Velocity	No	41	2.5537	0.75435	-3.685	<0.001*
	Yes	19	3.4158	0.32534		
RVSP	No	41	29.7561	12.10533	-3.193	<0.001*
	Yes	19	40.0526	7.83492		
TAPSE	No	41	18.9268	3.25876	-2.775	0.006*
	Yes	19	16.3158	2.13574		

Mann-Whitney U test; p≤0.05 considered statistically significant

Subjects with pulmonary hypertension had significantly higher TR velocity compared with those without pulmonary hypertension (3.42 ± 0.33 vs. 2.55 ± 0.75, p<0.001). RVSP was also significantly higher in subjects with pulmonary hypertension (40.05 ± 7.83 vs. 29.76 ± 12.11, p<0.001). In contrast, TAPSE was significantly lower in subjects with pulmonary hypertension (16.32 ± 2.14 vs. 18.93 ± 3.26, p=0.006).

Table 12: Comparison of ECG categories according to pulmonary hypertension

ECG	Category	No n	No %	Yes n	Yes %	Value	P value
TR Velocity	Normal	34	79.1	9	20.9	8.805	0.004*
	High	7	41.2	10	58.8		
RVSP	Normal	37	68.5	17	31.5	0.009	0.926
	High	4	66.7	2	33.3		
TAPSE	Normal	28	77.8	8	22.2	3.710	0.054
	High	13	54.2	11	45.8		

Chi-Square test; p≤0.05 considered statistically significant

Interpretation: A significant association was observed between TR velocity category and pulmonary hypertension (p=0.004). No significant association was observed for RVSP (p=0.926) or TAPSE (p=0.054). High TR velocity was associated with a greater proportion of subjects having pulmonary hypertension, while reduced TAPSE showed a non-significant trend toward increased pulmonary hypertension.

Table 13: Correlation between the BODE score and ECG parameters

ECG Parameters	BODE score – r value	P value
TR Velocity	0.753	<0.001*
RVSP	0.963	<0.001*
TAPSE	-0.813	<0.001*
Pulmonary hypertension	0.484	<0.001*

Spearman Correlation test; p≤0.05 is considered statistically significant

Interpretation: BODE score showed a strong positive correlation with TR velocity (r=0.753, p<0.001). A very strong positive correlation was observed with RVSP (r=0.963, p<0.001). TAPSE showed a strong negative correlation with BODE score (r=-0.813, p<0.001), while pulmonary hypertension showed a moderate positive correlation (r=0.484, p<0.001).

Table 14: Regression analysis for the presence of pulmonary hypertension

Variables	B	Standard error	Odds ratio	P value
Age	-0.003	0.046	0.997	0.951
Smoking (pack-years)	-0.004	0.017	0.996	0.787
Pollution exposure	-0.532	0.570	0.588	0.351
Illness duration	0.039	0.059	1.040	0.512
TR velocity	2.842	1.052	17.153	0.007*
RVSP	-0.128	0.203	0.880	0.529
TAPSE	0.016	0.204	1.016	0.939
BODE score	0.551	0.803	1.735	0.493

In logistic regression, TR velocity was the only significant independent predictor of pulmonary hypertension (OR=17.153, p=0.007). Age, smoking pack-years, pollution exposure, illness duration, RVSP, TAPSE, and BODE score were not significant predictors (p>0.05). Thus, increased TR velocity showed the strongest independent association with the presence of pulmonary hypertension.

DISCUSSION

Chronic obstructive pulmonary disease (COPD) is a progressive respiratory disorder characterized by persistent airflow limitation and associated systemic manifestations. In addition to pulmonary involvement, COPD has significant extrapulmonary effects, particularly on the cardiovascular system, leading to increased morbidity and mortality. Among these, right ventricular dysfunction and pulmonary hypertension are important complications that influence functional capacity, disease severity, and prognosis.

The assessment of disease severity in COPD has evolved beyond spirometric measurements alone. Multidimensional indices such as the Body Mass Index, Airflow Obstruction, Dyspnea, and Exercise Capacity (BODE) index provide a more comprehensive evaluation of disease burden and better predict clinical outcomes. Increasing BODE scores have been associated with worsening pulmonary function, reduced exercise tolerance, and higher mortality risk.

Echocardiography serves as a non-invasive and practical tool for evaluating right heart structure and function in patients with COPD. Parameters such as tricuspid regurgitation velocity, right ventricular systolic pressure, and tricuspid annular plane systolic excursion offer valuable insights into pulmonary vascular involvement and right ventricular performance. Early detection of these abnormalities is crucial, as cardiovascular complications significantly impact prognosis in COPD.

The present study was undertaken to evaluate the relationship between BODE staging and echocardiographic parameters, including pulmonary hypertension, in patients with COPD. This discussion aims to interpret the findings of the present study by first describing the distribution of variables within the study population, followed by a comparison with previously published studies, and finally analyzing the statistical significance of the observed associations.

Age Distribution: In the present study, the age of the subjects ranged from 40 to 80 years, with a mean age of 60.81 ± 9.37 years. The majority of patients belonged to the 51–60 years and 61– 70 years age groups, each contributing 33.3% of the study population, while 16.7% were seen in the 40–50 and 71–80 years groups. This distribution highlights that chronic obstructive pulmonary disease (COPD) predominantly affects the middle-aged and elderly population.

The increasing prevalence of COPD with advancing age can be explained by cumulative exposure to risk factors such as tobacco smoke, biomass fuel, environmental pollution, and age-related decline in lung function. Structural changes in the lungs, loss of

elastic recoil, and progressive airway remodeling further contribute to disease progression with age.[1,3] Similar age distributions have been reported by Gupta et al,[6] and Nasir et al,[5] where the mean age of COPD patients was above 55 years, emphasizing that COPD is largely a disease of older adults. Large epidemiological studies by Fletcher and Peto,[7] also demonstrated an accelerated decline in lung function after the fifth decade of life. In the present study, age did not show a statistically significant association with BODE staging ($p = 0.503$), indicating that disease severity and functional impairment may progress independently of chronological age.

Gender Distribution: In this study, males constituted 66.7% of the subjects, while females accounted for 33.3%. The male predominance observed reflects traditional smoking patterns and occupational exposure, which remain more common among males in many regions. The higher prevalence of COPD among males has been attributed to higher tobacco consumption and greater exposure to industrial pollutants. However, recent trends indicate a rising burden of COPD among females due to increased biomass fuel exposure and passive smoking.[8]

Studies by Salvi and Ghorpade,[9] from India have emphasized that indoor air pollution plays a significant role in COPD among women, especially in rural settings. Gupta et al.[6] also reported a male predominance similar to the present study. In this study, gender distribution did not show a statistically significant association with BODE staging ($p = 0.528$), suggesting that disease severity progression is not gender- dependent once COPD is established.

Smoking History: In the present study, 50% of subjects were never smokers, 31.7% were former smokers, and 18.3% were current smokers. Among smokers, most had a smoking exposure between 40–60 pack-years. Smoking remains the most important etiological factor for COPD, contributing to airway inflammation, oxidative stress, and parenchymal destruction.[10] Former smokers constituted a substantial proportion, reflecting smoking cessation following diagnosis or symptom progression. Several studies have shown that smoking accelerates decline in lung function and worsens prognosis in COPD. Celli et al,[11] demonstrated that smoking status significantly influences multidimensional indices such as the BODE score. In the present study, smoking status showed a highly significant association with BODE staging ($p < 0.001$). All subjects in BODE stages 1 and 2 were never smokers, whereas stages 3 and 4 had a predominance of former and current smokers. This highlights the strong role of smoking in disease severity and functional decline.

Pollution Exposure: In this study, 41.7% of subjects had high pollution exposure, 40% had moderate exposure, and only 18.3% had low exposure. This emphasizes the contribution of environmental pollution as an important risk factor for COPD. Long-term exposure to ambient air pollution and biomass fuel smoke leads to chronic airway inflammation and vascular remodeling. Studies from India have highlighted pollution as a major contributor to COPD even among non-smokers.[10] However, in the present study, pollution exposure did not show a statistically significant association with BODE staging ($p = 0.105$). This suggests that while pollution contributes to disease onset, its role in determining severity may be overshadowed by factors such as smoking burden and physiological impairment.

Duration of Illness: The mean duration of illness in the present study was 14.65 ± 6.78 years, with a range of 2–24 years. This indicates that most patients had long-standing disease at the time of evaluation. COPD is a slowly progressive disease, and prolonged duration is associated with worsening airflow limitation, pulmonary vascular changes, and right ventricular dysfunction.[12] Despite this, the present study did not find a statistically significant association between duration of illness and BODE staging ($p = 0.168$). This suggests that disease severity is more closely related to physiological impairment rather than duration alone.

GOLD Staging: In the present study, the majority of patients were in GOLD stage 3 (33.3%), followed by stage 4 (25%), stage 2 (23.3%), and stage 1 (18.3%). This reflects that most patients presented with moderate to severe airflow limitation. The GOLD classification remains the cornerstone for assessing airflow obstruction in COPD. Advanced GOLD stages are associated with increased mortality and morbidity. A very strong correlation was observed between GOLD staging and BODE staging in the present study ($r = 0.993$, $p < 0.001$). This finding is consistent with previous studies showing that airflow obstruction significantly influences multidimensional disease severity.[11]

BODE Index and Staging: The mean BODE score in this study was 5.82 ± 2.83 with most patients falling into BODE stage 3 (31.7%) and stage 4 (26.7%). This indicates a high burden of functional impairment among study subjects. The BODE index integrates body mass index, airflow obstruction, dyspnea, and exercise capacity, providing superior prognostic value compared to FEV1 alone. Similar mean BODE scores have been reported by Ong et al,[8] and Marin et al,[13] reinforcing its clinical utility (44,43).

Echocardiographic Parameters and BODE Staging: In the present study, echocardiographic parameters showed significant variation across BODE stages. TR velocity and RVSP increased progressively with advancing BODE stage, while TAPSE showed a significant decline. These findings indicate worsening pulmonary hypertension and right ventricular dysfunction with increasing disease severity. Chronic hypoxia leads to pulmonary vasoconstriction, vascular remodeling, and increased right ventricular afterload. Studies by Nasir et al,[5] Gökdeniz et al,[4] and Fenster et al.[14] have similarly demonstrated worsening right ventricular function with increasing COPD severity. All three parameters showed high statistical significance ($p < 0.001$),

confirming a strong association between BODE staging and right heart dysfunction.

Pulmonary Hypertension: Pulmonary hypertension was present predominantly in BODE stages 3 and 4, with no cases observed in stages 1 and 2. This demonstrates that pulmonary hypertension is a late complication of COPD. Previous studies by Weitzenblum and Chaouat and Vonk-Noordegraaf et al,[15] have emphasized that pulmonary hypertension develops secondary to chronic hypoxia and vascular remodeling in advanced disease. The association between pulmonary hypertension and BODE stage was highly significant ($p < 0.001$), highlighting its prognostic importance.

Correlation and Regression Analysis: The present study demonstrated strong positive correlations between BODE score and TR velocity ($r = 0.753$), RVSP ($r = 0.963$), and pulmonary hypertension ($r = 0.484$), with a strong negative correlation with TAPSE ($r = –0.813$), all of which were statistically significant ($p < 0.001$). Logistic regression analysis identified TR velocity as the only independent predictor of pulmonary hypertension (OR = 17.15, $p = 0.007$), underscoring its diagnostic value. Similar findings have been reported by Armentaro et al,[3] and Hilde et al.[16]

CONCLUSION

The present study was undertaken to evaluate the relationship between disease severity, as assessed by the BODE index, and echocardiographic parameters of right ventricular function and pulmonary hypertension in patients with chronic obstructive pulmonary disease. The findings of this study highlight the close interplay between pulmonary and cardiovascular involvement in COPD and emphasize the importance of a multidimensional approach to disease assessment.

The study population predominantly comprised middle-aged and elderly individuals, with a male preponderance. Most patients belonged to advanced stages of COPD, as reflected by higher GOLD and BODE stages. Smoking emerged as a significant determinant of disease severity, with a strong association observed between smoking status and higher BODE stages. Environmental pollution exposure and duration of illness, although prevalent among the study population, did not show a statistically significant association with BODE staging, suggesting that functional impairment and physiological derangements play a greater role in determining disease severity than exposure duration alone.

A strong positive correlation was demonstrated between GOLD staging and BODE staging, reinforcing the validity of the BODE index as a comprehensive marker of disease severity. More importantly, echocardiographic evaluation revealed progressive worsening of right ventricular function with increasing BODE stage. Tricuspid regurgitation velocity and right ventricular systolic pressure showed a significant stepwise increase, while tricuspid annular plane systolic excursion demonstrated a significant decline with advancing disease severity. These findings indicate increasing pulmonary vascular resistance and declining right ventricular systolic function in patients with severe COPD.

Pulmonary hypertension was observed predominantly in patients with higher BODE stages and was absent in patients with mild disease. The presence of pulmonary hypertension showed a statistically significant association with advanced BODE staging and adverse echocardiographic parameters. Among the echocardiographic variables studied, tricuspid regurgitation velocity emerged as an independent predictor of pulmonary hypertension on regression analysis, underscoring its clinical relevance in routine evaluation.

Correlation analysis further confirmed a strong positive association between BODE score and tricuspid regurgitation velocity, right ventricular systolic pressure, and pulmonary hypertension, along with a strong negative correlation with tricuspid annular plane systolic excursion. These findings collectively suggest that increasing multidimensional disease severity in COPD is closely linked with worsening right ventricular dysfunction and pulmonary vascular involvement.

In conclusion, the present study demonstrates that the BODE index is not only a reliable indicator of pulmonary disease severity but also a valuable marker of cardiovascular involvement in COPD. Routine incorporation of echocardiographic assessment, particularly in patients with higher BODE scores, may facilitate early detection of right ventricular dysfunction and pulmonary hypertension, allowing timely intervention and potentially improving clinical outcomes. A comprehensive, multidimensional evaluation approach should therefore be emphasized in the routine management and prognostic assessment of patients with chronic obstructive pulmonary disease.

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