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Can expected pCO_2 be calculated by $pCO_2=HCO_3+15$ formula in central venous blood gas samples?

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Abstract. – OBJECTIVE: In mixed acid-base disorders, it is essential to identify the dominant disorder, either metabolic or respiratory. The calculation of expected partial carbondioxide (pCO_2) value obtained from arterial blood gas sample can give a clue to the physician about the main disorder. There are several formulas to calculate the expected pCO_2 which are not practical to use and require an arterial blood gas sample. The aim of this study is to investigate whether expected pCO_2 could be calculated with a simple formula by adding 15 to the bicarbonate (HCO_3) value obtained from a central venous blood gas sample.

PATIENTS AND METHODS: 50 (42.7%) female and 67 (57.3%) male patients aged 18 years and older, hospitalized in the Intensive Care Unit (ICU) between January 2022 and June 2022, whose arterial and central venous blood gas samples were drawn at the same time, were included in this study. Expected pCO_2 values were calculated with both Winter's ($pCO_2 = 1.5 \times HCO_3 + 8$) and simple ($pCO_2 = HCO_3 + 15$) formulas from the data obtained from arterial and jugular central venous blood gas samples.

RESULTS: A statistically significant strong positive correlation was identified between arterial and venous expected pCO_2 values, which were calculated by using both Winter's and simple formulas [Pearson's correlation coefficient (r) = 1, *p*<0.001].

CONCLUSIONS: In ICU patients, ($pCO_2 = HCO_3 + 15$) formula can be used to calculate expected pCO_2 in central venous blood gas samples to identify the primary disorder as metabolic or respiratory in mixed acid-base disorders.

Key Words:
Bicarbonate, Central venous blood gas, Partial carbondioxide, Winter's formula.

Introduction

Mixed acid-base disorders are often encountered in daily intensive care setting. Predominant disorders, such as metabolic acidosis, metabolic alkalosis, respiratory acidosis and respiratory alkalosis, may mask the less dominant disorder. Therefore, identification of the acid-base disorder is essential to correct the primary disorder. For instance, respiratory compensation mechanisms are activated in order to compensate metabolic acidosis in mixed acidosis. Increased respiratory ventilation helps to decrease pCO_2. Thus, a new pCO_2 value is expected after compensation. This expected pCO_2 value in metabolic acidosis can be calculated either with Winter's formula ($pCO_2 = 1.5 \times HCO_3 + 8$) or a practical formula ($pCO_2 = 1.2 \times HCO_3 + 11.2$)[1-3]. If the expected pCO_2 value is lower than the measured pCO_2 value, a respiratory acidosis is revealed in addition to the metabolic acidosis. On the contrary, if the expected pCO_2 value is higher than the measured pCO_2 value, a respiratory alkalosis is revealed in addition to the metabolic acidosis. However, these formulas are both difficult to remember and time consuming to apply. As an alternative to these formulas, Marano et al[1] claimed that the expected pCO_2 value in arterial blood gas samples of hemodialysis patients with metabolic acidosis could be practically calculated with a simple formula by adding 15 to the bicarbonate value ($pCO_2 = HCO_3 + 15$).

Patients in the ICU often have acid-base disorders. Therefore, patients in the ICU are generally followed-up by routine arterial blood gas analysis. Nevertheless, arterial blood gas analysis requires an arterial catheter, which in return may cause several complications such as arterial spasm, bleeding, hematoma, embolism, reflex sympathetic dystrophy and aneurysm formation[4]. Furthermore, central venous blood gas analysis is a potentially more accessible alternative to arterial blood gas sampling in hemodynamically stable critically ill patients[4]. In addition, several studies[5-8] have addressed that pH, pCO_2, and HCO_3

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Table I. Descriptive statistics on blood gas analysis of critically ill patients (n=117).

Variable	Min	Max	Mean±SD	Median (1st-3rd Quartile)
pH arterial	7.14	7.60	7.418±0.098	7.436 (7.359-7.486)
pCO_2 arterial (mmHg)	18.70	77.90	40.168±11.617	39.1 (33.4-45)
HCO_3 arterial (mmol/L)	13.20	42.50	25.159±6.178	25.4 (20.3-29)
Expected pCO_2 Winter's formula – arterial (mmHg)	27.80	71.75	45.738±9.267	46.1 (38.45-51.5)
Expected pCO_2 Simple formula – arterial (mmHg)	28.20	57.50	40.159±6.178	40.4 (35.3-44)
pH central venous	7.11	7.57	7.382±0.091	7.391 (7.332-7.456)
pCO_2 central venous (mmHg)	22.00	84.50	45.768±11.814	45.2 (39-51.8)
HCO_3 central venous (mmol/L)	13.00	45.40	26.519±6.394	26.8 (21.7-30.1)
Expected pCO_2 Winter's formula – central venous (mmHg)	27.50	76.10	47.778±9.59	48.2 (40.55-53.15)
Expected pCO_2 Simple formula –central venous (mmHg)	28.00	60.40	41.519±6.394	41.8 (36.7-45.1)

values obtained from arterial and central venous blood gas analysis samples showed correlation.

In the light of this information, the aim of this study was to investigate whether "expected ($pCO_2 = HCO_3 + 15$)" calculated from central venous blood gas samples could be used as an alternative to both Winter's and Marano's simple formulas, which were calculated from arterial blood gas samples. In this study, we compared the expected pCO_2 values in arterial and central venous blood gas samples obtained from critically ill patients by applying Winter's and simple formulas.

Patients and Methods

Ethics Committee approval was obtained from Ankara City Hospital prior to this study (number: E2-21-1122, date: 22.12.2021). 50 female (42.7%) and 67 (57.3%) male adult patients (totally 117 patients) aged 18 years and older, who were hospitalized in the adult ICU of Ankara City Hospital between January 2022 and June 2022, and whose blood gas samples were drawn from the radial arterial line and jugular central venous catheter at the same time, were included in this study. Median age of the patients was 65 [interquartile range (IQR): 18]. Patients under the age of 18, pregnant women and patients with incomplete data were excluded. The arterial and central venous blood gas analysis results (pH, HCO_3 and pCO_2) of each patient were noted. Afterwards, expected pCO_2 values were calculated with both Winter's ($pCO_2 = 1.5 \times HCO_3 + 8$) and simple ($pCO_2 = HCO_3 + 15$) formulas for each arterial and central venous blood gas samples. These arterial and central venous expected pCO_2 values were noted for further statistical evaluation to identify if there was any correlation.

Statistical Analysis

Statistical evaluation was performed using SPSS version 23.0 program (IBM Corp., Armonk, NY, USA) and R software (available at: https://www.R-project.org/). Categorical variables were presented as numbers and percentages, while numerical variables were presented as mean±standard deviation. The distributions of the numerical variables were examined with Kolmogorov-Smirnov normality test. Correlations between numerical variables were evaluated with Pearson's correlation coefficient. Scatter plot was obtained by using ggplot2 R package (available at: https://www.R-project.org/). Statistical significance level was accepted as $p<0.05$.

Results

Arterial and venous blood gas samples were analyzed. Arterial pH values were between 7.14 and 7.60 (Mean±SD = 7.418±0.098), pCO_2 values were between 18.70-77.90 (Mean±SD = 40.168±11.617), HCO_3 values were between 13.20-42.50 (Mean±SD = 25.159±6.178) respectively (Table I). Expected pCO_2 values were calculated by using both Winter's and simple formula. Arterial Winter's formula results were between 27.80-71.75 (Mean±SD = 45.738±9.267), whereas simple formula results were between 28.20-57.50 (Mean±SD = 40.159±6.178). Central venous blood gas samples were analyzed. Central venous pH values were between 7.11-7.57

Table II. Correlation between blood gas values and formulas.

Variable	Is there a correlation between?	Pearson's correlation coefficient (r) (*p*-value)
pH	pH arterial *vs.* pH central venous	0.979 ($p<0.001$)
pCO_2 (mmHg)	pCO_2 arterial *vs.* pCO_2 central venous	0.964 ($p<0.001$)
HCO_3 (mmol/L)	HCO_3 arterial *vs.* HCO_3 central venous	0.983 ($p<0.001$)
Expected pCO_2 (mmHg)	Winter's arterial *vs.* Winter's central venous	0.983 ($p<0.001$)
Expected pCO_2 (mmHg)	Simple arterial *vs.* Simple central venous	0.983 ($p<0.001$)
Expected pCO_2 (mmHg)	Winter's arterial *vs.* Simple arterial	1.0 ($p<0.001$)
Expected pCO_2 (mmHg)	Winter's central venous *vs.* Simple central venous	1.0 ($p<0.001$)

(Mean±SD = 7.382±0.091), pCO_2 values were between 22.00-84.50 (Mean±SD = 45.768±11.814), HCO_3 values were between 13-45.40 (Mean±SD = 26.519±6.394), respectively. Central venous Winter's formula results were between 27.50-76.10 (Mean±SD = 47.778±9.59), whereas simple formula results were between 28.00-60.40 (Mean±SD = 41.519±6.394) (Table I).

Arterial and central venous blood gas samples of 117 patients, which were obtained from the same patients at the same time, were analyzed. Minimum (min), maximum (max), mean±standard deviation (SD) and median (1^{st}-3^{rd} quartile) values were noted. Expected pCO_2 values were calculated according to Winter's and simple formula with HCO_3 values obtained from both arterial and central venous blood gas samples. Winter's formula: expected $pCO_2 = 1.5 \times HCO_3 + 8$. Simple formula: expected $pCO_2 = HCO_3 + 15$.

Pearson's correlation coefficient (r) values were calculated to identify if arterial and central venous pH, pCO_2, HCO_3, expected pCO_2 values according to Winter's and simple formula were correlated with each other. Arterial and central venous pH values had r = 0.979, pCO_2 values had r = 0.964, HCO_3 values had r = 0.983, respectively (Table II). Moreover, expected pCO_2 values calculated with Winter's formula from arterial and central venous blood gases exhibited a Pearson's correlation coefficient of 0.983. Expected pCO_2 values calculated with the simple formula from arterial and venous blood gases exhibited a Pearson's correlation coefficient of 0.983. Expected pCO_2 values calculated from arterial blood gas samples with Winter's formula and simple formula had a Pearson's correlation coefficient of 1.0. Expected pCO_2 values calculated from central venous blood gas samples with Winter's formula and simple formula had a Pearson's correlation coefficient of 1.0 [correlation was significant at the 0.01 level (2-tailed)] (Table II). All these findings were plotted on a scatter plot to visualize the correlation between Winter's and simple formulas to predict expected pCO_2 (Figure 1).

Arterial and central venous pH, pCO_2, HCO_3, expected pCO_2 values, according to Winter's and simple formulas, were investigated for any correlation. Pearson's correlation coefficient (r) between 0.90-1.00 indicated that there was a very high relationship between two values. Statistical significance level was accepted as $p<0.05$.

Scatter plot is depicting the distribution of arterial and central venous pCO_2 and HCO_3 values. The expected pCO_2 values according to Winter's formula are represented with a dashed line, whereas the expected pCO_2 values according to the simple formula are represented with a linear line. Expected pCO_2 values determined with Winter's formula ($pCO_2 = 1.5 \times HCO_3 + 8$) and simple formula ($pCO_2 = HCO_3 + 15$) were calculated with data obtained from arterial and central venous blood gas samples, which were highly correlated with each other [Pearson's correlation coefficient (r) = 1].

Discussion

Mixed and metabolic acidosis are commonly encountered in both chronic kidney disease and critically ill patients. In order to compensate HCO_3 reduction and acidosis, hyperventilation occurs to reduce pCO_2[1,9]. If respiratory acidosis occurs, HCO_3 retention is observed. Thus, metabolic and respiratory acidosis can mask each other in mixed acid-base disorders. The prediction of the expected pCO_2 may help the physician to differentiate the main acute disorder from the minor chronic disorder[10]. Taking rapid action against the main acute disorder may help the physician to bring the disequilibrium into a steady state. Unfortunately, there is not a single universally accepted formula available to calculate the expected pCO_2 value.

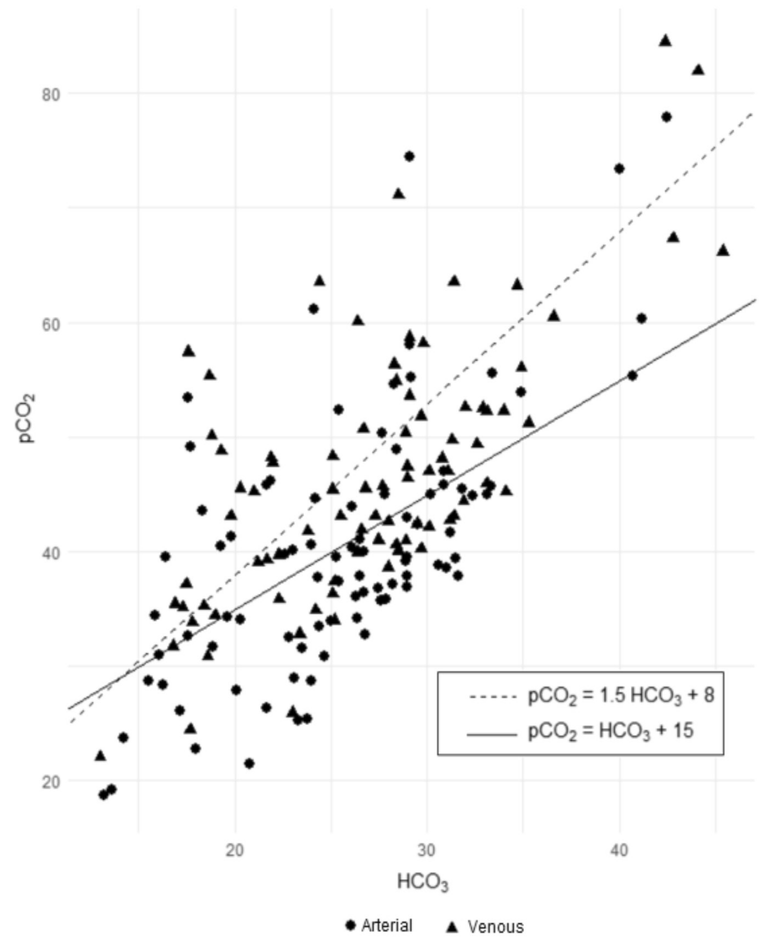

Figure 1. Scatter plot for Winter's and simple formulas for expected pCO_2.

In this study, we evaluated whether expected $pCO_2 = HCO_3 + 15$ formula could be applied to central venous blood gas samples instead of arterial blood gas samples as an alternative to Winter's formula in critically ill patients to predict the expected pCO_2. Our results revealed that central venous blood gas samples could also be used instead of arterial blood gas samples to compute expected pCO_2 with a simple $HCO_3 + 15$ formula. Besides, this simple formula and more time consuming Winter's formula revealed statistically similar results (Pearson's correlation coefficient = 1.0, $p < 0.001$).

However, Winter's ($pCO_2 = 1.5 \times HCO_3 + 8$) and simple ($pCO_2 = HCO_3 + 15$) formulas cannot be used interchangeably in some clinical situations, since the simple formula can only be used when the HCO_3 value is above a certain value. Marano et al[1] reported that Winter's formula was not suitable to be used in hemodialysis patients with mixed-acid base disorders related to a large root mean square error (RMS), whereas ($pCO_2 = HCO_3 + 15$) formula exhibited a smaller RMS error compared to Winter's formula. Moreover, ($pCO_2 = HCO_3 + 15$) formula outshined all the other formulas in simplicity. Nevertheless, Marano et al[2] claimed that bicarbonate value of 12 mmol/L applied with these formulas yielded the same pCO_2 value. Therefore, Marano et al[2] recommended to use the ($pCO_2 = HCO_3 + 15$) formula when the blood gas HCO_3 value was above 12 mmol/L, and to use the Winter's formula when bicarbonate value was lower than 12 mmol/L to cause less error to predict pCO_2.

Limitations

Furthermore, our study had several limitations. Since our ICU was a mixed ICU, blood gas samples were not taken from a homogeneous patient group.

A homogeneous patient group should be reanalyzed by applying different formulas to predict the expected pCO_2. Moreover, a prospective multi-center study with a larger sample size should be performed to provide more information about the applicability of these formulas related to the prediction of expected pCO_2 in different clinical situations.

Conclusions

As a result, the expected pCO_2 can be calculated from central venous blood gas sample by using a simple formula ($pCO_2 = HCO_3 + 15$) when the critically ill patient is hemodynamically stable, and thus the origin of the acid-base disorder can be accurately determined.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

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Informed Consent

Informed consent was obtained from all participants included in the study.

Ethics Approval

This study was approved by the Ethics Committee of Ankara City Hospital (Approval number: E2-21-1122, date: 22.12.2021).

Authors' Contributions

Mehmet Eren Yuksel: Conception/design of the work, acquisition of data, drafting and reviewing the work.
Seval Izdes: Conception/design of the work, acquisition of data, drafting and reviewing the work.
Ilknur Aydar: Conception/design of the work, analysis of data, drafting and reviewing the work.
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