BRIEF REPORT

Relation between ultrasound-measured diaphragm movement and partial pressure of carbon dioxide in blood from patients with acute hypercapnic respiratory failure after the start of noninvasive ventilation in an emergency department

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Objective. To evaluate the correlation between variations in ultrasound-measured diaphragm movement and changes in the arterial partial pressure of carbon dioxide (PCO_2) after the start of noninvasive ventilation (NIV).

Methods. Descriptive study of a prospective case series comprised of nonconsecutive patients aged 18 years or older with hypercapnic respiratory failure who were placed on NIV in an emergency department. We recorded clinical data, blood gas measurements, and ultrasound measurements of diaphragm movement.

Results. Twenty-one patients with a mean (SD) age of 83 (13) years were studied; 11 (52.4%) were women. The mean (SD) range of diaphragm movement and PCO_2 values at 4 moments were as follows: 1) at baseline: diaphragm movement, 13.90 (7.7) mm and PCO2, 71.75 (11.4) mm Hg; 2) after 15 minutes on NIV: diaphragm movement, 17.10 (9.1) mm; 3) at 1 hour: diaphragm movement, 22.40 (10.4) mm and PCO_2, 63.45 (16.0) mm Hg; and 4) at 3 hours: diaphragm movement, 26.60 (19.5) mm and PCO_2, 61.85 (13.0) mm Hg. We detected a statistically significant correlation between the difference in range of diaphragm movement at baseline and at 15 minutes and the decrease in PCO_2 after 1 hour of NIV ($r=-0.489$, $P=.035$).

Conclusion. In patients with hypercapnic respiratory failure, the increase in range of diaphragm movement 15 minutes after starting NIV is associated with a decrease in PCO_2 after 1 hour.

Keywords: Ultrasonography. Diaphragm. Hypercapnia. Noninvasive ventilation.

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Relación entre la movilidad diafragmática medida por ecografía y la presión parcial arterial de CO_2 en pacientes con insuficiencia respiratoria aguda hipercápnica tras el inicio de la ventilación mecánica no invasiva en urgencias

Objetivo. Correlacionar la variación de la movilidad diafragmática (MD), medida a través de ecografía, con el cambio en la presión parcial arterial de CO_2 de (pCO_2) tras el inicio de la ventilación mecánica no invasiva (VMNI).

Método. Estudio descriptivo de una serie de casos prospectivo que incluyó por oportunidad a los pacientes de 18 o más años con insuficiencia respiratoria hipercápnica en los que se inició la VMNI en urgencias. Se recogieron variables clínicas, gasométricas y mediciones ecográficas de la MD directa (MDD) y MD portal (MDP).

Resultados. Se incluyeron 21 pacientes, con una edad media de 83 (DE 13) años, de ellos 11 mujeres (52,4%). Los valores de MDD y pCO_2 fueron: 1) basal: MDD 13,9 (DE 7,7) mm y pCO_2 71,7 (DE: 11,4) mmHg; 2) 15 minutos: MDD 17,1 (DE 9,1) mm; 3) 1 hora: MDD 22,4 (DE 10,4) y pCO_2 63,4 (DE: 16,0) mmHg; 4) 3 horas: MDD 26,6 (DE: 19,5) mm y pCO_2 61,8 (DE :13,0) mmHg. Hubo correlación estadísticamente significativa entre la diferencia a los 15 minutos y basal de MDD y el descenso a la hora de pCO_2 ($r = -0{,}489$; $p = 0{,}035$).

Conclusión. El aumento de la MDD a los 15 minutos del inicio de la VMNI se relaciona con una disminución de la pCO_2 a la hora en los pacientes con insuficiencia respiratoria hipercápnica.

Palabras clave: Ecografía. Diafragma. Hipercapnia. Ventilación mecánica no invasiva.

Introduction

Acute hypercapnic respiratory failure (AHRF) is caused by hypoventilation, which is related to a decrease in diaphragmatic motion (DM)[1,2]. Studies published in recent years indicate a relationship between decreased DM and the presence of hypercapnia[3,4]. The methods used to evaluate DM are ultrasound measurement of the portal vein[3-5] and the right hemidiaphragm[6-8].

Non-invasive mechanical ventilation (NIMV) is the usual ventilatory therapy used in the emergency department (ED) in patients with AHRF[9-11]. To our knowledge, there is currently no information on the relationship between DM and partial arterial CO_2 pressure

(pCO_2) in patients treated with NIMV. The hypothesis was that if hypercapnia is produced by a decrease in DM and NIMI improves hypercapnia, NIMV should lead to an increase in DM. Therefore, the objective of the study was to correlate the variation of the DM, measured by ultrasonography, with the change in pCO_2 after initiation of NIV in patients with ARFH seen in an ED.

Method

We designed a descriptive study of a prospective series of cases that was carried out in the ED from the General University Hospital Reina Sofía (HGURS) of Murcia from January 1 to March 30, 2016. The study followed the laws and regulations in force and Was approved by the HGURS Clinical Research Ethics Committee.

Patients ≥ 18 years of age with AHRF (pO_2 / FiO_2 < 300, pCO_2 > 45 mmHg and pH <7.35) who started NIMV in the ED and who consented to participation in the study were included in the study. Exclusion criteria were the need for invasive mechanical ventilation (IMV), upper airway compromise, facial trauma, pneumothorax, high risk of bronchoaspiration, patients with tracheostomy and hemodynamic instability (SBP < 100 mm Hg or MAT < 70 mmHg] or low level of consciousness (Glasgow Coma Scale < 13).

Demographic data (age and sex), medical conditions, main diagnosis, clinical variables, analytical and respirator parameters were collected from the medical history. Ventilators used for NIMV were BiPAP model ST or Trilogy 202 (Respironics; Murrysville, PA, EDA). The investigator was not the doctor responsible for the urgent care process. Patients were monitored for the first three hours (baseline, 15 minutes, 1 hour and 3 hours) after the onset of NIMV, and clinical, gasometric and ultrasound variables were recorded.

DM was calculated by performing ultrasound at the foot of the bed by an emergency physician, the only researcher, accredited with basic level 1 by WINFOCED. To estimate the DM, two methods of ultrasound measurement were used:

1) Direct DM (DDM): measurement of the displacement of the dome of the diaphragm between inspiration and expiration[6-8,12,13] placing the 5 mHz convex probe in the anterior medial axillary line and parallel to the intercostal space. Mode B was used to visualize the lower border of the costophrenic angle and the lower pole of the right kidney to locate the diaphragmatic dome[6]. It was then changed to M mode to measure the displacement between inspiration and expiration in millimetres (Figure 1).

2) Portal DM (PDM): measurement in mm of the displacement of the left branch of the portal vein between inspiration and expiration[3-5], placing the convex 5 mHz probe in the right subcostal region with an angle of incidence perpendicular to the craniocaudal axis in mode B (Figure 1). The ultrasound device used was a General Electric Healthcare Logi (Jiangsu, China).

Qualitative variables are described as absolute values and percentages, and continuous variables as mean and standard deviation (SD) (normal distribution) or median and interquartile range (IQR) (non-parametric distribution), according to the Kolmogorov-Smirnov test. Qualitative variables were compared using chi-squared test or Fisher's exact test, and ANOVA or Kruskal-Wallis test was used for the comparison of quantitative variables. For the evaluation of changes in the main variables (diaphragmatic measures, vital constants and gasometric values) we used ANOVA for repeated measures independently of the distribution of the quantitative variable. The concordance

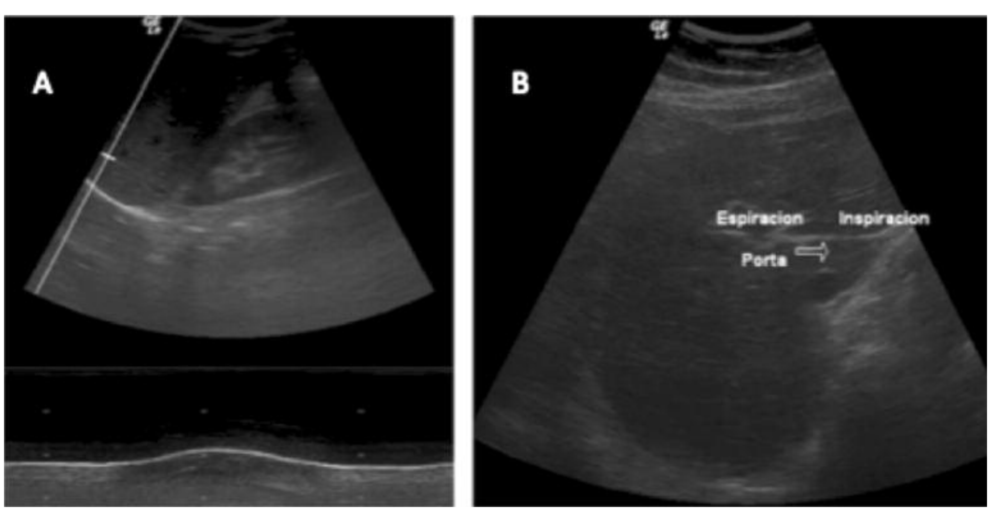

Figure 1. Ultrasound images of the two methods of measuring diaphragm motion. A) Direct diaphragmatic motion: displacement of the diaphragmatic dome in the right anterior axillary line parallel to the intercostal space. Mode B and mode M. B) Motion of the portal diaphragm: displacement of the left branch of the portal vein between inspiration and expiration in the right subcostal region. Mode B.

of the two ultrasound variables was assessed by Lin's concordance coefficient and the Bland-Altman method. To estimate correlations, Pearson's r or Spearman's rho test was used as appropriate. The accepted level of significance was $p < 0.05$. For statistical calculations, we used IBM SPSS Statistics v-22 program (IBM, New York, NY, USA).

Results

We selected 31 potentially eligible patients, of whom 21 were finally included. Two were excluded because immediate ventilatory support was required, 1 due to an agonizing situation and 7 due to poor echographic window for both measurements. Of the 21 patients, 4 patients presented poor echographic window for PDM. Mean age was 83 (SD 13.5) years; 11 (52.4%) were women. With regard to personal history and home treatment, 18 patients (81.8%) had hypertension, 6 (27.3%) diabetes mellitus, 9 (40.9%) chronic obstructive pulmonary disease (COPD), 8 (36.4%) hypoventilation syndrome, 10 (45.5%) chronic home oxygen therapy, 6 (27.3%) home CPAP and 1 (4.5%) home BiPAP. Regarding admission diagnosis, 9 cases (40.9%) had acute pulmonary oedema, 8 (38.1%) COPD exacerbation, 2 (9.0%) hypoventilation-obesity syndrome, 1 (4.6%) intrinsic asthma and 1 (4.6%) had pneumonia.

Of the 21 patients included, we measured DDM in all and PDM in 17. The two diaphragmatic measurements had low baseline concordance (0.293, 95% CI: -0.340-0.744), at 15 minutes (0.607, CI 95: 0.082-0.869), at 1 hour (0.460, 95% CI: 0.125 - 0.808) and at 3 hours (0.431; CI: 95%: - 0.160-0.794).

Table 1 shows the clinical data, the gasometric variables, the respirator parameters and the diaphragmatic measures at the different moments of assessment. In the first 15 minutes after initiating NIMV, DDM presented an average increase of 3.1 (95% CI: 0.9-2.2) mm and PDM 3.0 mm (95% CI: 0.93-3.93). At 1 hour, there was an average increase of 6.61 mm (95% CI: 3.2-9.2) for DDM, and 4.60 mm (95% CI: 1.67-5.61) for PDM. At 1 hour after initiating NIMV, pCO_2 decreased on average by 8.34 mmHg (95% CI: 2.16-14.4).

Regarding baseline to 15-minute measurements we observed a statistically significant correlation between DDM and the decrease of pCO_2 ($r = -0.489$; $p = 0.035$). The correlation between baseline and 1-hour DDM was statistically significant ($r = -0.642$, $p = 0.010$).

Discussion

The present study shows that there is a correlation between DM and pCO_2 after initiating NIMV in patients with AHRF. The change in DDM between baseline and 1 hour was the most important measurement, but the difference in DDM between baseline and 15 minutes may be the most clinically useful because it allows us to predict within 15 minutes of initiating NIMV what the decrease of pCO_2 at 1 hour will be. Thus, bedside ultrasound DDM could be a predictor of success or early failure of ventilation in patients with ARFH. The only similar study to ours is that by Kim *et al.*[8], who assessed DM and the probability of IMV weaning; they reported that a DM greater than 10 mm is a predictor of success for weaning. However, at present there are no publications that assess DM as a predictor of success or failure of NIMV.

The present study has a number of limitations, including those inherent in the design of the study, the limited sample size and the fact that it grouped patients with different etiologies of AHRF, which ruled out a study based on individualized diagnoses. However, it can be concluded that there is an association between DM and arterial pCO_2 after initiation of NIMV in patients with AHRF. Future studies will show whether the increase in DDM at 15 minutes from the onset of NIMV is related to a decrease in pCO_2 at 1 hour, and therefore whether it can be considered a predictor of success or failure of NIMV.

Table 1. Summary of ultrasound measurements, blood gas values, vital signs and ventilatory parameters

	Baseline	15 min		1 hour		3 hours	
	Mean (SD)	Mean (SD)	p	Mean (SD)	p	Mean (SD)	p
DM portal (mm	3.1 (4.1)	6.5 (3.3)	0.020	7.5 (4.4)	0.007	9.8 (8.9)	< 0.001
Direct DM (mm)	13.9 (7.7)	17.1 (9.5)	0.294	22.4 (10.4)	0.023	25.6 (19.5)	0.006
Sat O_2 (%)	96.0 (8.0)	95.4 (5.0)	0.999	95.0 (4.0)	0.999	96.0 (4.0)	0.999
FiO_2 (%)	33 (14.0)	21 (2.0)	0.044	25 (2.0)	0.011	25.0 (2.5)	0.007
pH	7.279 (0.05)	–	NA	7.321 (0.06)	0.015	7.34 (0.1)	0.015
pCO_2 (mm Hg)	71.7 (11.4)	–	NA	63.45 (16.0)	0.032	61.8 (13.0)	0.009
HCO_3 – (mmol / L)	33.34 (6.25)	–	NA	32.6 (6.0)	0.685	32.8 (6.2)	1.00
Respiratory rate (min^{-1})	19 (7.0)	18 (6.0)	0.013	17 (3.0)	0.008	18.0 (4.0)	0.026
Heart rate (min^{-1})	81.5 (11.8)	78.6 (11.2)	0.368	77.8 (11.9)	0.415	77.6 (12.3)	0.292
Mean arterial pressure (mm Hg)	89.6 (16.3)	84.7 (15.1)	0.744	84.7 (12.8)	0.390	85.9 (11.3)	1.00
IPAP (cm H_2O)	–	16.0 (1.5)	NA	17.0 (2.0)	0.031*	18.0 (2.0)	0.010*
EPAP (cm H_2O)	–	6.0 (2.0)	NA	6.0 (3.0)	0.487*	6.0 (3.0)	0.249*
Support pressure (cm H_2O)	–	10.0 (0.0)	NA	10.0 (1.5)	0.311*	10.0 (1.5)	0.357*

NA: not applicable; DM: diaphragmatic motion; SD: standard deviation; Sat O_2: oxygen saturation; HCO_3: bicarbonate; IPAP: inspiratory positive airway pressure; EPAP: expiratory positive airway pressure.
*P values on comparison with values at 15 minutes.

Conflicting interests

The authors declare no conflict of interest

Financing

The authors declare no conflict of interest reated to this article..

Ethical Responsibilities

The Ethics and Clinical Research Committee of the Hospital Reina Sofía de Murcia approved the study.

Informed consent was obtained from all participants.

All authors confirmed the maintenance of confidentiality and respect for patients' rights in the author's responsibilities document, publication agreement and assignment of rights to EMERGENCIAS.

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