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THE ASSOCIATION BETWEEN INTRACARDIAC HEMODYNAMICS AND LUNG FUNCTION IN PATIENTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE

Abstract

Study objective. To assess the association between intracardiac hemodynamics and airway obstruction with pulmonary hyperinflation in patients with chronic obstructive pulmonary disease. **Materials and methods.** Ninety-six patients with chronic obstructive pulmonary disease, aged 40 to 75 years, without concomitant cardiovascular disease, were examined and divided into 4 groups according to the severity of the disease. The patients underwent general clinical examination, spirometry, 24-hour pulse oximetry and echocardiography with assessment of linear and volumetric parameters, as well as diastolic function of left and right ventricles. **Results.** Linear and volumetric parameters of the left ventricle, LV myocardial mass and geometry in the examined patients with chronic obstructive pulmonary disease matched threshold values. The progression of the severity of chronic obstructive pulmonary disease was accompanied by decrease of the end-diastolic size of the left ventricle, ratio of peak early to late diastolic filling velocity for the left ventricle (E/A) without significant changes in the left ventricle isovolumetric relaxation time (IVRT). Moderate correlations of the inspiratory capacity with the end-diastolic size of the left ventricle (r=0.612; p=0.001) and the left ventricle E/A (r=0.464; p=0.001); forced expiratory volume in 1 second (FEV_1) with the left ventricle E/A (r=0.600; p=0.011) were established. As a result of the logistic regression performed, the predictor value of the inspiratory capacity was confirmed (Wald χ^2 — 5.795; p=0.024). Impairment of left ventricular diastolic function of grade I was revealed in 12 (31.6 %) patients in group 2, in 7 (24.1 %) patients in group 3, and in 9 (56.2 %) patients in group 4. **Conclusion.** Airway obstruction severity and pulmonary hyperinflation progression in patients with chronic obstructive pulmonary disease and without concomitant cardiovascular disease is associated with a decrease of left ventricular size and diastolic filling, contributes to the development of the left ventricular diastolic dysfunction, predominantly due to the decrease in filling velocity parameters.

Keywords: *COPD, pulmonary hyperinflation, inspiratory capacity, left ventricle diastolic dysfunction*

Conflict of interests

The authors declare that this study, its theme, subject and content do not affect competing interests

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TAPSE — tricuspid annular plane systolic excursion; ABP — arterial blood pressure; RVBD — right ventricle basal diameter, DBP — diastolic blood pressure; IC — inspiratory capacity; LVPW — left ventricular posterior wall thickness; LVMMR — left ventricular myocardial mass ratio; EDS — end diastolic size; LV — left ventricle; LA — left atrium; LAVI/BSA — left atrial volume index/body surface area; FEV_1 — forced expiratory volume in 1 second; RA — right atrium; RA/BSA — right atrial volume index/body surface area; BSA — body surface area; SBP — systolic blood pressure; PASP — pulmonary artery systolic pressure; RVW — right ventricular wall thickness; COPD — chronic obstructive pulmonary disease; DT — early diastolic filling deceleration time; E/A — ratio of peak early to late diastolic filling velocity; LV E/e' — ratio of early transmitral flow velocity (E) to average mitral annular velocity (e'); LV-IVRT — isovolumetric relaxation time of the left ventricle; SpO_2 — average daily saturation

The results of a number of recent studies indicate an adverse effect of pathophysiological features of chronic obstructive pulmonary disease (COPD) on diastolic function of the right and left ventricle in the absence of cardiovascular diseases, significant risk factors for their development, and chronic pulmonary hypertension. It was shown that besides the traditional factors (age, hypertension, diabetes mellitus, obesity) affecting the left ventricle (LV) diastolic function, bronchial obstruction and pulmonary hyperinflation also lead to hemodynamic disorders [1–6]. The results of the prospective, observational COSYCONET study (COPD and Systemic Consequences — Comorbidities Network) to assess COPD progression over time and interactions with comorbidities demonstrated the predictor value of the pulmonary hyperinflation (intrathoracic lung volume) and bronchial obstruction (forced expiratory volume in 1 second — FEV_1) parameters for development of LV diastolic filling impairment [3]. It should be recognized that studies on the association between intracardiac hemodynamics and lung function parameters in patients with COPD are rare and controversial.

The objective of our study is to assess the association between intracardiac hemodynamics and parameters of airway obstruction and pulmonary hyperinflation in patients with COPD.

Materials and methods

Comparative cross-sectional study was conducted in 96 patients with COPD at the state outpatient clinic. The Study Protocol was approved by the Ethics Committee of the Federal State Budgetary Institution of Higher Education "State University of Medicine and Dentistry named after A.I. Evdokimov" of the Ministry of Health of Russia.

Inclusion criteria:
1. Men and women aged 40 to 75 years;
2. Stage 1–4 COPD (GOLD);
3. Informed patient consent to participate in the study.

Exclusion criteria:
1. Exertional angina pectoris;
2. History of myocardial infarction/acute cerebrovascular accident;
3. Cardiac rhythm disturbances;
4. Chronic heart failure;
5. Grade 2–3 hypertension;
6. Type 1 or 2 diabetes mellitus;
7. Chronic kidney disease;
8. Body mass index ≥ 30 kg/m^2;
9. Moderate/severe COPD exacerbation in the previous 30 days;
10. Malignancy.

COPD pharmacotherapy included long-acting bronchodilators (anticholinergic and/or β_2-agonists), the patients received monotherapy with angiotensin-converting enzyme inhibitors, angiotensin I receptor antagonists or diuretic for concomitant arterial hypertension grade 1.

Anthropometric parameters (height, weight, Kettle body mass index — BMI), as well as office blood pressure (BP) by Korotkoff's method, and cholesterol, creatinine and fasting glucose in plasma were measured in all patients. COPD Assessment Test (CAT)

and Modified Medical Research Council Dyspnea Scale (mMRC) were used for comprehensive assessment of symptoms and severity of dyspnea.

Lung ventilation function was assessed on a Master Lab instrument, a volume-constant body plethysmography system, manufactured by the Erich Jaeger company, Germany, using spirography methods with computer-based calculation of parameters. The parameters obtained were assessed in accordance with GOLD guidelines (Global Initiative for Chronic Obstructive Lung Disease) of 2018. Twenty-four-hour pulse oximetry monitoring was performed to assess the average daily oxygen saturation using a MIROxi pulse oximeter (made in Italy).

Echocardiography was performed on Vivid 7 Expert, a cardiovascular ultrasound system manufactured by GE Medical Systems. Left ventricular structural and functional parameters were assessed: end-diastolic size (LV-EDS), end-systolic size (LV-ESS), end diastolic size (LV-EDS), left ventricular posterior wall thickness (LVPW), left ventricular myocardial mass ratio (LVMMR), ejection fraction (LVEF) by modified Simpson's biplane method. Left atrial (LA) parameters were estimated: LA size and LA volume index: LA/body surface area (BSA). When evaluating the right heart chambers, the following parameters were analyzed: right atrial minor diameter index (RA/BSA), right ventricular basal diameter (RVBD), right ventricular wall thickness (RVWT), tricuspid annular plane systolic excursion (TAPSE), pulmonary artery systolic pressure (PASP) [7]. To assess RV and LV diastolic function the following parameters were evaluated: mitral ratio of peak early to late diastolic filling velocity (E/A); isovolumetric relaxation time of the LV (LV IVRT); deceleration time of early diastolic filling of the LV (LV DT); ratio of early transmitral flow velocity (E) to average mitral annular velocity (e') (LV E/e'); ratio of peak early to late diastolic filling velocity (RV E/A); deceleration time of early diastolic filling of the RV (RV DT) [7].

To exclude coronary heart disease, 24-hour Holter ECG monitoring on the Astrocard E2bp, exercise stress echocardiography on the Vivid 7 Expert manufactured by GE Medical Systems, and treadmill testing on the Schiller BP-200 plus tester were performed.

Data analysis was performed using the statistical software package SPSS 22.0. Before calculations, the distribution normality was checked using the Kolmogorov-Smirnov two-sided goodness-of-fit test and a test for equality of variances using the Levene's method. Most samples did not pass the normality tests, therefore nonparametric statistical methods were used. The Mann-Whitney test was used to evaluate statistical differences among the comparison groups. Data are presented by median, 25th and 75th quartiles. Multiple correlation analysis was performed with adjustment for gender, age, and ABP, using Spearman's rank correlation coefficient (r). Logistic regression was used, the dependent variables were reduced to a dichotomized type. Differences were considered statistically significant at $p < 0.05$.

Results

Depending on COPD severity, the patients were divided into 4 groups (Table 1). When comparing the clinical and demographic parameters of the studied groups, a statistically significant increase in age was revealed in group 2 compared with groups 1 and 4 ($p=0.041$; $p=0.007$. respectively). Age parameters in patients of group 3 significantly exceeded those in group 1 ($p=0.01$). Group 2 patients had higher body mass index values than those in groups 3 and 4 ($p=0.015$; $p=0.003$, respectively).

Besides the typical significant intergroup differences in FEV_1, statistically significant differences in inspiratory capacity (IC) were revealed, the value of which was minimal in group 4 patients compared with other groups ($p < 0.001$). Average daily pulse oximetry values (SpO_2) in the groups were comparable, except for group 4 patients, who had values lower than those in group 1 ($p=0.02$). The severity of symptoms and dyspnea in patients in group 4, according to the CAT and mMRC questionnaires, significantly exceeded those in groups 1, 2, and 3. Maximum comparable frequency of COPD exacerbations was observed in groups 2 and 4, significantly exceeding those in groups 1 and 3.

Systolic blood pressure (SBP) values in the study groups corresponded to the target level; SBP values in the group 2 patients significantly exceeded those in groups 3 and 4 (p=0.05; p=0.012). Smoking index and blood glucose level had no significant intergroup differences between the studied groups. The highest cholesterol level was observed in group 1, the lowest level — in group 3, with no clinically significant increase in all groups. The average daily heart rate (HR) in group 4 patients

Table 1. *Demographic, clinical and functional characteristics of the patients examined*

Parameter	GOLD 1	GOLD 2	GOLD 3	GOLD 4	p	p	p	p	p	p
	1	2	3	4	1-2	1-3	1-4	2-3	2-4	3-4
Number of patients, n (%)	13 (13.5)	38 (39.6)	29 (30.2)	16 (16.7)						
Age, years	59.0 [56.0; 61.0]	68.0 [67.0; 70.0]	65.0 [60.0; 69.0]	61.5 [56.0; 64.0]	0.041	0.01	ns	ns	0.007	ns
Men/women, n	12/1	27/11	29/0	16/0						
BMI, kg/m^2	24.8 [22.6; 28.2]	28.55 [24.4; 29.1]	23.05 [19.4; 29.1]	22.51 [21.4; 25.7]	ns	ns	ns	0.015	0.003	ns
Smoking index, pack-year	50.0 [40.0; 50.0]	40.0 [15.0; 45.00]	50.0 [45.0; 75.0]	40.00 [39.38; 44.0]	ns	ns	ns	ns	ns	ns
FEV_1, % of normal value	85.5 [82.0; 89.0]	61.0 [52.0; 68.0]	43.0 [34.0; 46.0]	26.0 [25.75; 30.0]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Inspiratory capacity, % of normal value	99.6 [98.0; 102.0]	88.5 [84.0; 97.0]	69 [59.0; 81.0]	58.0 [50.0; 55.0]	0.002	<0.001	<0.001	<0.001	<0.001	0.001
$SpO_{2,\%}$	96.0 [92.6; 96.5]	93.55 [92.7; 94.8]	93.5 [92.4; 94.5]	92.6 [90.28; 93.6]	ns	ns	0.02	ns	ns	ns
mMRC, points	0.0 [0.0; 1.0]	1.0 [1.0; 2.0]	1.0 [1.0; 1.0]	2.0 [1.75; 3.0]	<0.001	<0.001	<0.001	ns	0.028	0.012
CAT, points	13.0 [9.3; 21.3]	19.0 [13.0; 26.0]	16.0 [13.0; 26.0]	25.0 [17.0; 32.8]	ns	ns	0.007	ns	0.039	0.004
COPD exacerbations/ year, n	1.0 [1.0; 2.0]	2.0 [1.0; 2.5]	1.0 [1.0; 2.0]	2.0 [1.0; 2.5]	0.03	ns	<0.05	0.005	ns	0.007
Hypertension grade 1, n (%)	4 (30.8)	20 (52.6)	8 (27.6)	5 (31.2)						
SBP (office), mm Hg	127.0 [121.0; 130.0	130.0 [128.0; 137.0]	123.0 [118.0; 131.0]	120.5 [110.0; 133.0]	ns	ns	ns	0.05	0.012	ns
DBP (office), mm Hg	82.0 [80.00; 84.00]	77.0 [73.0; 82.0]	79.0 [76.0; 82.0]	72.0 [69.0; 75.0]	ns	ns	ns	ns	ns	ns
Glucose, mmol/L	4.8 [4.5; 4.8]	5.05 [4.6; 5.6]	4.8 [4.5; 5.2]	4.9 [4.6; 5.3]	ns	ns	ns	ns	ns	ns
Cholesterol, mmol/L	5.2 [5.0; 6.9]	4.95 [4.7; 6.3]	4.2 [4.1; 6.0]	4.9 [4.8; 5.15]	ns	0.035	ns	0.001	ns	0.005
HR, bpm	77.0 [67.0; 80.0]	77.0 [67.0; 80.0]	72.0 [68.0; 88.5]	82.5 [75.5; 89.75]	ns	ns	0.015	ns	0.008	0.023

Note: the data are presented as median, first and third quartiles (Me; Q25; Q75). Significance of intergroup differences (p) was evaluated using the Mann-Whitney test; ns — not significant

was significantly higher compared with patients in groups 1, 2, and 3 (p=0.015; p=0.008; p=0.023, respectively).

The LA and LV linear and volumetric parameters, as well as LV geometry were studied in patients with COPD, the medians of the analyzed parameters corresponded to the threshold values (Table 2).

The comparative intergroup analysis of the hemodynamic parameters revealed a significant decrease in LA size in patients in group 2 compared with group 1 (p=0.04), and in patients in group 4 compared with groups 1 and 2 (p=0.001; p=0.011, respectively). LAVI/BSA in groups 3 and 4 was significantly lower than that in group 1 (p=0.011; p=0.04, respectively).

In group 4 patients, there was a decrease of LV EDS compared with groups 1, 2, and 3 (p<0.001; p<0.001; p=0.003, respectively), and LV EDV decrease compared with groups 1 and 2 (p=0.006; p=0.014). When assessing LV ESV in group 4 patients, a decrease was observed compared with groups 1 and 2 (p=0.006; p=0.013, respectively).

There were no intergroup differences of the LVPW thickness and LVMMR, except for the LVMMR parameter in patients in groups 3 and 4 (p=0.026): the values of this parameter corresponded to normal values.

Table 2. *Echocardiography parameters in patients with COPD*

Parameter	GOLD 1	GOLD 2	GOLD 3	GOLD 4	p	p	p	p	p	p
	1	2	3	4	1-2	1-3	1-4	2-3	2-4	3-4
LA, cm	3.8 [3.5; 3.8]	3.5 [3.2; 3.8]	3.5 [3.1; 3.9]	3.15 [3.0; 3.5]	0.04	ns	0.001	ns	0.011	ns
LAVI/BSA, mL/m²	32.1 [21.7; 32.8]	29.3 [26.0; 34.3]	28.4 [22.3; 31.2]	26.9 [23.0; 29.8]	ns	0.011	0.04	ns	ns	ns
RAVI/BSA, mL/m²	1.5 [1.4; 1.5]	1.6 [1.2; 2.2]	1.3 [1.2; 1.3]	1.5 [1.3; 1.7]	ns	ns	ns	ns	ns	ns
LV EDS, cm	5.0 [4.8; 5.3]	4.8 [4.4; 5.4]	4.7 [4.7; 4.9]	4.2 [4.1;4. 5]	ns	ns	<0.001	ns	<0.001	0.003
LV EDV, mL	111.0 [95.0; 124.0]	101.0 [93.0; 121.0]	96.0 [87.0; 122.0]	94.0 [78.0; 97.0]	ns	ns	0.006	ns	0.014	ns
LV ESV, mL	29.0 [23.0; 36.0]	32.0 [31.0; 37.0]	36.0 [32.0; 43.0]	39.0 [34.0; 51.0]	ns	ns	0.006	ns	0.013	ns
RVBD, cm	2. 4 [2.4; 2.8]	2. 6 [2.4; 2.8]	2.6 [2.5; 2.8]	2.7 [2.2; 2.9]	ns	ns	0.035	ns	ns	ns
LVPW, cm	0.95 [0.95; 1.2]	0.98 [0.9; 1.1]	0.94 [0.9; 1.2]	0.98 [0.93; 1.1]	ns	ns	ns	ns	ns	ns
RVWT, cm	0.5 [0.5; 0.6]	0.5 [0.5; 0.6]	0.5 [0.5; 0.6]	0.6 [0.5; 0.8]	ns	ns	<0.05	ns	ns	ns
LVMMR, g/m²	101.9 [79.7; 119.6]	100.7 [87.1; 116.9]	93.9 [81.4; 116.8]	83.2 [69.1; 102.8]	ns	ns	0.026	ns	0.038	ns
LVEF, %	66.5 [65.0; 68.0]	64.0 [62.0; 66.0]	60.0 [58.0; 65.0]	62.0 [60.0; 67.0]	ns	<0.05	0.011	ns	ns	ns
TAPSE, cm	2.2 [1.91; 2.43]	2.0 [2.0; 2.0]	1.95 [1.9; 2.0]	1.8 [1.8; 2.0]	ns	ns	0.001	0.018	0.02	0.02
PASP, mm Hg	25.7 [22.5; 31.9]	26.7 [22.1; 22.0]	27.8 [22.95; 28.5]	31.3 [28.5; 34.0]	ns	ns	0.001	ns	0.028	0.002

Note: See Table 1.

Despite that LV global systolic function (ejection fraction) in patients in the study groups was in the normal range, a decrease in this parameter was observed in patients in groups 3 and 4 compared with patients in group 1 (p <0.05; p=0.011, respectively).

RAVI/BSA values in all groups were comparable. When assessing RVBD, a significant increase in group 4 compared with group 1 was observed (p=0.035). PASP in patients in groups 1, 2, and 3 did not exceed normal values, moderate pulmonary hypertension was observed in group 4: PASP = 31.3 mm Hg. RVWT in group 4 exceeded 0.5 cm, which was significantly different from group 1 (p <0.05).

In group 4 patients, a significant decrease in the TAPSE value was discovered, compared with other groups (p=0.018; p=0.02; p=0.02, respectively). TAPSE changes in the study groups varied within normal range.

Analysis of the parameters of the LV diastolic function (Table 3) in the study group patients revealed that the LV E/A decreased as COPD severity increased. A minimal value of this parameter was observed in patients in group 4; the differences between groups 1 and 3 were significant (p <0.01; p <0.01, respectively). There were no significant intergroup differences in the LV IVRT. The LV DT value increased as COPD severity increased. Differences in this parameter between all groups were statistically significant, except for LV DT values in patients in groups 2 and 3, where these values were comparable. LV diastolic dysfunction presented with the I grade (impaired relaxation) according to the European Association of Cardiovascular Imaging guidelines and American Society of Echocardiography guidelines [7], was revealed in 12 (31.6 %) patients in group 2, in 7 (24.1 %) patients in group 3, and in 9 (56.2 %) patients in group 4. As the severity of COPD progressed, a tendency to decrease in the LV E/e' was observed, which values did not differ from normal values.

As regards RV, a significant decrease in RV E/A was observed in patients in group 4 compared with groups 1, 2, and 3 (p=0.002; p=0.001; p=0.016). RV DT changes were diverse: there was a significant increase in this parameter in patients in group 2 compared with group 1 (p=0.017) with its subsequent decrease in groups 3 and 4 (the differences with group 4 were significant (p=0.009).

To reveal the association between lung function and hemodynamics parameters, correlation analysis was performed (Table 4). As a result, moderate direct correlation of IC with LV EDS (r=0.612; p=0.001) (Fig. 1) and with LAVI/BSA (r=0.433; p <0.001) was discovered, and moderate inverse

Table 3. *Parameters of left and right ventricular diastolic function in patients with COPD*

Parameter	GOLD 1	GOLD 2	GOLD 3	GOLD 4	p	p	p	p	p	p
	1	2	3	4	1-2	1-3	1-4	2-3	2-4	3-4
LV E/A, units	0.93 [0.85; 1.22]	0.81 [0.72; 0.99]	0.81 [0.74; 0.87]	0.77 [0.69; 1.07]	ns	0.01	0.01	ns	ns	ns
LV IVRT, ms	87.0 [84.5; 92.5]	100.0 [89.0; 114.0]	94.0 [90.0; 113.5]	100.0 [90.0; 111.0]	ns	ns	ns	ns	ns	ns
LVDT, ms	206.0 [142.5; 290.3]	233.0 [206.0; 244.0]	242.5 [200.0; 268.0]	265.0 [208.5; 280.0]	0.007	<0.001	0.01	ns	0.049	<0.01
LV E/e', units	6.9 [5.7; 7.4]	6.3 [5.5; 7.7]	7.0 [5.9; 9.6]	5.2 [3.3; 8.5]	ns	ns	ns	ns	ns	ns
RV E/A, units	1.35 [0.99; 1.41]	1.15 [0.99; 1.25]	1.08 [0.85; 1.2]	0.90 [0.74; 1.1]	ns	ns	0.002	ns	0.001	0.016
RVDT, ms	207.0 [200.8; 248.3]	247.5 [217.8; 302.8]	230.0 [203.0; 277.0]	222.0 [189.0; 256.0]	0.017	ns	ns	ns	0.009	ns

Note: See Table 1.

correlation of IC with RVBD (r=-0.533; ρ=0.042) was found.

Moderate direct correlation of FEV_1 with LAVI/BSA (r=0.380; ρ <0.001) and LV EDS (r=0.350; ρ=0.005) was discovered. The relationship between the FEV_1 and structural and functional RV parameters was inverse for RVBD (r=-0.465; ρ=0.022), PASP (r=-0.575; ρ=0.003), and RVWT (r=-0.406; ρ=0.003).

A moderate negative relationship between the average daily SpO_2 and PASP (r=-0.546; ρ=0.006), as well as a moderate direct relationship between the average daily SpO_2 and TAPSE (r=0.379; ρ=0.002) were discovered.

Correlation analysis of the relationship between IC and LV diastolic function parameters demonstrated a moderate direct relationship with LV E/A (r=0.464; ρ=0.001) (Fig. 2) and a moderate inverse relationship with LV DT (r=-0.599; ρ<0.001). A relationship with FEV_1 was discovered for LV E/A (r=0.600; ρ=0.011).

Due to the correlations discovered, logistic regression was used to assess the impact of functional characteristics of COPD on the parameters of the LV diastolic function. A mathematical model with the agreement percent of 81.6 % was built, which included IC and FEV_1 parameters besides the traditional factors (age, BMI, SBP, DBP) that contribute to the LV diastolic dysfunction (LV E/A <0.8).

Table 4. *Correlation of intracardiac hemodynamics and lung functional parameters*

Parameter	IC, % of normal value		FEV_1, % of normal value		SpO_2, %	
	r	ρ	r	ρ	r	ρ
LAVI/BSA, mL/m²	0.433	<0.001	0.380	<0.001	0.503	0.058
LV EDS, cm	0.612	0.001	0.350	0.005	0.305	ns
RVBD, cm	-0.533	0.042	-0.465	0.022	ns	ns
RVWT, cm	ns	ns	-0.406	0.003	ns	ns
TAPSE, cm	ns	ns	ns	ns	0.379	0.002
PASP, mm Hg	ns	ns	-0.575	0.003	-0.546	0.006
LV E/A, units	0.464	0.001	0.600	0.011	ns	ns
LVDT, ms	-0.599	<0.001	ns	ns	0.132	ns

Note: the correlation coefficient was calculated using the Spearman rank method

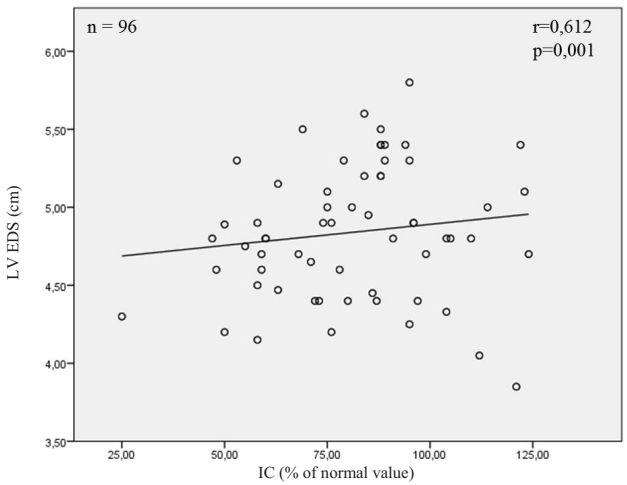

Figure 1. *Correlation between IC and LV EDS*

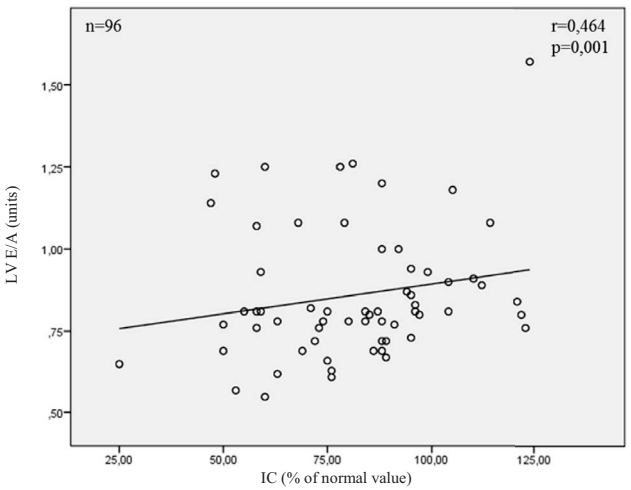

Figure 2. *Correlation between IC and LV E/A*

According to the results obtained, the contribution of IC (Wald χ^2=5.795; p=0.024) was discovered, in addition to the significant influence of DBP (Wald χ^2=10.872; p=0.002), SBP (Wald χ^2 =10.264; p=0.003), BMI (Wald χ^2=8.546; p=0.008), and age (Wald χ^2=6.696; p=0.020) to the LV diastolic function.

Discussion

We conducted a comparative study of the intracardiac hemodynamics parameters in 96 patients with COPD of varying severity (GOLD 1–4) and without any significant cardiovascular diseases. All parameters, except for RVWT and PASP, corresponded to normal values [7]. It was discovered that the progression of COPD severity was associated with significant decrease in the LV EDS value. Minimal values of LV EDS were observed in patients in group 4 (GOLD 4), and moderate direct correlation of this parameter with IC and FEV_1 was found. IC parameter characterizes the maximum air volume that a patient can inspire after expiration at rest; it corresponds to the difference between total lung capacity and functional residual capacity and can be used as a surrogate marker of static pulmonary hyperinflation [8].

When the LV diastolic function parameters were assessed, a significant decrease in LV E/A in patients in groups 3 and 4 compared with group 1 was found, as well as statistically significant LV DT prolongation with increase in COPD severity. Among all patients examined impairment of the LV diastolic function of grade I was observed in 28 individuals. The maximum number of patients with diastolic dysfunction (56.2 %) was in group 4. Correlation analysis demonstrated a moderate positive relationship of LV E/A with IC and FEV_1, a moderate negative relationship of LV DT with IC was found. The results of the logistic regression allowed to discover the impact of IC on the development of LV diastolic dysfunction along with age, BMI, SBP, and DBP.

The results obtained are consistent with published data on the negative impact of chronic obstruction and pulmonary hyperinflation on structural and functional cardiac parameters in the absence of cardiovascular diseases, hypertension, diabetes mellitus, dyslipidemia, and significant remodeling of the right heart chambers due to chronic pulmonary hypertension [1–6. 9]. It was found that an increase in pulmonary volumes contributes to redistribution of pulmonary blood flow with decrease in filling of pulmonary veins, intrathoracic blood volume and LV preload, which in turn can lead to decrease in the left heart chamber sizes [2, 4].

Impairment of normal breathing mechanics in COPD due to prolongation of expiration with pronounced increase in internal positive end expiratory pressure also leads to decrease in venous return and LV diastolic filling [10]. The decrease in LV E/A as COPD severity increases, revealed in this study, as well as the positive relationship of this parameter with IC and FEV_1 indicates impairment of the LV filling due to the reduction the preload in the absence of significant changes in LV relaxation, which is consistent with published data [11, 12]. It can be assumed that the decreased LV preload leads to a decrease in LV filling velocity parameters, predominantly due to early diastolic filling velocity.

The revealed RV parameter changes (increase in RVWT and RVBD in group 4 patients, inverse correlations of RVBD, RVWT and PASP with SpO_2) demonstrate the known processes of RV remodeling in the presence of chronic pulmonary hypertension [9].

The revealed negative correlation between RVBD and IC can reflect the compression effect of pulmonary hyperinflation on pulmonary blood flow with an increase in the RV afterload. A tendency to decrease in TAPSE in the study groups and a direct correlation with SpO_2 is consistent with the concept of the RV systolic function impairment in early stages of COPD [13].

Conclusion

The results of the comparative study conducted indicate that bronchial obstruction and pulmonary hyperinflation contribute to the RV remodeling, that is manifested by a decrease in its size

and diastolic filling in patients with COPD who do not have significant cardiovascular diseases and severe chronic pulmonary hypertension. The progression of bronchial obstruction and pulmonary hyperinflation severity contributes to the formation of LV diastolic dysfunction, predominantly due to the decreased filling velocity.

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