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Superiority of transcutaneous CO_2 over end-tidal CO_2 measurement for monitoring respiratory failure in nonintubated patients: A pilot study☆,☆☆

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ABSTRACT

Purpose: Arterial blood gas measurement is frequently performed in critically ill patients to diagnose and monitor acute respiratory failure. At a given metabolic rate, carbon dioxide partial pressure ($Paco_2$) is entirely determined by CO_2 elimination through ventilation. Transcutaneous partial pressure of carbon dioxide ($PtcCO_2$) monitoring permits a noninvasive and continuous estimation of arterial CO_2 tension ($Paco_2$). The accuracy of $PtcCO_2$, however, has not been well studied.

To assess the accuracy of different CO_2 monitoring methods, we compared $PtcCO_2$ and end-tidal CO_2 concentration ($EtCO_2$) to $Paco_2$ measurements in nonintubated intensive care unit (ICU) patients with acute respiratory failure.

Methods: During a 2-month period, we conducted a prospective observational cohort study in 25 consecutive nonintubated and spontaneously breathing patients admitted to our ICU. Arterial blood gases were measured at study inclusion, 30, 60, and 120 minutes later. At each sampling time, $EtCO_2$ was continuously monitored using a Philips Smart Capnoline Plus, and $PtcCO_2$ was measured using was measured using SenTec device. The aim of the study was to assess agreement between $PtcCO_2$ and $Paco_2$ and between $EtCO_2$ and $Paco_2$ in nonintubated ICU patients with acute respiratory failure. Bland-Altman techniques and Pearson correlation coefficients were used. The differences over time (at 30, 60, and 120 minutes) between $Paco_2$ and $EtCO_2$ and between $PtcCO_2$ and $Paco_2$ were evaluated using 1-way analysis of variance.

Results: Transcutaneous partial pressure of carbon dioxide and $Paco_2$ were well correlated ($R = 0.97$), whereas the correlation between $EtCO_2$ and $Paco_2$ was poor ($R = 0.62$) probably due to the presence of an alveolar dead space in a few patients, most notably in the group with chronic obstructive pulmonary disease. The difference over time remained stable for both $Paco_2$ vs $EtCO_2$ (analysis of variance; $P = .88$) and $Paco_2$ vs $PtcCO_2$ ($P = .93$).

Conclusion: We found large differences between $EtCO_2$ and $Paco_2$ in spontaneously breathing nonintubated ICU patients admitted for acute respiratory failure. Our study argues against the use of $EtCO_2$ monitoring in such patients but raises the possibility that $PtcCO_2$ measurement may provide reasonable estimates of $Paco_2$.

1. Introduction

In a wide range of respiratory disorders, patients with mild respiratory failure and those being weaned off or in need of mechanical ventilation in the intensive care unit (ICU) are at risk for severely hypercapnic respiratory failure. Arterial carbon dioxide partial pressure ($Paco_2$) monitoring in these patients is used to assess alveolar ventilation and predict the need for mechanical ventilation. End-tidal CO_2

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☆☆ Author's contributions: NT, FL, and ML conceived the study and designed the trial. NT, FL, and HN supervised the conduct of the trial and data collection. SG, BS, NT, and ML undertook recruitment of patients and managed the data, including quality control. HM provided statistical advice on study design and analyzed the data. NT, HM, FL, and ML drafted the manuscript, and all authors contributed substantially to its revision. NT takes responsibility for the manuscript.

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concentration ($EtCO_2$) is a noninvasive surrogate for partial pressure of arterial CO_2 ($Paco_2$). Previous studies have demonstrated the value of $EtCO_2$ monitoring during procedural sedation-analgesia, cardiopulmonary resuscitation, and confirmation of endotracheal tube position [1-5]. However, relatively accurate $EtCO_2$ values may be difficult to obtain in nonintubated patients [6] due to contamination of the expired gas sample by room air, mouth breathing, and oxygen flow delivery through the ipsilateral nasal cannula [7-9]. To address this issue, several manufacturers have developed nasal cannulae with an oral guide designed to capture expiratory flow from the upper airways [3].

In light of the limitations of $EtCO_2$ monitoring, devices to measure transcutaneous partial pressure of carbon dioxide ($PtcCO_2$) at the bedside are a promising alternative. Transcutaneous CO_2 devices have been studied in several clinical settings [10,11], including invasive and noninvasive ventilation in ICUs and overnight studies of sleep-disordered breathing with varying results [12].

The aim of the study was to assess agreement between $PtcCO_2$ and $Paco_2$ and between $EtCO_2$ and $Paco_2$ in nonintubated ICU patients with acute respiratory failure.

2. Methods

The appropriate ethics committee (CPP Nord-Ouest III) approved the study (A12-D28-VOL13). Written informed consent was obtained from all patients before study inclusion.

2.1. Study design and setting

From May to July 2013, we conducted a prospective observational cohort study in 25 consecutive patients admitted to the ICU of the university hospital in Caen, France. For sample size estimation, see the statistic section.

2.2. Monitoring system

The Philips Smart Capnoline Plus (Philips, Böblingen, Germany) is a nasal cannula for use in nonintubated patients with the dual purpose of delivering oxygen and collecting $EtCO_2$ samples from both the nose and mouth (Fig. 1). This nasal cannula is designed to deliver oxygen without affecting CO_2 monitoring. The length of the cannula is approximately 255 cm, and the delay of CO_2 measurement is approximately 240 milliseconds. The SenTec (SenTec AG, Basel, Switzerland) consists of a heated $PtcCO_2$ electrode and a pulse oximetry sensor, which are clipped to the earlobe. As recommended by the manufacturer, the electrode was calibrated in a docking station before each measurement, using a service gas (mixture of 8% CO_2, 12% O_2, and 80% N_2) (SenTec AG), which took approximately 4 to 11 minutes. The sensor membrane was changed every 14 days. The skin was cleansed thoroughly with isopropanol 70% then dried. A small drop of sensor gel (SenTec AG) was applied to the center of the sensor membrane surface, which was then secured to the earlobe with a low-pressure ear clip and a tape in front of the ear. The electrode temperature was set at 42°C to increase blood flow, thereby improving skin permeability to gases and arterializing the capillaries to record $PtcCO_2$ values and subsequently to estimate $Paco_2$. Transcutaneous partial pressure of carbon dioxide monitoring began after 5 to 8 minutes (recommended for warming of the measurement site, complete local arterialization, and equilibration of CO_2 concentrations between the skin and sensor).

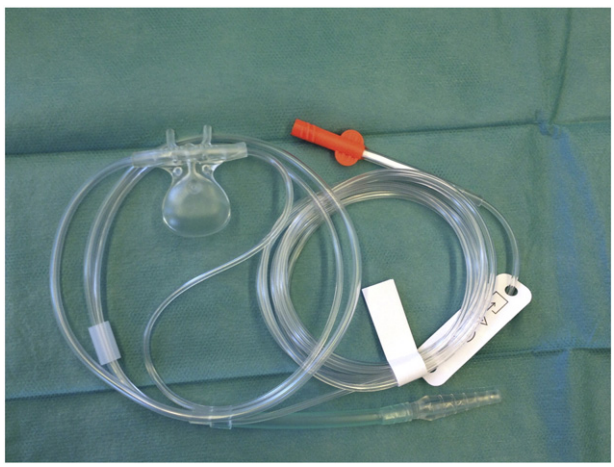

Fig. 1. The Philips Smart Capnoline Plus used for oxygen therapy and continuous $EtCO_2$ monitoring. This nasal cannula is designed to deliver oxygen without affecting CO_2 monitoring. The length of the cannula is approximately 255 cm, and the delay of CO_2 measurement is approximately 240 milliseconds.

2.3. Study design and population

During the study period, 25 consecutive patients with acute respiratory failure requiring oxygen therapy via a nasal cannula and monitoring via an arterial catheter were eligible. Of the 25 patients, 11 were admitted to the ICU for acute exacerbation of chronic obstructive pulmonary disease (COPD) requiring noninvasive ventilation and were evaluated between two sessions of noninvasive ventilation (NIV). The remaining 14 patients required endotracheal mechanical ventilation for acute respiratory failure and were evaluated immediately after extubation. Exclusion criteria were agitation, oxygen requirement greater than 5 L/min, and refusal of informed consent.

We prospectively gathered data on anthropometric characteristics, chronic respiratory comorbidities, and reason for ICU admission. The Philips Smart Capnoline Plus was used for oxygen therapy and continuous $EtCO_2$ monitoring. The SenTec device was attached using a disposable ear clip and a drop of contact gel, according to the manufacturers' recommendations. Transcutaneous partial pressure of carbon dioxide was recorded continuously.

A physician not involved in the study obtained arterial blood samples, at times 0, 30, 60, and 120 minutes, via a catheter previously inserted into the radial artery (Arterial Leader Cath Artériel; Vygon, Écouen, France). At each sampling time (0, 30, 60, and 120 minutes) and during the last minute before arterial sampling, an experienced clinician recorded $EtCO_2$ breath by breath and calculated the mean $EtCO_2$ for that period. At the end of the minute, while $PtcCO_2$ remained stable (variation <1 mm Hg), if the patient was unable to attain a discernible alveolar plateau, we asked him to perform a prolonged expiration during the measurement to ensure that the alveolar plateau was attained. Similarly, pulse oximetry, arterial blood pressure, heart rate, and body temperature were checked just before arterial blood sampling. These physiological data were monitored to check that the patient's condition remained stable over the study period. Arterial blood gas (ABG) values were measured using a Radiometer ABL 330 analyzer (Tacussel, Copenhagen, Denmark).

2.4. Data analysis

We estimated the required sample size based on published $EtCO_2$ and $Paco_2$ values measured in ICU patients [9,13] and using G*Power software (3.1.3, Franz Faul; Universitat Kiel, Kiel, Germany). Sample sizes of 59 measures were required to achieve 95% power for detecting an effect size of 0.4 (corresponding to “medium” on Cohen's scale) with α set at .05.

The data were described as mean ± SD. Relationships between 2 variables were evaluated by computing the Pearson correlation coefficient, and agreement between 2 variables was estimated using the Bland-Altman method, in which bias was the mean difference between $Paco_2$ and $PtcCO_2$ and the upper and lower limits of agreement were the mean of the differences ± 1.96 SDs above and below the mean difference. Precision (the ability to reproduce the same measurement) was