ORIGINAL ARTICLES

Lung Function in Cardiac Dysfunction

S. Ricart,[a] P. Casan,[a] J. Bellido-Casado,[a] M. González,[a] C. Cotes,[b] L. López,[b] J. Belda,[a] and A. Bayés-Ginés[b]

[a]Departamento de Neumología, Hospital de la Santa Creu i de Sant Pau, Facultad de Medicina,
Universitat Autònoma de Barcelona, Barcelona, Spain.
[b]Departamento de Cardiología, Hospital de la Santa Creu i de Sant Pau, Facultad de Medicina,
Universitat Autònoma de Barcelona, Barcelona, Spain..

OBJECTIVE: The alterations in lung function caused by heart failure were first described some decades ago. The advent of new tools for the diagnosis and investigation of heart disease, such as echocardiography, has subsequently made it possible to classify cardiac dysfunction with greater precision. The objective of this study was to analyze and compare a series of lung function and gas exchange variables in patients who had been classified into 4 groups according to type of heart disease as diagnosed by echocardiography.

MATERIALS AND METHOD: Emergency room patients whose main symptom was acute dyspnea caused by cardiac or respiratory disease were included in the study. The final sample comprised 71 patients whose echocardiogram revealed cardiac dysfunction. Spirometry was carried out and resting arterial blood gases measured in this group.

RESULTS: Of the 71 patients with cardiopathy, 31 had systolic dysfunction, 27 diastolic dysfunction, 7 cor pulmonale, and 6 primary valve disease. Spirometry revealed a generally obstructive pattern, more marked in the group with cor pulmonale. Analysis of arterial blood gases revealed slight hypoxemia with normocapnia in all groups, but this was more accentuated in the patients with cor pulmonale and diastolic dysfunction. An analysis of the correlations (Pearson's r) between cardiac and pulmonary variables revealed the statistically significant associations between cardiac mass and other variables to be as follows: forced vital capacity r=0.34 (P=.02), forced expiratory volume in one second r=0.526 (P=.0001), forced expiratory volume in one second as a percentage of predicted r=0.3 (P=.037), and forced midexpiratory flow rate r=0.31 (P=.03). The correlation between left ventricular ejection fraction and PaO_2 was r=–0.312 (P=.01); the correlation between left ventricular end-diastolic diameter and PaO_2 was r=0.369 (p=.006).

CONCLUSIONS: In patients with cardiac dysfunction, spirometry reveals a generally obstructive pattern, which is more accentuated in patients with right ventricular dysfunction owing to the existence of prior lung disease. The associations found between the cardiac and lung function variables do not help the physician to determine the predominant diagnosis for a patient more precisely or to establish a prognosis.

Key words: *Heart failure. Spirometry. Arterial blood gasometry. Echocardiography.*

Función pulmonar en la disfunción cardíaca

OBJETIVO: Las modificaciones de la función pulmonar producidas por la insuficiencia cardíaca se describieron hace ya varias décadas. La incorporación de nuevos instrumentos de diagnóstico y valoración, como la ecocardiografía, ha permitido una mejor clasificación de la disfunción cardíaca. El objetivo de este estudio fue analizar y comparar diversas variables de función pulmonar y del intercambio de gases en 4 grupos de pacientes, clasificados en función de la patología cardíaca diagnosticada por ecocardiografía.

MATERIAL Y MÉTODO: Se incluyó en el estudio a pacientes que acudieron a urgencias por disnea aguda, de origen cardíaco o respiratorio, como principal síntoma. La muestra final estuvo compuesta por 71 individuos con disfunción cardíaca evidenciada mediante ecocardiografía, a los que se realizaron una espirometría y la determinación de gases arteriales en reposo. Los datos se expresan como media y desviación estándar.

RESULTADOS: De los 71 pacientes con cardiopatía, 31 mostraron disfunción sistólica, 27 diastólica, 7 *cor pulmonale* y 6 patología valvular primaria. La espirometría mostró un patrón globalmente obstructivo, más marcado en el grupo con *cor pulmonale*. El análisis de los gases en sangre evidenció una ligera hipoxemia con normocapnia en todos los grupos, pero más acentuada en los grupos de *cor pulmonale* y disfunción diastólica. La correlación entre variables cardíacas y respiratorias mostró asociación estadísticamente significativa entre la masa cardíaca y la capacidad vital forzada (r = 0,34; p de Pearson = 0,02), el volumen espirado en el primer segundo (r = 0,526; p = 0,0001), en volumen espirado en el primer segundo en porcentaje del valor de referencia (r = 0,3; p = 0,037) y el flujo mesoespiratorio forzado (r = 0,31; p = 0,03). También mostraron correlación la fracción de eyección del ventrículo izquierdo y la presión arterial de O_2 (r = –0,312; p = 0,01), así como el diámetro telediastólico del ventrículo izquierdo y la presión arterial de O_2 (r = 0,369; p = 0,006).

CONCLUSIONES: La espirometría de pacientes con disfunción cardíaca muestra globalmente un patrón obstructivo, más acentuado en pacientes con disfunción ventricular derecha al existir patología pulmonar previa. Las asociaciones halladas entre variables de función cardíaca y pulmonar no permiten valorar de una forma más precisa la patología predominante en cada paciente ni establecer un pronóstico.

Palabras clave: *Insuficiencia cardíaca. Espirometría. Gasometría arterial. Ecocardiografía.*

Introduction

Heart failure (HF) is defined as the inability of the heart to pump blood effectively enough to meet the metabolic needs of the body's tissues, or a situation in which this can only be achieved at the cost of raised end-diastolic pressure. It can be classified as acute or chronic, left or right, forward or backward, systolic or diastolic, and high output or low output. This nomenclature is generally used in the clinical context and in the early stages of the disease. Over time, the differences between all of these forms become gradually less evident.[1]

HF gives rise to changes in lung function. Classically, a restrictive pattern has been described, secondary to pulmonary edema, and occurring even in the absence of clinical or radiographic signs. This may be accompanied by a certain degree of bronchial obstruction, which causes wheezing (so called "cardiac asthma"), but the forced expiratory volume in 1 second (FEV_1)/forced vital capacity (FVC) ratio is only slightly reduced. Carbon monoxide (CO) transfer generally diminishes, but this may be compensated by an increase in pulmonary venous pressure or by the extravasation of erythrocytes, which remain in the lung capturing CO. Arterial gas measurements in patients with HF reveal hypoxemia with normal or reduced $PaCO_2$. However, it is not uncommon to find hypercapnia in the most severe cases, and even metabolic or mixed acidosis, which can lead to extremely low pH values.[2]

This is the classic description of the repercussions of HF on pulmonary function described as early as 1957.[3] Recently, a new way of evaluating HF in the emergency department has been proposed, based on the measurement of HF-generated products of neurohormone activation, such as cerebral natriuretic peptide. However, echocardiography is still considered to be the standard noninvasive technique for evaluating HF because it provides the means to classify cardiac dysfunction according to more objective parameters.[5] Using this technique, the cause of HF is currently classified as one of the following: systolic dysfunction, diastolic dysfunction, cor pulmonale, or valvular abnormality.

In the present study, we evaluated patients admitted to the emergency department with acute dyspnea caused by ventricular dysfunction, which was analyzed by echocardiogram. Our objectives were to study the lung function of patients with cardiac dysfunction, to compare the spirometric and gas exchange variables according to their functional origin, and to analyze the relationship between the variables defining cardiac dysfunction and those obtained in the lung function study.

Materials and Method

Patients over 40 years old of both sexes who came to the emergency department of our hospital and whose main symptom was dyspnea were included in the study. The following were exclusion factors: dyspnea caused by chest trauma; lack of patient autonomy; acute coronary syndrome, unless the predominant presentation was HF; and terminal renal or hepatic failure. Also excluded were patients on the waiting list for heart transplant, and those transferred from other hospitals.

The period for inclusion was from April 2002 through February 2003. Informed consent was obtained from all patients. The study was approved by the hospital's ethics committee. The lung function and echocardiographic studies were carried out 7 to 10 days after admission. During the patients' stay in hospital, records were kept of several clinical variables that could help elucidate whether the dyspnea was of cardiac or respiratory origin. The definitive diagnosis was established on the basis of an overall assessment of all of the clinical and functional information obtained.

Lung function testing included forced spirometry performed according to the recommendations of the Spanish Society of Pulmonology and Thoracic Surgery (SEPAR)[6] using a Datospir-500 spirometer (SibelMed, Barcelona, Spain). Resting arterial gases were measured using the standard laboratory procedure and quantified by an ABL-500 analyzer (Radiometer, Copenhagen, Denmark). The following variables were measured: FVC (L/min), FVC (percentage of predicted), FEV_1 (L/min), FEV_1 (percentage of predicted), FEV_1/FVC (%), forced midexpiratory flow rate ($FEF_{25\%-75\%}$) (percentage of predicted), pH, PaO_2 (mm Hg), $PaCO_2$ (mm Hg), and bicarbonate (mEq/L).

Electrocardiography was performed using a Philips SONOS 5500 Doppler ultrasound system (Philips Medical Systems, Andover, MA, USA) following the routine procedure used in the cardiology department.[7] The following parameters were measured: left ventricular end-diastolic diameter (LVEDD) (mm), left ventricular end-systolic diameter (mm), interventricular septum thickness (mm), myocardial mass (g), fractional shortening (%), left ventricular ejection fraction (%), presence of aortic or mitral stenosis, mitral failure or valvular prosthesis, diameter of the mitral and tricuspid rings (mm), right ventricular diameter (mm), and right ventricular motility (mm). The patients were then assigned to one of the following 4 groups on the basis of these parameters: systolic dysfunction, diastolic dysfunction, cor pulmonale, or cardiac dysfunction caused by valve disease.

Statistical comparison was performed using 2-way ANOVA and the Student t test for independent data. The relationship between variables was analyzed using Pearson's r and linear regression. P values less than .05 were considered significant.

Results

Ninety-nine patients were admitted to the study. Subsequently, 2 patients were excluded because they were transferred to another hospital, 8 patients died in the emergency department, and in 2 cases electrocardiography could not be performed. The remaining 87 patients (50 males and 37 females) were included in the final sample studied. The mean (SD) age was 70 (11) years.

On the basis of the clinical and functional criteria specified above, 43 patients (49.4%) were diagnosed with cardiac dyspnea; 16 (18.4%) with dyspnea of respiratory origin, and 28 (32.2%) with dyspnea of mixed cause. Of the 71 patients in whom heart disease was confirmed by echocardiogram (the 43 with cardiac dyspnea and the 28 with mixed dyspnea), echocardiography revealed systolic

TABLE 1
Characteristics of Lung Function According to Type of Heart Disease Identified by Echocardiography*

	Total	Systolic Dysfunction	Diastolic Dysfunction	Cor Pulmonale	Valvular Dysfunction
No. of patients	71	31	27	7	6
FVC, %	64 (19)	68 (19)	65 (17)	49 (13)	58 (19)
FEV_1, %	59 (21)	61 (22)	61 (21)	38 (14)	55 (17)
FEV_1/FVC	63 (13)	65 (13)	62 (13)	55 (16)	69 (7)
$FEF_{25\%-75\%}$, %	47 (33)	46 (31)	56 (43)	26 (17)	39 (9)
pH	7.44 (0.03)	7.45 (0.04)	7.45 (0.04)	7.42 (0.02)	7.44 (0.02)
PaO_2, mm Hg	73 (14)	77 (12)	69 (12)	67 (25)	77 (10)
$PaCO_2$, mm Hg	42 (7)	40 (7)	43 (6)	45 (6)	44 (8)
HCO_3^-, mEq/L	28 (5)	27 (5)	27 (6)	29 (4)	29 (5)

*The data are expressed as means (SD). FVC indicates forced vital capacity; FEV_1, forced expiratory volume in 1 second; $FEF_{25\%-75\%}$, midexpiratory flow rate; HCO_3^-, bicarbonate.

dysfunction in 31 (44%) and diastolic dysfunction in 27 (38%), cor pulmonale in 7 (10%), and cardiac dysfunction caused by primary valve disease in 6 patients (8%). The echocardiogram was normal in the 16 patients with dyspnea of exclusively respiratory origin.

The study of lung function in the 71 heart disease patients revealed a moderately obstructive ventilatory pattern. The existence of any restrictive defect could not be investigated because static lung volumes had not been obtained. Measurements of gas exchange and acid-base balance revealed slight hypoxemia and normocapnia, with pH and bicarbonates within the normal range. The mean values of each variable are shown in Table 1.

Comparison of the lung function results of the group of patients with cardiac dyspnea to those of the group of patients with dyspnea of mixed origin revealed greater obstruction among the latter, but the only statistically significant difference found was in the FEV_1/FVC ratio ($P=.0001$). FVC and FEV_1 were slightly but significantly lower in the group with cor pulmonale (48.8% [13%] and 38.5% [14.1%], respectively) than in the group of patients with systolic dysfunction (67.8% [19.6%] and 61.3% [22.2%]) ($P=.03$ and $P=.02$, respectively). Significant differences were also found in these variables on comparison of the group with cor pulmonale (48.8% [13%] and 38.5% [14.1%], respectively) and the group with diastolic dysfunction (65.6% [17.1%] and 61.4% [21.5%]) ($P=.04$ and $P=.02$, respectively). Blood gas analysis revealed more marked hypoxemia in the patients with cor pulmonale (68 [25.1] mm Hg) and diastolic dysfunction (69 [12.3] mm Hg) than in the other groups ($P=.02$) (Table 1).

A table of correlations between cardiac and respiratory variables revealed statistically significant relations between cardiac mass and the following parameters: FVC ($r=0.34$; $P=.02$), FEV_1 ($r=0.526$; $P=.0001$), FEV_1 (%) ($r=0.3$; $P=.037$), FEV_1/FVC ($r=0.4$; $P=.006$), and $FEF_{25\%-75\%}$ ($r=0.31$; $P=.03$) (Figure). A significant correlation was also found between left ventricular
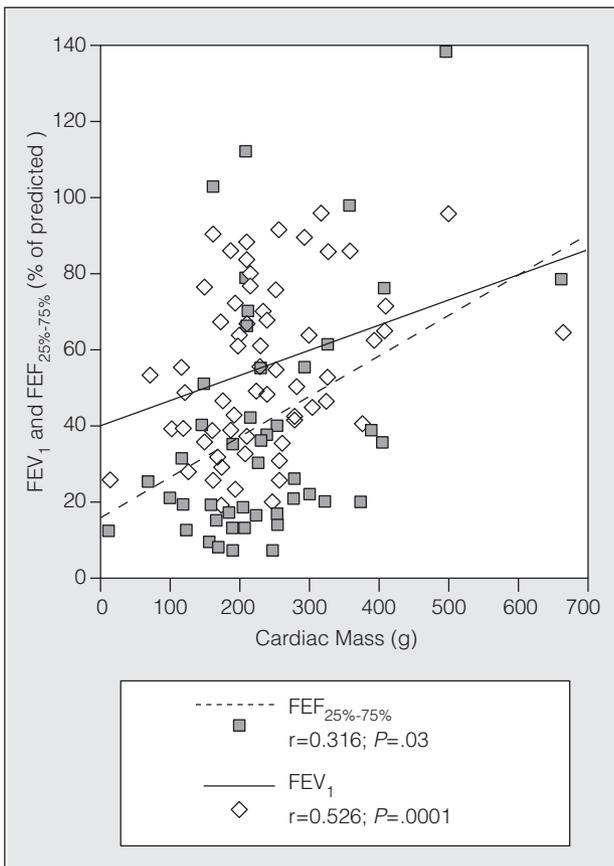

Figure. Relationship between cardiac mass on the one hand and forced expiratory volume in one second (FEV_1) and forced midexpiratory flow rate ($FEF_{25\%-75\%}$) on the other.

TABLE 2
Relationship Between Cardiac Mass (g) and LVEF (%) and the Different Lung Function Variables*

	FVC (%)	FEV_1 (L)	FEV_1 (%)	$FEF_{25\%-75\%}$ (%)	PaO_2 (mm Hg)
Cardiac mass, g					
r	0.336	0.526	0.299	0.316	
P	0.02	0.0001	0.037	0.03	
LVEF, %					
r					–0.312
P					0.016

*The data shown are Pearson correlation coefficients (r) and statistical significance (P). LVEF indicates left ventricular ejection fraction; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; $FEF_{25\%-75\%}$, midexpiratory flow rate.

ejection fraction and PaO_2, (r=–0.312; P=.01), and between LVEDD and PaO_2 (r=0.369; P=.006) (Table 2). In spite of the good correlation between cardiac mass and LVEDD (r=0.711; P=.0001), no significant correlation was found between LVEDD and FEV_1. Linear regression analysis revealed that left ventricular ejection fraction was the variable that best predicted PaO_2.

Comparison of lung function variables between patients with and without right ventricular dilation (defined as a diameter of greater than 25 mm) revealed statistically significant differences in FVC, FEV_1, and $FEF_{25\%-75\%}$ (Table 3). The same comparison between groups with and without right ventricular motility (with hypomotility defined as displacement of less than 20 mm of the tricuspid ring) revealed no significant differences.

Discussion

A slight to moderate obstructive pattern was observed in the lung function of patients with HF, more marked in the patients with mixed pathology (cardiac and respiratory) than in those with HF alone. FVC and FEV_1 values were lower in the group of patients with cor pulmonale than in the groups with diastolic or systolic dysfunction. Hypoxemia was more marked in the groups with cor pulmonale or diastolic dysfunction than in the other groups. These findings can be explained by the fact that the patients with cor pulmonale all had mixed cardiac and respiratory disease. Moreover, their lung function was already impaired by the underlying lung disease. Since no data on static lung volumes were recorded, we cannot assess whether any of these patients had a mixed respiratory pattern.

Despite the fact that these alterations in lung function were more marked in the patients with right ventricular failure, a correlation has been reported between the severity of alterations in lung function and that of chronic congestive HF.[8] The muscular weakness present in patients with HF gives rise to impaired performance on spirometry, which, together with the peribronchial edema caused by HF, would explain this correlation.

Spirometry revealed greater obstruction in the patients with right ventricular dilation, the differences in FVC, FEV_1, FEV_1/FVC, and $FEF_{25\%-75\%}$ being statistically significant with respect to the group without dilation. Conversely, no difference was observed when these variables were compared according to whether or not the patient had normal right ventricular motility. These results agree with those reported by other authors, who found greater obstruction on spirometry in patients with cor pulmonale owing to the presence of the underlying lung disease. Despite the fact that right ventricular hypomotility is a very unfavorable prognostic sign in patients with myocardial disease, no correlation was found between this parameter and lung function. The explanation of the lack of correlation lies in the composition of the sample studied: of the 18 patients with right hypocontractility, 10 belonged to the group with systolic dysfunction and only 3 to the group with cor

TABLE 3
Characteristics of Lung Function According to the Morphology and Function of the Right Ventricle*

	Right Ventricle Dilated (>25 mm)	Without Dilation	Significance (Bilateral)
FVC, %	57 (17)	73 (18)	0.0001
FEV_1, %	47 (19)	64 (21)	0.001
$FEF_{25\%-75\%}$	31 (22)	51 (38)	0.016

*The data are expressed as means (SD). FVC indicates forced vital capacity; FEV_1, forced expiratory volume in 1 second; $FEF_{25\%-75\%}$, midexpiratory flow rate.

pulmonale. Given that the lung function characteristics of these two groups are different, it is difficult to identify an overall tendency when studying the group as a whole, and analysis by subgroups is impossible because of the small number of cases involved.

A slight positive correlation was found between cardiac mass and both FVC and FEV_1 expressed as absolute values. Given that all three of these variables are related to patient size and weight, the anthropometric characteristics of the sample were treated as confounding variables. However, the correlation found between FEV_1 (%) and $FEF_{25\%-75\%}$ cannot be explained in the same way because these variables for each individual were expressed in reference to tables of predicted values for the size and weight. The correlation indicates, contrary to what might be expected, that patients with greater ventricular hypertrophy are not suffering from HF. Therefore, since there is no substantial peribronchial edema, FEV_1 and $FEF_{25\%-75\%}$ are not reduced. Consequently, the increase in heart size would indicate an adaptive response on the part of the organ rather than a failure of the system. This slight positive correlation is not sustained when only the subgroup of patients with systolic or diastolic dysfunction is studied. These results differ from those of Enright et al,[9] who report an inverse correlation between cardiac mass and FVC and FEV_1. This discrepancy could be explained by differences in the sample studied: while in Enright's study all the patients were pure heart disease patients and even smokers were excluded, our study included patients with heart disease, respiratory disease, or both. This greater heterogeneity could produce bias, which might even invert the real direction of the association. One of the limitations of the present study was the difficulty of properly quantifying smoking history, since the clinical histories were taken in the emergency department and not always in the easiest of circumstances. Other authors have not found any relationship between cardiac and lung function in patients with HF in advanced functional classes,[10] so that further studies will be necessary to determine in what kind of patients cardiac and/or lung function measurements could be useful in more completely evaluating the patient's condition and prognosis.

A negative correlation was found between left ventricular ejection fraction and PaO_2. This can be explained by the fact that the patients with more intense hypoxemia are those with respiratory disease, who maintain a good ejection fraction despite the existence

of cor pulmonale. The positive correlation between LVEDD and PaO_2 can also be explained in the same way: adequate gas exchange is found in cardiopathic patients with left ventricular dilation, while PaO_2 is lower in those without left ventricular dilation (the patients with right ventricular failure due to respiratory disease and those with diastolic dysfunction). It should be emphasized that spirometry revealed an obstructive pattern in over half the patients in the subgroup with diastolic dysfunction.

These results highlight the difficulty of assessing the condition of older patients with heart disease, because their cardiopathy is often combined with respiratory diseases, and with disorders derived from the lung-heart interaction. We should, therefore, keep in mind that the academic classifications, notwithstanding their usefulness in the pathophysiology of disease, are difficult to apply in routine clinical practice. For this reason, new methods for delimiting and evaluating cardiac dysfunction separately from respiratory disease are being studied. Research in the field of cardiology is directed towards the study of the products of neurohormone activation (auricular and cerebral natriuretic peptides, cerebral natriuretic propeptide, and others) as markers of cardiopathy.[11] In respiratory medicine, the studies tend more towards the search for markers of inflammation, such as exhaled nitric oxide, used to quantify the extent of pulmonary involvement.[12] In recent years, a large number of studies have highlighted the role of sleep apnea as a significant cause of cardiovascular mortality and morbidity.[13,14] In light of this close interaction between the respiratory apparatus and the cardiovascular system, the treatment of patients with cardiac or respiratory disease should be approached from a broader perspective. Recently, treatment with continuous positive airway pressure in patients with congestive HF and sleep apnea has been shown to improve both cardiac function parameters,[15] and respiratory signs and symptoms.

The present study was carried out on a sample of elderly patients with multiple disorders, a type of patient seen increasingly in the emergency departments of any hospital. Other authors have evaluated the changes in lung function specifically related to HF in patients who were candidates for heart transplantation and have observed that, in part, changes of a predominantly restrictive type were reversible after surgery (in nonsmokers).[16] In light of the close interaction that exists between the heart and the lungs, the future development of a simple and rapid method of identifying which organ is initially responsible for the patient's dyspnea is imperative. The relationships between heart and lung function variables found in this study help to clarify common pathogenetic mechanisms,

but do not, *a priori*, allow us to draw firm conclusions about the meaning of the associations. In the absence of the methods that must be developed in the future, it will continue to be the traditional questions physicians ask their patients that will elucidate the principal origin of their disease.

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