Plinska analiza periferne venske krvi in pulzna oksimetrija za oceno akutne dihalne odpovedi v urgentni ambulanti

Use of Peripheral Venous Blood Gas Analysis and Oximetry to Assess Respiratory Failure in the Emergency Department

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Izvleček

Namen: *Diagnoza akutne dihalne odpovedi temelji na plinski analizi arterijske krvi (ABGA, iz ang. Arterial Blood Gases Analysis). Odvzem krvi za PAAK je neprijeten, ob odvzemu pa lahko nastanejo zapleti. Naš cilj je bil primerjati rezultate ABGA s plinsko analizo periferne venske krvi (PVBGA, iz ang. Peripheral Venous Blood Gases Analysis) in pulzno oksimetrijo pri odraslih bolnikih z dispnejo in/ali sumom na akutno dihalno odpoved.*

Metode: Opravili smo prospektivno raziskavo, v katero smo vključili 102 bolnika (od tega 56 moških). Raziskavo smo opravili v obdobju od marca do maja

Abstract

Purpose: *The diagnosis of acute respiratory failure (ARF) is based on arterial blood gas analysis (ABGA), which is associated with patient discomfort and requires an additional vascular puncture. Our aim was to compare ABGA with peripheral venous blood gas analysis (PVBGA) and pulse oximetry in adult patients with dyspnea and/or suspected ARF.*

Methods: *We included 102 patients (56 males) in a prospective study performed in a medical emergency department from March–May 2019. Patients with overt signs of circulatory shock or severe respiratory failure were not included.*

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2019 na Internistični nujni pomoči. Bolnikov z izraženo hudo dihalno odpovedjo ali cirkulatorno odpovedjo nismo vključevali.

Rezultati: *Ugotovili smo signifikantne pozitivne korelacije med rezultati ABGA in PVBGA (za pH ρ = 0,590, za HCO_3 ρ = 0,901 in za pCO_2 ρ = 0,740) ter nesignifikantne razlike med saturacijo kisika v ABGA in oksimetriji (95 % proti 94 %; p = 0,49). Ko smo od venskega pCO_2 odšteli 1 kPa in venskemu pO2 dodali 4 kPa, ni bilo več statistično pomembnih razlik med perifernimi venskimi in arterijskimi pCO_2 in pO2 (4,8 v primerjavi s 4,7 kPa; p = 0,26 in 9,5 v primerjavi s 8,9 kPa; p = 0,21).*

Zaključek: *Z upoštevanjem rezultatov PVBGA in oksimetrije bi lahko pridobili dovolj podatkov za sprejemanje kliničnih odločitev pri izbrani skupini bolnikov z dispnejo in/ali dihalno odpovedjo.*

Results: *We showed significant positive correlations between ABGA and PVBGA results (for pH, ρ=0.590; for HCO_3, ρ=0.901; and for pCO_2, ρ=0.740), and insignificant differences between oxygen saturation based on ABGA and pulse oximetry (95% vs. 94%; p=0.49). When we subtracted 1 kPa from the venous pCO_2 and added 4 kPa to the venous pO_2, there were no statistically significant differences between peripheral venous and arterial pCO_2 and pO_2 (4.8 vs. 4.7 kPa, p=0.26 and 9.5 vs. 8.9 kPa, p=0.21, respectively).*

Conclusion: *The combination of PVBGA and pulse oximetry provided sufficient data to make clinical decisions in a select group of patients with dyspnea and/or ARF.*

INTRODUCTION

The gold standard for the diagnosis of acute respiratory failure (ARF) is based on the results of arterial blood gas analysis [ABGA] (1). The blood for ABGA is usually obtained by radial artery puncture or from an indwelling arterial catheter. Both procedures are associated with patient discomfort, and rarely, significant complications (2). In addition to patient comfort, the benefits of assessing respiratory or metabolic status using peripheral venous blood include more streamlined diagnostic procedures because all blood can be obtained from a peripheral venous cannula (3-6). Several studies (7-13) have been conducted involving patients with different respiratory and metabolic diseases who did not require a high fraction of inspired oxygen and were not in circulatory failure, in which differences were reported, as follows: 0.02–0.04 units lower pH and approximately 1 kPa higher pCO_2 in venous blood (statistically significant); and insignificant differences between oxygen saturation, as measured by ABGA compared to noninvasive oximetry. Rang et al. (13) conducted a survey among emergency physicians regarding the above differences, which revealed that the differences were considered too large for interchangeability of results; however, adding correction factors to venous values could allow for interpretation of the results.

The aim of our study was to compare the pCO_2, pO_2, pH, and HCO_3 values between ABGA and peripheral venous blood gas analysis (PVBGA), and oxygen saturation between ABGA (SaO_2) and pulse oximetry (SpO_2) in adult patients with dyspnea and/or ARF. In addition, we tested a simple method of approximating the arterial pCO_2 and pO_2.

MATERIALS AND METHODS

We conducted a prospective observational study with data collection from March–May 2019 in a medical emergency department of a university hospital with approximately 100,000 patient visits/year. The aim was to compare the pCO_2, pO_2, pH, and HCO3 values between ABGA and PVBGA and to compare SaO_2 with SpO_2 in adult patients with dyspnea and/or suspected ARF. We hypothesized the following: pCO_2 is 1 kPa lower in ABGA compared to PVBGA; there is no difference in pH and HCO_3 between ABGA and PVBGA; and there is no difference between SaO_2 and SpO_2.

Institutional Ethics Committee approval was obtained (No. 22/19) and patient/surrogate consent was obtained. We included adult patients (age > 18 years) with dyspnea and/or suspected ARF (hypoxemic or hypercapnic) in whom the attending physician decided to obtain blood for ABGA. The exclusion criteria were body mass index (BMI) < 18 kg/m2 and > 45 kg/m2, pregnancy, inability to obtain informed consent, patients in profound circulatory shock or severe respiratory failure in whom lifesaving procedures were required, patients in whom any changes in oxygen substitution therapy were made between blood withdrawals for ABGA and PVBGA, and patients in whom peripheral venous or arterial access could not be obtained.

A prior power analysis showed that approximately 50 patients would be needed to detect a 1 kPa higher pCO_2 in PVBGA compared to ABGA with 80% power and an alpha of 0.05. To increase the accuracy of the study we planned to include approximately 100 patients.

Measurements

The collected variables were pCO_2 pO_2, pH, and HCO_3 (ABGA and PVBGA), SpO_2, and SaO_2. In addition to the study data, we also collected basic demographic data, data on therapy with oxygen and bronchodilators, and data required for an Acute Physiology and Chronic Health Evaluation (APACHE) II score calculation (7).

Study intervention

Our standard procedure for treatment of patients with dyspnoea and/or suspected ARF was to obtain peripheral venous access as soon as possible, usually in the right cubital region. Blood for ABGA was usually withdrawn from the right radial artery (2,3).

In this study the attending physician requested the withdrawal of blood for ABGA based on a clinical indication. Blood for PVBGA was withdrawn from a peripheral venous catheter as soon as possible after radial artery puncture (maximally within 5 min). If a tourniquet was used during the insertion of the peripheral venous catheter, the tourniquet was removed at least 5 min before blood was withdrawn for PVBGA. If possible, the right cubital region and right radial artery were used for access to peripheral venous and arterial blood. No changes in oxygen substitution therapy were permitted 5 min before blood for study purposes was withdrawn. Blood for ABGA and PVBGA was sent to a central laboratory (ABL800 FLEX; Radiometer, Brønshøj, Denmark). We used fingertip oximetry measurements for SpO_2 (PM-60; Mindray Bio-Medical Electronics Co., Shenzen, China). When results were available, clinical decisions were made based on the ABGA results; the PVBGA results were only used for study purposes.

Data analysis

Statistical analyses were performed using SPSS IBM Statistics 24.0 (IBM Inc., Armonk, NY, USA), R (R Core Team 2019, https://www.R-project.org/), and GPower 3.1.9.2 software. [source?] Data were first tested for normality of distribution using the Kolmogorov-Smirnov test of normality. The statistical differences between two categorical dichotomous variables were determined using Fisher's exact test. A comparison of continuous variables across two groups was carried out using the Mann-Whitney U-test. The correlation between two continuous variables was determined using Spearman's rank correlation. Generalized linear models (GLMs) were fitted to confirm linear relationships between arterial (dependent variable) and venous parameters adjusted for age, sex, chronic obstructive pulmonary disease (COPD), and clinical signs of congestive heart failure. Statistical power was calculated post hoc for each comparison of the

variables using the Wilcoxon-Mann-Whitney test and a point biserial correlation model.

RESULTS

Baseline characteristics

A total of 102 patients (56 males and 46 females; mean age, 70±16 years) were enrolled. During the study period, nine additional patients were eligible for inclusion, but were not included; five patients were not included because blood for PVBGA was not obtained, two patients because the blood sample was hemolyzed, one patient because a BMI<18 kg/m2, and one because oxygen therapy was changed between the withdrawal of blood for ABGA and PVBGA.

The characteristics of the study patients are summarized in Table 1. In our study population, 65% of patients were admitted to the hospital, 44% received oxygen therapy, and 39% received bronchodilator therapy. Of the patients, 25% had been previously diagnosed with COPD, 37% of patients had clinical signs of congestive heart failure on presentation to the emergency department, and 24% of patients had been previously diagnosed with congestive heart failure. The mean arterial blood pressure on admission was 101 ± 17 mmHg and the mean heart rate 85 ± 19 bpm. The body temperature was > 37.0°C in 16% of patients. The median serum lactate concentration in ABGA samples was 1.5 ±. 0.8 mmol/L. None of the patients required vasoactive or inotropic support with norepinephrine, dopamine, or dobutamine. The APACHE II score was 11.4 ± 5.2 points.

Main results

Arterial and venous parameters were first assessed for statistically significant differences (Fig. 1). The median pH in ABGA samples was significantly different from the pH in PVBGA samples (7.43 vs.7.39; p=2.03×10-10). Statistically significant differences were also detected between the median HCO3 in ABGA and PVBGA samples (23.8 vs. 25.7 mmol/L; p=7.30×10-5), and between the median arterial pCO2 and venous pCO2 (4.8 vs. 5.7 kPa; p=1.27×10-10). There was a statistically significant difference between the median

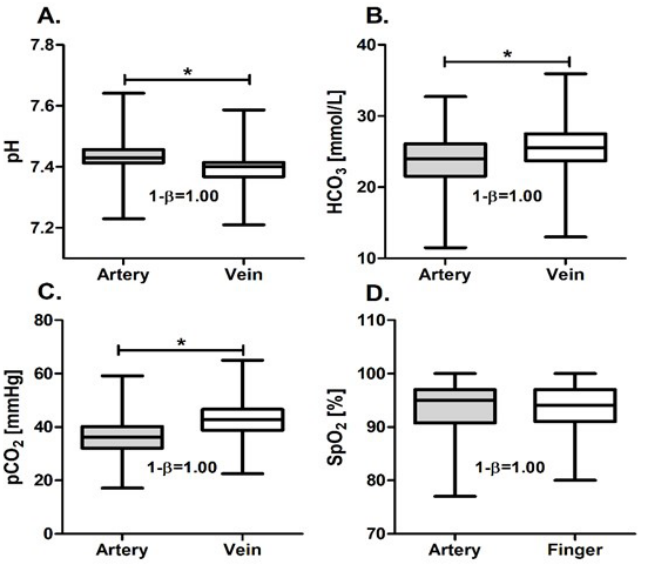

Figure 1. *Comparison of arterial and venous parameters. A: pH; B: HCO_3; C: pCO_2; D: SpO_2. Data are presented as the median, interquartile range, and minimum-to-maximum. P values were assessed using the Mann-Whitney U-test. Power was calculated using the Wilcoxon-Mann-Whitney test. *P < 0.05.*

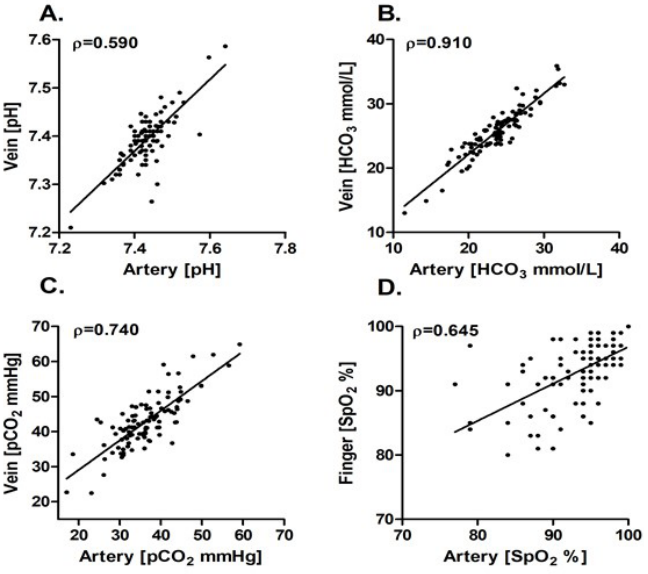

Figure 2. *Correlations between arterial and venous parameters. A: pH; B: HCO3; C: pCO_2; D: SpO_2. Correlations were determined using a Spearman rank correlation. Power was calculated using a point biserial correlation model and R2 coefficients of determination.*

Table 2. *Characteristics of included patients*

	Number of patients (n=102)	%
Sex		
Male	56	55
Female	46	45
Age groups		
18–40	7	0.7
41–65	24	23.6
66–79	41	40.2
≥ 80	30	29.4
Cause of dyspnea/ ARF		
Pneumonia	25	23.6
Other respiratory tract infections	12	11.3
AECOPD	13	12.3
Acute asthma exacerbation	6	5.7
Heart failure	25	23.6
Sarcoidosis	1	0.9
Chemical pneumonitis	1	0.9
Pulmonary embolism	3	2.8
Pleural effusion	2	1.9
Other causes (cardiac, psychologic)	24	22.6
COPD (stable disease or AECOPD)	26	25
Hospital admission		
Yes	66	64.7
No	36	35.3
Body temperature		
< 37°C	111.86	84.3
37°C–37.5°C	10	9.8
≥ 37.6°C	6	5.6
Respiratory rate		
≥ 20 breaths/minute	10	9.8

pO2 in ABGA and PVBGA samples (9.5 vs. 4.9 kPa; p<0.0001).

Oxygen saturation was compared between SaO_2 and SpO_2. Comparison of SpO_2 did not show any statistically significant differences between the median SaO_2 and SpO_2 (95% vs. 94%; p=0.49).

The correlations between ABGA and PVBGA and between SaO_2 and SpO_2 were assessed. There was a strong positive statistically significant correlation between ABGA/SaO_2 and PVBGA/SpO_2 parameters for pH (ρ=0.590), HCO3 (ρ=0.901), pCO_2 (ρ=0.740), and SpO_2 (ρ=0.645; Fig. 2).

We further assessed pCO_2 after subtracting 1 kPa from the venous pCO_2 variable as a "rule of thumb" to approximate the arterial pCO_2. With the aforementioned application, the statistically significant difference was no longer observed between the arterial and venous pCO_2 with a median of 4.8 kPa and 4.7 kPa (p=0.26), respectively (Fig. 3).

We also assessed pO_2 with the addition of 4 kPa to the venous pO_2 variable as a "rule of thumb" to approximate the arterial pO_2. The aforementioned statistically significant difference was no longer evident (9.5 vs. 8.9 kPa; p=0.21).

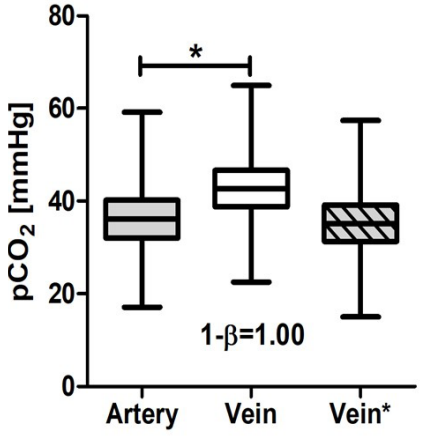

Figure 3. *Subtraction of 7.5 mmHg from venous pCO_2. Vein*: venous data with subtraction. Data are presented as the median, interquartile range, and minimum-to-maximum. P values were assessed using the Mann-Whitney U-test. Power was calculated using the Wilcoxon-Mann-Whitney test.*P < 0.05.*

DISCUSSION

We compared the pH, pCO_2, and HCO_3 between ABGA and PVBGA, and SaO_2 with SpO_2 in patients with undifferentiated dyspnea and/or suspected ARF. We also tested a simple method of approximation of arterial pCO_2 and pO_2 from peripheral venous blood. The emphasis was on the general patient population in the ED setting, and not on critically ill patients, who required ABGA and insertion of an arterial line.

Use of PVBGA and oximetry for assessment of patients with dyspnea and suspected ARF has two important advantages over the use of ABGA, as follows: increased patient comfort because arterial radial puncture is not required; and more streamlined and simplified workflow, because all required blood samples could be obtained from a peripheral venous catheter without the need for additional needle puncture.

The correlations between ABGA and PVBGA have been described before; however, these studies were performed in different settings and patient populations. [references?] Thus far, all studies have been observational. Gokel et al. [reference #?] compared the ABGA and PVBGA results in 121 patients with metabolic acidosis (uremia and diabetic ketoacidosis) and 31 healthy controls. Gokel et al. [reference #?] showed a good correlation between arterial and venous pH and HCO_3 in patients with metabolic acidosis and healthy subjects, with a 0.05 unit lower venous pH and 2 mmol/l higher venous HCO_3. This difference remained unchanged in spite of a wide range of pH and HCO_3 concentrations reported [pH, approximately 7.15 in the metabolic acidosis group and 7.39 in healthy subjects; and HCO_3, approximately 10 mmol/l in the metabolic acidosis group and 25 mmol/l in healthy subjects] (8). Similarly, Malatesha et al. (9) showed a good correlation between arterial and peripheral venous pH and HCO_3 with a venous pH decreased difference of 0.02 units and an increased venous HCO_3 of 2 mmol/L in a group of 95 mixed medical patients with metabolic and respiratory disorders. McCanny et al. (10) reported a 0.04 unit lower venous pH and 1.1 kPa higher venous pCO_2 in 94 patients with COPD and respiratory failure. In a meta-analysis by Bingheng et al. (11) in which the ABGA and PVBGA results were compared in patients with acute exacerbation of COPD (AECOPD), good correlations were observed for pCO_2, pH, and HCO_3. Bingheng et al. (11) also proposed an algorithm for evaluating patients with AECOPD based on PVBGA or ABGA (11). A good correlation and similar differences between arterial and peripheral venous pH and HCO_3 (0.03 units and 1 mmol/L, respectively) were also demonstrated in a high altitude setting (12). Zeserson et al. (14) also observed a good correlation between ABGA and PVBGA in a mixed medical population in the emergency department and ICU setting, and between SaO_2 and SpO_2 (14). None of the studies observed a correlation between arterial and venous pO_2 (10-12,14).

The results of our study are in agreement with previously published studies. We observed an approximate 0.04 unit lower pH, an approximate 0.9 kPa higher pCO_2, an approximate 2 mmol/L higher HCO_3 in PVBGA compared to ABGA, and no difference between SaO_2 and SpO_2. Differences between ABGA and PVBGA in pH, pCO_2, and HCO_3 were statistically significant; however, the clinical relevance of these differences was minimal (8-10,12,14), and all relationships between arterial and peripheral venous variables exhibited a strong predictive value, i.e., the trend toward lower or higher values was consistent. In agreement with other studies, we observed a significant difference between pO_2 in ABGA and PVBGA, but when we added 4 kPa there was no longer a difference, allowing for rapid approximation of arterial pO_2 from PVBGA in patients who are not shocked and require a low fraction of inspired oxygen (FiO_2). In accordance with other studies, we have also shown that among patients not in shock with a low FiO_2, SpO_2 served as a good substitute for SaO2; however, great care and caution should be exercised when approximating pCO_2 and pO_2 from PVBGA, and the clinical status of the patient needs to be taken into account to avoid misinterpreting the results.

In two observational studies conducted in a

population of patients (not in shock) in an ICU setting by Middleton et al. [reference #?] and Hassanloei et al., [reference#?] a similar 0.02–0.03 unit decreased venous pH difference was also apparent between ABGA and central venous BGA. Middleton et al. [reference #?] and Hassanloei et al., [reference#?] also observed significant correlations in pH, pCO_2, and HCO3 between ABGA and central venous BGA, implying that among patients in whom delivery and utilization of oxygen in peripheral tissues was not impaired, changes in pH, pCO_2, and HCO_3 could be determined by blood sampling from the venous side of the circulation (15,16).

The veno-arterial difference in pH, pCO_2, and HCO_3 are influenced by local and systemic factors, which need to be taken into account before results are interpreted. First, hypoperfusion due to the use of a tourniquet for peripheral venous catheter insertion can be associated with local ischaemia and changes in metabolism that can affect pH, pCO_2, and HCO_3 levels (17). Second, systemic changes in oxygen metabolism among patients in shock have profound effects on venous pH, pCO_2, and HCO_3, which prevent interpretation with an aim to evaluate ventilation, and enable interpretation of central venous-arterial changes with an aim to assess the adequacy of the circulation, both in patients with septic (18) and cardiogenic shock (19).

A number of studies have shown that SpO_2 in combination with clinical presentation in patients who are not in shock and did not require vasopressors and a high fraction of inspired oxygen was a good parameter of oxygenation (12,14,20-24), and SpO2 was commonly used to screen for hypoxemia (12,20,23-27).

A number of factors can shift the oxygen dissociation curve affecting the relationship between arterial pO_2 and SaO_2, potentially leading to a false-normal SpO_2, such as profound pyrexia, alkalosis, hypercarbia, anemia, dyshemoglobinemia, and carbon monoxide poisoning or methemoglobinaemia, which must be taken into consideration (21).

None of the patients that were included to the current study initially received palliative treatment or were admitted with "do not resuscitate" orders; however, a combination of PVBGA and oximetry could be beneficial for some patients in this group, in whom preservation of the quality of life takes advantage over more invasive procedures (28).

A limitation of our study was that it was a single center observational study. Also, the results of our study should not be generalized to the critically ill population, who often have to wait for admission to an ICU from the emergency department (29-31). However, patients in whom a "noninvasive" approach (PVBGA and oximetry) should not be used can be defined as patients in shock (with elevated lactate levels or require vasopressors) or patients who require a FiO2 > 60% (15,18,26,27). Approximately 5% of patients presenting with dyspnea as the main complaint in the emergency department were admitted to the ICU due to severe ARF or shock, which made the pool of non-critically ill patients that might benefit from a "noninvasive" approach in terms of patient comfort and streamlined workflow considerable (32,33).

CONCLUSION

In our population of patients not in shock who did not require a FiO2>60% and presented with dyspnea and/or suspected ARF, the pH, pCO_2, and HCO3 on PVBGA correlated well with the pH, pCO_2, and HCO_3 on ABGA, with constant differences of 0.04 units, 0.9 kPa, and 2 mmol/L, respectively. The SpO_2 correlated well with SaO_2. Simple subtraction of 1 kPa from peripheral venous pCO_2 and addition of 4 kPa to peripheral venous pO_2 might be used as a "rule of thumb" to approximate the arterial pCO_2 and pO_2. The combination of PVBGA and SpO_2 measured by oximetry could provide sufficient information on which to make clinical decisions regarding ventilation, oxygenation, and acid-base status for patients not in shock and with a low FiO_2. A prospective interventional study is warranted to determine whether some patients with ARF can be treated based on the results of PVBGA and SpO_2.

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