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A pilot assessment of alpha-stat vs pH-stat arterial blood gas analysis after cardiac arrest[☆]

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ABSTRACT

Purpose: Resuscitated cardiac arrest (CA) patients typically receive therapeutic hypothermia, but arterial blood gases (ABGs) are often assessed after adjustment to 37°C (alpha-stat) instead of actual body temperature (pH-stat). We sought to compare alpha-stat and pH-stat assessment of Pa_{O_2} and Pa_{CO_2} in such patients.

Materials and methods: Using ABG data obtained during the first 24 hours of intensive care unit admission, we determined the impact of measured alpha vs calculated pH-stat on Pa_{O_2} and Pa_{CO_2} on patient classification and outcomes for CA patients.

Results: We assessed 1013 ABGs from 120 CA patients with a median age of patients 66 years (interquartile range, 50-76). Median alpha-stat Pa_{O_2} changed from 122 (95-156) to 107 (82-143) mm Hg with pH-stat and median Pa_{CO_2} from 39 (34-46) to 35 (30-41) mm Hg (both $P < .001$). Using the categories of hyperoxemia, normoxemia, and hypoxemia, pH-stat estimation of Pa_{O_2} reclassified approximately 20% of patients. Using the categories of hypercapnia, normocapnia, and hypocapnia, pH stat estimation of Pa_{CO_2} reclassified approximately 40% of patients. The mortality of patients in different Pa_{O_2} and Pa_{CO_2} categories was similar for pH-stat and alpha-stat.

Conclusions: Using the pH-stat method, fewer resuscitated CA patients admitted to intensive care unit were classified as hyperoxemic or hypercapnic compared with alpha-stat. These findings suggest an impact of ABG assessment methodology on Pa_{O_2}, Pa_{CO_2}, and patient classification but not on associated outcomes.

1. Introduction

Arterial blood gas (ABG) analysis is common in post–cardiac arrest (CA) patients admitted to the intensive care unit (ICU) after return of spontaneous circulation (ROSC). Many such patients receive therapeutic hypothermia (TH). Arterial blood gas analyses in such patients inform decisions about oxygenation and ventilation management. In this regard, several recent clinical studies have examined the relationship between arterial oxygen concentration (Pa_{O_2}) and arterial carbon dioxide concentration (Pa_{CO_2}) and mortality and/or discharge home among CA patients admitted to the ICU [1-5]. These studies have shown that arterial hypoxemia and hypocapnia are independently associated with increased mortality [2-4]. In addition, compared with normocapnia, hypercapnia was independently associated with a greater likelihood of discharge home among survivors [5]. Thus, patient classification into different categories of oxygenation and carbon dioxide control may have prognostic, therapeutic, and trial design implications. It also logically relies on the correct ABG-derived estimation of Pa_{O_2} and Pa_{CO_2}. Unfortunately, in patients potentially exposed to TH, the correct method of ABG assessment is controversial.

Blood gas monitoring is common in the early management of CA patients admitted to the ICU. Arterial blood gas tensions are affected by temperature [6]. Specifically, as temperature falls, pH increases and both Pa_{O_2} and Pa_{CO_2} decrease. Conversely, as temperature rises, pH decreases and both Pa_{O_2} and Pa_{CO_2} increase [6]. After ROSC and ICU admission, ABGs are typically assessed based on values

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adjusted to 37°C (alpha-stat). However, many patients may have a core temperature of 33°C to 34°C at the time of ABG measurement, suggesting that gas tension assessment at the patient's actual body temperature (pH-stat) may be the more physiologically relevant approach. The impact of using alpha- or pH-stat in these patients, however, remains unclear [7].

Accordingly, we sought to compare the associations and association impact of measured alpha-stat vs calculated pH-stat ABG interpretation for CA patients. Specifically, we wished to determine the magnitude of the effect on $Pa{O_2}$ and $Pa{CO_2}$ values in our cohort. Moreover, we wished to test the hypothesis that the reclassification of patients into the categories of hypocapnia or hypoxemia, normocapnia, or normoxemia and hypercapnia or hyperoxemia would be significantly affected between ABG analysis methods. Finally, we wished to describe the association between outcomes based on $Pa{O_2}$ and $Pa{CO_2}$ classification with each method.

2. Methods

2.1. Study design, population, and setting

We conducted a retrospective comparative study of nontraumatic CA patients admitted to our tertiary teaching hospital (Austin Hospital, Melbourne, Victoria). We obtained Human Research Ethics Committee approval before commencement (Human Research Ethics Committee approval no. H2013/05104). The need for informed consent was waived because the study required no intervention and no breach of privacy or anonymity.

We included nontraumatic adult inhospital CA (IHCA) and out-of-hospital CA (OHCA) patients admitted to our ICU between May 2007 and December 31, 2011. After exclusion of patients with a short time to ROSC (<5 minutes) who showed signs of rapid awakening and responsiveness upon ROSC, our unit protocol for the management of post-CA patients during the audit period was to implement TH on all suitable CA patients (ie, those patients with a primary CA, ROSC, and for active treatment).

Using core body temperature measurements, cooling was induced within the first 4 to 6 hours with a target body temperature of 33°C to 34°C. Therapeutic hypothermia was maintained for 24 hours before passive rewarming over the following 8 to 12 hours. Our standard unit practice during this period was to assess ABG samples according to the alpha-stat method.

2.2. Data collection and management

For each patient, we obtained the following variables: demographics, hospital and ICU admission source, CA characteristics (Ventricular fibrillation/Ventricular tachycardia [VF/VT] initial rhythm, location of CA, time to ROSC, ABG parameters, and the corresponding physiological variables) and ICU care processes (sedation and narcotic analgesic use, neuromuscular blockade use, vasopressor requirement, coronary angiogram, TH use, nutrition commencement, and bicarbonate use) over the first 24 hours of ICU admission, and Acute Physiology and Chronic Health Evaluation (APACHE) III score [7] as well as vital status and destination at hospital discharge.

2.3. Data analysis

All analyses were performed using SPSS version 19.0 (SPSS, Inc, Chicago, IL). Categorical data are reported as proportions and compared with χ^2 test or McNemar exact test, wherever appropriate. Continuous data are expressed as means with SD or medians with interquartile range as appropriate and compared by the Student *t* test if parametric or Mann-Whitney *U* test if nonparametric. A 2-sided $P < .05$ was considered significant.

Using all ABGs available in the first 24 hours after ICU admission, we evaluated the impact of measured alpha-stat and calculated pH-stat analysis on $Pa{O_2}$ and $Pa{CO_2}$. Temperature correction was determined by the following equations [8]:

$$\mathrm{PaO_2(Tp)} = \mathrm{PaO_2} \times 10^\wedge\Big\{\Big(549 \times 10^\wedge{-11} \times \mathrm{PaO_2}^\wedge 3.88 + 0.071\Big) \times (\mathrm{Tp}-37)/\Big(9.72 \times 10^\wedge{-9} \times \mathrm{PaO_2}^\wedge 3.88 + 2.3\Big)\Big\}$$

$$\mathrm{PaCO_2(Tp)} = \mathrm{PaCO_2} \times 10^\wedge 0.019(\mathrm{Tp}-37)$$

In these equations, temperature (Tp) is measured in degrees Celsius (°C), arterial oxygen tension ($Pa{O_2}$) in millimeters of mercury and arterial carbon dioxide tension ($Pa{CO_2}$) in millimeters of mercury.

Furthermore, within all such ABGs, a $Pa{O_2}$ value and a $Pa{CO_2}$ value were selected as the "worst ABG" value according to APACHE III methodology [9]. This method selects "$Pa{O_2}$" and "$Pa{CO_2}$" values associated with the ABG containing the highest alveolar-arterial (A-a) gradient for patients with a fraction of inspired oxygen ($F{IO_2}$) greater than or equal to 0.5 or the one associated with the lowest $Pa{O_2}$ level for patients with a $F{IO_2}$ of less than 0.5.

For the purposes of this study, using such APACHE III–based value, we defined *hypoxemia* as a $Pa{O_2}$ less than 60 mm Hg, *hyperoxemia* as a $Pa{O_2}$ greater than 120 mm Hg, and *normoxemia* as any value between hypoxemia and hyperoxemia. We also defined *hypocapnia* as a $Pa{CO_2}$ less than 35 mm Hg, *hypercapnia* as a $Pa{CO_2}$ greater than 45 mm Hg, and *normocapnia* as any value between hypocapnia and hypercapnia. Using these values we then determined:

(i) the proportion of patients classified into hypo-, normo-, and hyper- groups for $Pa{O_2}$ and $Pa{CO_2}$ and their outcomes,
(ii) the proportion and outcomes of patients who were reclassified into different $Pa{O_2}$ and $Pa{CO_2}$ groups following pH-stat reanalysis, and
(iii) vital status at hospital discharge and discharge home among survivors for patients according to each method of $Pa{O_2}$ and $Pa{CO_2}$ classification.

2.4. Multivariable analysis

Because most reclassification with pH-stat method was expected to be downward, we assessed the relationship between such downward reclassifications and outcomes. We selected patients in hyperoxemia/hypercapnia class and normoxemia/normocapnia class with the alpha-stat method and developed multivariable logistic regression models. Regression models were adjusted for initial cardiac rhythm of VF/VT, IHCA, time to ROSC, APACHE III, TH, treatment limitation (including withdrawal of therapy), and downward reclassification from one oxygen or carbon dioxide category to another.

3. Results

There were 1013 ABGs from 120 CA patients with a median age of 66 years (interquartile range, 50-76 years) and 77 (64%) males. Two thirds were OHCA and one third were IHCA. The initial rhythm was VF/VT in 50% of patients, and the median time to ROSC was 20 minutes (10-30 minutes). Baseline characteristics, CA characteristics, ICU care processes, and outcomes for all patients are given in Table 1. Their physiological parameters obtained during the first 24 hours of ICU admission using alpha-stat are shown in Table 2.

3.1. Comparison of ABG data between alpha-stat and pH-stat

The mean body temperature for the overall cohort was 34.2°C (33.5°C-35.7°C). For patients treated with TH, the mean body