Austin Journal of Pulmonary & Respiratory Medicine

Open Access

Austin Publishing Group

Rapid Communication

Acute Heart Failure as a Cause of Hypercapnia

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Received: October 22, 2022; **Accepted:** November 18, 2022; **Published:** November 25, 2022

Abstract

The purpose of this study is to investigate whether hypercapnia in patients with Acute Cardiogenic Pulmonary Edema (ACPE) is secondary to acute Heart Failure (HF) alone or there is underlying Chronic Obstructive Pulmonary Disease (COPD).

We conducted a retrospective study to analyze the characteristics of patients with ACPE hospitalized between 2020 and 2021. Hypercapnia was defined as PaCO2 >45 mm Hg. The study included patients ≥18 years admitted to an intermediate respiratory care unit.

A total of 156 patients with ACPE were admitted [(mean age: 79±9.8 years; men, 82 (52%); HF, 82 (52.6%); COPD, 43 (27.6%); the two diseases, 27 (17.3%)]. Non-invasive ventilation reduced significantly heart rate, blood pressure, $PaCO_2$ and the number of patients with HCO3- <26 mmol/L, and increased significantly SaO_2 and pH. HF patients were prevailingly female, significantly older, and exhibited a lower heart rate and $PaCO_2$ (65±17.2 mm Hg), as compared to patients with COPD (76.8±21.3) or with the two diseases (74.5±23.2).

In ACPE patients, the presence of hypercapnia does not necessary indicate an underlying COPD.

Keywords: Acute cardiogenic pulmonary edema; Acute heart failure; Chronic obstructive; Non-invasive ventilation; Pulmonary disease

Abbreviations

ACPE: Acute Cardiogenic Pulmonary Edema; COPD: Chronic Obstructive Pulmonary Disease; HF, Heart Failure; IRCU: Intermediate Respiratory Care Unit; NIV: Non-Invasive Ventilation

Introduction

Heart Failure (HF) and Chronic Obstructive Pulmonary Disease (COPD) are closely related [1], since they share symptoms and known risk factors, may cause similar functional alterations [2,3] and are frequently concurrent [4].

In patients with HF and COPD who develop respiratory failure, determining whether it is secondary to HF decompensation, COPD exacerbation or to interaction between the two conditions is challenging. In this setting, in the presence of hypercapnic respiratory failure, it is difficult to establish whether it is caused by Acute Cardiogenic Pulmonary Edema (ACPE) alone, or an underlying COPD has contributed to this complication.

The purpose of this study is to elucidate whether hypercapnia in ACPE patients is secondary to acute HF alone or there is an underlying COPD that explains it.

Methods

We conducted a retrospective study to analyze the characteristics of ACPE patients hospitalized between 2020 and 2021. Diagnoses of acute HF, CPE and COPD were established in accordance with *European Society of Cardiology* [5,6] and *Global Initiative for Chronic Obstructive Lung Disease* [7] guidelines, respectively. Hypercapnia was defined as $PaCO_2$ >45 mm Hg.

The study population included all adult patients (≥18 years) with a diagnosis of ACPE admitted to an Intermediate Respiratory Care Unit (IRCU) to receive Non-Invasive Ventilation (NIV). Patients younger than 18 years were excluded.

The variables analyzed included 1) demographic (age, gender, smoking, comorbidities); 2) clinical (vital signs on admission and discharge); 3) analytical (pH, pCO_2, pO_2 and $HCO3^-$, on admission and discharge); 4) length of IRCU stay; 5) NIV treatment; and 6) clinical outcome (discharge or exitus). The study was approved by the Ethics Committee of the hospital (2022/016).

Descriptive statistics were used to summarize the characteristics of patients (percentage of qualitative variables and mean ± SD for quantitative variables). Differences in qualitative variables were assessed using Chi-square test, whereas differences in mean values were evaluated using Student's *t*-test for related samples, and ANOVA or (repeated-measures/independent-measures) an analysis of variance for comparison of more than two groups. Statistical significance was established at 5%. All statistical analyses were performed using the IBM SPSS Statistics v20 software package.

Results

During the study period, a total of 565 patients were admitted to the IRCU, of whom 156 (27.6%) developed ACPE. Mean age was 79±9.8 years [(male, 82 (52%)]. Previous diagnoses, length of stay, administration of NIV therapy, mortality, vital signs, and arterial blood gas (the two latter on admission and discharge) are

Citation: Ricoy J, Soto-Feijóo R, Rodríguez-Núñez N, Toubes ME, Rábade C, Lama A, et al. Acute Heart Failure as a Cause of Hypercapnia. Austin J Pulm Respir Med. 2022; 9(2): 1093.

Table 1: Characteristics of patients with acute pulmonary edema.

Characteristics (n = 156)			
Age (mean, years)	79 ± 9.9 (range: 50-94)		
Male [n (%)]	82 (52.6)		
Smokers [n (%)]	74 (47.4)		
Dyslipemia [n (%)]	84 (53.8)		
Arterial hypertension [n (%)]	125 (80.1)		
Ischemic heart disease [n (%)]	20 (12.8)		
Vascular disease [n (%)]	101 (64.7)		
Cardiac arrhythmia [n (%)]	75 (48.1)		
Heart failure [n (%)]	82 (52.6)		
COPD [n (%)]	43 (27.6)		
Heart failure and COPD [n (%)]	27 (17.3)		
DILD [n (%)]	2 (1.3)		
Diabetes mellitus [n (%)]	60 (38.5)		
NIV [n (%)]	155 (99.4)		
IRCU stay (days)	6 ± 5.2		
Mortality [n (%)]	15 (9.6)		
Variable	**On admission (n = 156)**	**On discharge (n = 141)**	**p**
Heart rate (bpm)	86 ± 20	76 ± 14	<0.001
Systolic arterial pressure (mm Hg)	143 ± 27	125 ± 19	<0.001
Diastolic arterial pressure (mm Hg)	79 ± 19	68 ± 11	<0.001
Mean arterial pressure.	100 ± 19	87 ± 11	<0.001
SaO_2 (%)	83 ± 12	93 ± 3	< 0.001
PaO_2 (mm Hg)	66.2 ± 43	66.5 ± 13.6	0.978
pH	7.28 ± 0.08	7.42 ± 0.06	<0.001
$PaCO_2$ (mm Hg)	68 ± 18	49.4 ± 10.6	<0.001
Bicarbonate (mmol/L)	30.8 ± 5.6	31.5 ± 5.2	0.154
Bicarbonate <26 mmol/L [n (%)]	28 (17.9)	24 (15.6)	<0.001

COPD: Chronic Obstructive Pulmonary Disease; **DILD:** Diffuse Interstitial Lung Disease; **IRCU:** Intermediate Respiratory Care Unit; **NIV:** Non-Invasive Ventilation.

Table 2: Differences between patients diagnosed with HF, COPD or both on admission.

Characteristics	HF (n = 55)	COPD (n = 16)	HF + COPD (n = 27)	p
Age (years)	82.6 ± 6.6	73.6 ± 10.3	76.7 ± 11.2	<0.001
Male [n (%)]	20 (36.4)	11 (68.8)	25 (92.6)	<0.001
Smokers [n (%)]	14 (26.5)	15 (93.8)	26 (96.3)	<0.001
Heart rate (bpm)	81 ± 18	101 ± 18	86 ± 20	0.003
Systolic arterial pressure (mm Hg)	147 ± 25	137 ± 26	141 ± 25	0.056
Diastolic arterial pressure (mm Hg)	78 ± 17	80 ± 29	77 ± 19	0.357
Mean arterial pressure.	101 ± 18	99 ± 22	93 ± 15	0.161
SaO_2 (%)	85 ± 11	78,3 ± 15	85 ± 12	0.159
PaO_2 (mm Hg)	67.9 ± 39.9	75.4 ± 70	74.9 ± 40	0.732
pH	7.29 ± 0.07	7.24 ± 0.09	7.27 ± 0.08	0.078
$PaCO_2$ (mm Hg)	65 ± 17.2	76.8 ± 21.3	74.5 ± 23.2	0.038
Bicarbonate (mmol/L)	30.6 ± 6.2	32.1 ± 5.7	32.9 ± 5.9	0.247
Bicarbonate <26 mmol/L [n (%)]	12 (21.8)	1 (6.2)	2 (7.7)	0.140
NIV [n (%)]	55 (100)	16 (100)	27 (100)	---
Stay (days)	9.7 ± 7.6	10 ± 9	7.8 ± 5	0.485
Mortality [n (%)]	5 (9.3)	1 (6.2)	3 (11)	0.868

COPD: Chronic Obstructive Pulmonary Disease; **HF:** Heart Failure; **NIV:** Non-Invasive Ventilation.

shown in (Table 1). On discharge, non-invasive ventilation reduced significantly heart rate, blood pressure, $PaCO_2$, the number of patients with HCO3- <26 mmol/L and increased SaO_2 and pH significantly.

The number of patients with SaO_2 ≤90%, PaO_2 ≤60 mm Hg, pH ≤7.35, $PaCO_2$ >45 mm Hg and $HCO3^-$ <26 mEq/L on admission was 107 (68.6%), 93 (59.6%), 142 (91%), 149 (95.5%) and 28 (17.9%), respectively. In contrast, 24 patients (15.4%) had a baseline PaO_2 >80 mm Hg.

Table 2 compares the characteristics of patients by diagnosis on admission (HF, COPD, or concurrent HF and COPD). Patients with HF were significantly older, with a higher prevalence among women and a lower percentage of smokers, and a significantly lower mean HF and $PaCO_2$ (albeit the latter was >45 mm Hg).

Discussion

The results confirm that i) hypercapnia is very frequent in ACPE patients (95.5%); ii) it is not necessarily secondary to an underlying COPD (absent in 72.4% of cases); and iii) NIV therapy is useful in this setting [5,6,8]. Previous studies uncovered that COPD was not the cause of all cases of acidosis in ACPE patients. In a series of 1069 patients with acidosis (mean $PaCO_2$ 57±16.5 mm Hg; mean HCO_3^-

21±4 mmol/L), the percentage of diagnoses of COPD did not reach 20% [9]. In another study, the prevalence of COPD was significantly higher (65%) in patients with hypercapnia and HCO_3^- >30 mEq/L, as compared to patients with HCO_3^- <26 mEq/L (25%) (p=0.002) [10]. This may be explained by the different metabolic responses activated to compensate respiratory acidosis depending on whether it is acute (HCO_3^- is increased by 1 mmol/L for each $PaCO_2$ increase of 10 mm Hg above 40 mm Hg), or chronic (HCO_3^- is increased by 4-5 mmol/L for each $PaCO_2$increase of 10 mm Hg above 40 mm Hg) [11]. In a recent study involving 28 ACPE patients treated with NIV, from which COPD patients were excluded, a third of patients exhibited hypercapnia on admission [12]. In our series, in agreement with previous case series reports, a significant proportion of patients showed elevated HCO_3^-, acidosis and hypercapnia unrelated to COPD. This suggests that metabolic response had started some days earlier.

In patients with HF/ACPE without COPD, hipercapnia is related to hypoventilation rather than pulmonary perfusion or diffusion, since it is 20 times higher in CO_2 than in O_2 [13]. Hypoventilation may be mediated by several underlying mechanisms. In HF (both, with preserved or reduced ejection fraction), left-sided filling pressure leads to pulmonary congestion and interstitial edema, resulting in pulmonary hypertension, right heart dysfunction and peripheral congestion [3]. When interstitial edema progresses, alveolar spaces are occupied, resulting in airway obstruction in advances stages [3], which will cause hypoventilation and hypercapnia [14]. Respiratory muscle fatigue may also induce hypoventilation and hypercapnia [15].

In this study, 24 patients (15.4%) exhibited a PaO_2 >80 mm Hg on ED admission after having received O_2 on the ambulance without O_2 flow control, which would explain the lack of PaO_2 improvement on discharge. In this series, $PaCO_2$ elevation may be partially explained by this circumstance. However, although it is widely accepted that the administration of O_2 in COPD may cause hypercapnia [16], a consensus document for prehospital management of acute HF [17] does not provide any recommendation about the O_2 administration method. To date, there are no reports of patients with acute decompensated HF who have experienced adverse events such as hypercapnia after an episode of hyperoxia [18,19]. Finally, a recent study revealed a significant association between prehospital hypercapnia in patients with acute HF and NIV administration in the emergency department, ICU admission, and prolonged hospital stays. However, the authors do not mention the deleterious effects of O_2 administration [20].

In summary, in ACPE, the presence of hypercapnia does not necessary indicate an underlying COPD.

Author Contributions

Jorge Ricoy Gabaldón. Conceived and designed the study. Performed data analysis and interpretation. Reviewed intellectual content. Approved final manuscript.

Roi Soto Feijóo. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Nuria Rodríguez-Núñez. Statistical analysis. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Mª Elena Toubes. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Carlos Rábade Castedo. Performed data analysis and interpretation. . Conducted a critical review of intellectual content. Approved final manuscript.

Adriana Lama López. Performed data analysis and interpretation. . Conducted a critical review of intellectual content. Approved final manuscript.

Vanessa Riveiro Blanco. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Ana Casal Mouriño. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Luis Valdés. Conceived and designed the study. Performed data analysis and interpretation. Conducted a critical review of intellectual content. Approved final manuscript.

Conflict of Interest

Authors declare no conflict of interest.

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