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RESEARCH ARTICLE

Correlation between Arterial and Central Venous Blood Gas Values in Critically Ill Patients

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Abstract

Arterial blood gas (ABG) analysis is a commonly and golden standard performed procedure that is often used to assess the acid-base status along with adequacy of ventilation and oxygenation among predominantly critically/acutely ill patients. Unfortunately, prolonged arterial catheterization or repeated direct blood sampling from the artery is associated with rare, but serious, complications to the patient as well as the health care providers. Patients who require frequent blood gas testing often have indwelling central venous catheters for the administration of intravenous medications or the monitoring of central vascular pressures, allowing for repeated central venous blood gas (VBG) analysis. Venous blood gas analysis requires fewer punctures, is a relatively safer procedure for both the patient and health care provider, and may be alternative to ABG analysis (Walkey et al., 2010), (Lorente et al., 2006), Scheer et al., 2002), (Valentine et al., 2005).This study was aimed to determine the correlation between arterial and central venous blood gas measurements for monitoring of acid-base balance & oxygenation in the critically ill patients. Prospective comparative study of 90 samples from 45 patients with diverse medical& surgical conditions was conducted. Arterial and venous values for pressure of hydrogen (pH), partial pressure of carbon dioxide (PCO2), bicarbonate (HCO3), partial pressure of oxygen (PO2), and oxygen saturation (SO2)were obtained simultaneously from each patient. Identity plot was used to check the perfect agreement between the paired measurements. The strength of the relationship between the arterial and venous gas values was assessed with the Pearson product–moment correlation coefficient test. Arterial pH and venous pH were found to be correlated significantly (Pearson correlation coefficient $r = 0.93$, 95% confidence limits of $r = 0.90$ to 0.96, $P < 0.001$). There was a strong correlation between the arterial and venous PCO2($r = 0.85$, 95% confidence limits of $r = 0.79$ to 0.90, $P < 0.0001$), HCO3 ($r = 0.96$, 95% confidence limits 0.93 to 0.97, $P = 0.0001$). The correlation between the arterial and venous PO2 and SO2 were not statistically significant PO2 levels ($r = - 0.38$, 95% confidence limits of $r = 0.19 - 0.55$, $P>0.05$) &($r = -0.08$, 95% confidence limits of $r = -0.28 - 0.13$, $P >0.05$) respectively. **Conclusion:** there was a perfect correlation between the arterial and central venous measurements of acid – base (pH, PCO2, HCO3-) in the critically ill patients. While, it is difficult to conclude at least a basic agreement between the arterial and central venous measurements of oxygenation (PO2 & SO2).

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Introduction:

Patient safety has been broadly conceptualized as the prevention of unnecessary patient harm or potential harm (Council of the European Union, 2009 & WHO 2010). In relation to this goal of harm prevention, patient safety can be practically defined as the pursuit of the reduction and mitigation of unsafe acts within the healthcare system, as well as the use of best practices shown to lead to optimal patient outcomes. Nurses are the main group of healthcare providers in the intensive care units; they are generally closer to patients than other clinicians and spend the most time in the patient care departments. As they continually oversee, coordinate and provide care, nurses are well positioned to strengthen the safety net for patient care within hazardous ICU environments. The critically ill patients, by their nature, are suffering from many life threatening problems that required continuous monitoring and management (Lankshear et al., 2008), (Frank et al., 2008), (Ramanujam et al., 2008).

A crucial goal of the management of critically ill patient is the maintenance and optimization of cellular (and organ) health. This goal can be accomplished by maintenance of oxygenation, perfusion, fluid, electrolytes, acid base balance and others (Adrogué et al., 1998).Acid base and oxygenation disorders are likewise critical, especially when these derangements develop quickly. In addition, severe abnormalities can be the direct cause of organ dysfunction. Monitoring of acid base and oxygenation is a crucial step in the management of critically ill patients. Arterial blood gas (ABG) is a valuable tool in the assessment of a multitude of illnesses and injuries and it represents the criterion standard for determining a ventilated and nonventilated patient's acid-base status. Critical care nurse caring for critically ill patients should be skillful in the continuous bedside assessment and management and she needs to understand the issues related to the blood gas interpretation and skillfully perform blood gas sampling (Lankshear et al., 2008), (AK A. et al., 2006).

Arterial sampling can be obtained either by direct arterial puncture or by insertion of arterial catheter. Although the arterial blood gas is considered as a standard, it is not without drawbacks including local hematoma, bleeding, infection, aneurysm formation, arterial thrombosis or embolization with subsequent ischemic injury to the digits, needle stick injuries to health care providers, and sometimes even reflex sympathetic dystrophy. In addition, the procedure is technically more demanding and is more painful. Central venous sample is easier to obtain, the procedure being less painful, and there is an advantage of blood being drawn at a time when the patient is getting sampled for other investigations. Furthermore, central venous sampling is a safer procedure than arterial sampling and may reduce complications from prolonged arterial cannulation (Lorente et al., 2006), Scheer et al., 2002), (Pinsky) (2007), (Darren et al., 2005).

Although the venous sample is relatively safer and painless for patient, a question regarding the reliability and accuracy had been raised. Could the venous blood gas (VBG) measurements of pH, PCO2, HCO3-, PO2and SO2obtained from central venous catheter as reliable as the same measurements obtained from the artery for the monitoring of acid – base disorders & oxygenation in critically ill patients, obviating the need for arterial puncture? In order to answer this study was conducted.

Research Design and Patients:

A prospective comparative study design was used to conduct this study. A convenience sample of 45 adult patients presenting to the ICUs of teaching hospital in university of Alexandria, from June to September 2012, were enrolled. Patients were eligible if they were aged between 18 – 80 years old, were hemodyamically stable (systolic blood pressure equal or more than 90mmHg) and did not have severe bleeding.

Method:

This study was conducted over the course of 3 months at the main university hospital. Permission to conduct the research was obtained from the authority figures in the hospital & intensive care units. After having the study explained, a verbal consent was obtained from the patient or the relative. Tool was developed by the researcher and it was examined for its content and face validity by providing it to ten experts in nursing & medical education. A pilot study was conducted on five patients to test the clarity and applicability of the tool. ABG-VBG sample was obtained per patient. Arterial and VBGs were drawn simultaneously for each eligible participant per the order of the ICU physician. Arterial samples (0.5–1 ml) were obtained using heparinized plastic syringe either from radial or femoral arteries either by direct puncture of the artery or from arterial catheters and analyzed via blood gas analyzer. For venous sampling, 5 mL blood was obtained from the central catheters-located in either the distal superior or inferior vena cava and was kept a side. Then 0.1 mL of venous blood was obtained in the heparinized syringe and sent for analysis via blood gas analyzer. Then 5 mL of venous blood was returned back to the patient and the catheter was flushed with normal saline 0.9. Patients were sampled for arterial and venous blood with minimum delay (always 2 min) between the samples. Additional data collected on a standardized data collection form included patients' age, sex, primary diagnosis, intubation status and use of inotropic agents. The results were analyzed and statistical significance was set at $p < 0.05$.

Results:

Results were presented as mean± standard deviation for continuous variables and number (%) for counts. Correlation coefficient and Identity plots were used to ascertain correlation between the arterial and central venous measurement of pH, PCO_2, PO_2, HCO_3^- and SO_2 levels in critically ill patients. It is obtained as a scatter plot of the two measurements along with the line y = x. The strength of the relationship between the arterial and venous gas values was assessed with the Pearson product–moment correlation coefficient test.

Table 1. Patient Demographics and Characteristics

Item	(n=45)	%
Age Group (in years)		
18-28	12	26.7
29-39	8	17.8
40-50	16	35.6
51-80	9	20
Gender		
Male	30	66.7
Female	15	33.3
Diagnosis		
Pulmonary Disorders	16	35.6
Cardiovascular Disorders	8	17.8
Neurological Disorders	9	20
Renal Disorders	8	17.8
Trauma	4	8.9
Mechanically Ventilated		
Yes	33	73.3
No	12	26.7
Treated with Inotropes		
Yes	8	17.8
No	37	82.2
Method of Arterial Sampling		
Aspiration from Arterial Catheter	6	13.3
Aspiration from the artery directly	39	86.7

Table 1 shows distribution of the studied patients by gender, age, intubation status, using of inotropes and methods of arterial sampling. A total of 45 patients who required ABG analysis were enrolled in the current study30 (66.7%) males and 15 (% 33.3) females). Among the studied patients, 12 (26.7%) of them belongs to the age group 18-28, 8 (17.8%) belongs to the age group 29-39, 16 (35.6%) belongs to 40-50 and the remaining 9 (20%) belongs to the age group 51-80. In relation to the diagnosis of the patients, 35.6% of the patients were diagnosed with pulmonary disorders, 17.8% were diagnosed with cardiovascular disorders, 20% were diagnosed with neurological disorders, 17.8% were diagnosed with renal disorders and 8.9% were diagnosed with trauma. Almost 73.3% of patients were ventilated and 26.7% were non-ventilated. Among the 45studied patients8 (17.8%) had used inotropes. Regarding the methods of arterial sampling, the majority of the samples were aspirated through direct puncture of the arteries 39 (86.7%).

Table 2. Mean and Standard Deviation (SD) of the Arterial and Central Venous Blood Gas Values

Parameter	n	ABG	VBG
		Mean ± SD	Mean ± SD
pH	90	7.418 ± 0.090	7.39 ± 0.085
PCO_2(mmHg)	90	29.2 ± 6.72	34.9 ± 7.5
HCO_3(mmHg)	90	19.33 ± 3.45	21.52 ± 3.43
PO_2(mmHg)	90	131 ± 60.56	60.35 ± 21.3
SpO_2(%)	90	97.3 ± 2.47	82.3 ± 13.65

pH= pressure of hydrogen, PCO_2= partial pressure of carbon dioxide, HCO_3= bicarbonate, PO_2= partial pressure of oxygen, SO_2= oxygen saturation.

Table 2 depicts the mean and SD of the values of arterial and venous pH, pCO2, $HCO_{3,}$ $PO_2$and SO_2.

Table3. Correlation between Arterial and Central Venous Blood Gas Values

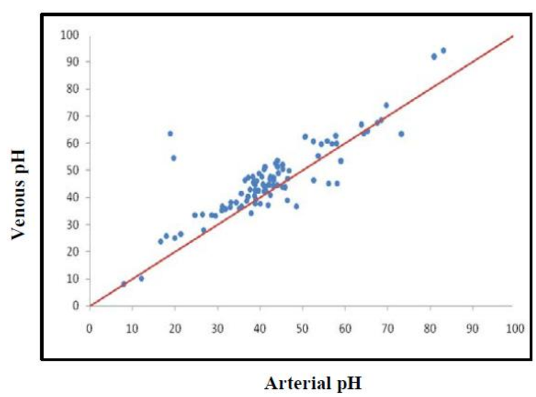
Parameter	**Correlation coefficient**	**95% confidence interval**	**p-Value**
pH	0.93	0.90 , 0.96	<.0001**
PaCO2	0.85	0.79 , 0.90	<.0001**
HCO3	0.96	0.93 , 0.97	<.0001**
PaO2	- 0.09	- 0.19 to 0.55	0.4402
SaO2	-0.08	-0.28 , 0.13	0.4418

**** indicates a significant association (p-value <0.05)**

In table 3, simple linear regression was used to establish the relationship between the arterial values and the central venous values for pH, PCO_2, PO_2, HCO_3, and SO_2. Arterial pH and venous pH were found to be correlated significantly (Pearson correlation coefficient r = 0.93, 95% confidence limits of r = 0.90 to 0.96, P < 0.001). There was a strong correlation between the arterial and venous PCO_2(r = 0.85, 95% confidence limits of r = 0.79 to 0.90, P < 0.0001), HCO3 (r = 0.96, 95% confidence limits 0.93 to 0.97, P = 0.0001). The correlation between the arterial and venous PO_2 and SO_2 were not statistically significant PO_2 levels (r = - 0.38, 95% confidence limits of r = 0.19 - 0.55, P >0.05) & (r = -0.08, 95% confidence limits of r = -0.28 - 0.13, P >0.05) respectively.

Identity Plots for Assessing Perfect Agreement

Figure 1. Identity Plot - Arterial versus Central Venous Measurement of pH



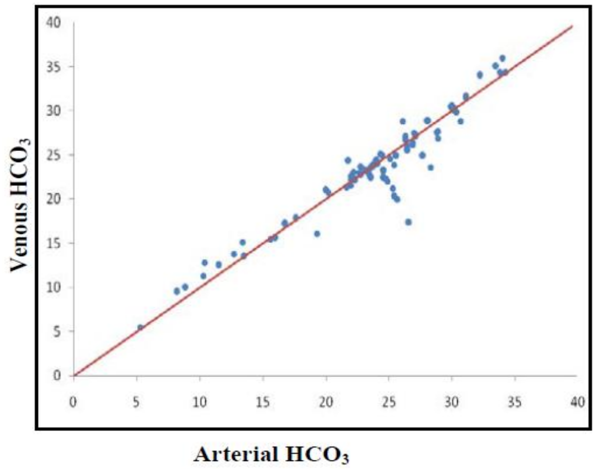


Figure 3. Identity Plot - Arterial versus Central Venous Measurement of HCO_3

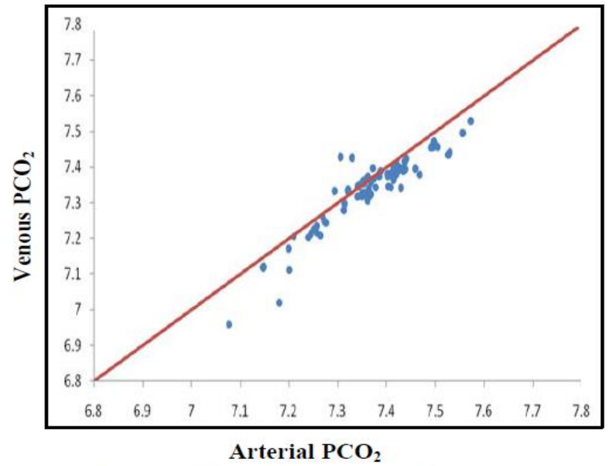


Figure 2. Identity Plot - Arterial versus Central Venous Measurement of pH

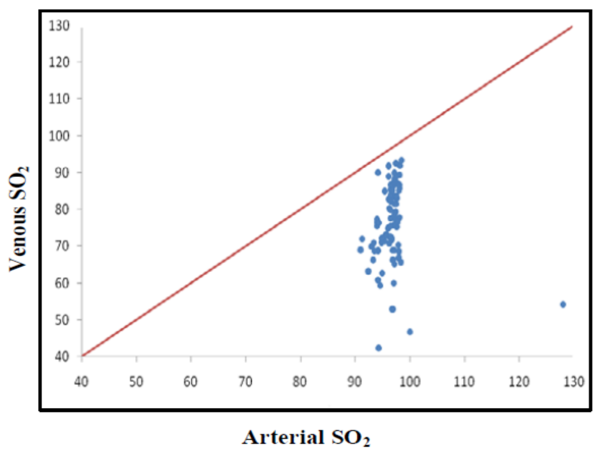


Figure 5. Identity Plot - Arterial versus Central Venous Measurement of SO_2

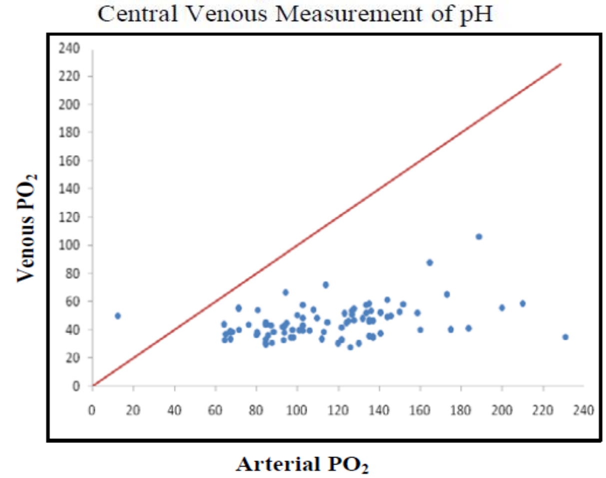


Figure 4. Identity Plot - Arterial versus Central Venous Measurement of PO_2

In relation to the identity plots (figures1-5), they were used to ascertain perfect agreement between the arterial and central venous measurement of pH, PCO_2, HCO_3, PO_2 and, SO_2 levels in ill patients.

Figure 1 shows the identity plot - arterial versus central venous measurement of pH. Most of the paired measurements were close to the line of perfect agreement (indicated by a diagonal red line). Hence it can be concluded a significant agreement between the arterial and central venous measurement of pH.

Figure 2 shows the identity plot - arterial versus central venous measurement of PCO_2. Most of the paired measurements were showed a slight departure from the line of perfect agreement (indicated by a diagonal red line). Hence it can be concluded a moderate to significant agreement between the arterial and central venous measurement of PCO_2.

Figure 3 shows the identity plot - arterial versus central venous measurement of HCO_3**.** Most of the paired measurements were close to the line of perfect agreement (indicated by a diagonal red line). Hence it can be concluded a significant agreement between the arterial and central venous measurement of HCO3.

Figures 4 & 5showthe identity plot - arterial versus central venous measurement of PO_2& SO_2.Most of the paired measurements were showed a marginal departure from the line of perfect agreement (indicated by a diagonal red line) towards lower part of the plot. That is in all cases, the venous PO_2&$SO_2$are lower than arterial PO_2&SO_2. Hence it is difficult to conclude at least a basic agreement between the arterial and central venous measurement of PO_2& SO_2.

Discussion:

Over the years, researchers have searched for alternatives to arterial sampling to reduce the incidence of the procedure's related complications and to maintain the patient safety. This prospective comparative study was conducted to determine the correlation between the VBG & ABG values. Forty five consecutive patients admitted to the intensive care units were recruited in the current study. They consisted of 18 patients (60%) males and 12 patients (40%) females. Among them, 3 (10%) of them belongs to the age group 18-28, 8 (27%) belongs to the age group 29-39, 4 (13%) belongs to 40-50 and the remaining 15 (50%) belongs to the age group 51-80 years. Almost 83% of patients were ventilated and 17% were non-ventilated. Among the 30 subjects under study, 7 (23%) had used inotropes. A simple linear regression was used to establish the relationship between the arterial values and the central venous values for pH, PCO2, PO2, HCO3, and SO2. In Arterial & venous of pH PCO2& HCO3were found to be correlated significantly (p-value <0.05) while arterial and venous PO2& SO2were found to be poorly correlated. This result (poor correlation between PaO2 & SaO2 and PvO2 & SvO2) can be explained by that, physiologically, there is a big difference between normal arterial and venous oxygenation (PaO2: 80 – 100 mmHg while PvO2: 28 – 48 mmHg. SaO2: 95 – 100%. SvO2: 50 – 70%). Moreover, identity plots were used to ascertain perfect agreement between the arterial and central venous measurement of pH, PCO2, HCO3-, and the finding revealed that, perfect agreement between the arterial and central venous measurements of acid – base (pH, PCO2, HCO3-) levels in the critically ill patients. The high correlation between the arterial and venous pH, PCO2 and HCO3, it can be explained by the same physiological theory. This means that, arterial pH: 7.35 – 7.45 while venous pH: 7.32 – 7.42. Arterial PCO2: 35 – 45 mmHg while venous PCO2: 38 – 52 mmHg. Arterial HCO3:22 – 26 mEq/L while venous HCO3: 19 -25 mEq/L. Barthwal (2004).

In addition to the current study, multiple studies have looked to the VBG as a less invasive and reliable alternative method for monitoring of acid – base and oxygenation conditions. Despite demonstrating similar systematic differences between venous and arterial blood, these studies reached disparate conclusions regarding the reliability and accuracy of the VBG. Examples of these studies, the study that was conducted by Walkey and his coworkers, they investigated the reliability of the VBG as a substitute for arterial blood gas (ABG) in multiple care settings and they found a high agreement between normal VBG with a normal ABG and they recommend using of the central VBG as a reliable alternative to ABG (Walkey et al., 2010). On the same vein, Treger at el performed a prospective trial to assess the agreement between arterial and central VBG measurements in a medical ICU. Adult patients who were admitted to the ICU and required both a central venous line and an arterial line were enrolled. When an ABG was performed, a central venous sample was obtained to examine the agreement among the pH, PCO2, and bicarbonate. They concluded that, central venous pH, PCO2, and bicarbonate can replace their arterial equivalents in many clinical contexts encountered in the ICU (Tregeret al., 2010).

Furthermore, Koul and his coworkers studied 100 randomly selected patients, who were adjudged to require ABG analysis by the treating physician. All patients had arterial blood sampled, which was drawn via an arterial puncture into a heparinized syringe. Simultaneously, venous blood was also sampled. Venous and arterial blood samples were taken within 5 min of each other. In addition, the measurement of oxygen saturation (SpO2) was obtained from a finger pulse oximeter. The results of the study have demonstrated a very strong correlation between the arterial and venous measurements of pH, PCO2, and HCO3 level with a high degree of agreement and clinically acceptable difference on Bland Altman difference plotting and but much less for PO2. The researchers concluded that, venous blood gas assessment in conjunction with finger pulse oximetry could obviate the routine use of arterial puncture in patients requiring ABG analysis (Koul PA et al., 2011).

Similarly, in a cross-sectional and analytical study aimed to evaluate the validity of VBG and its clinical agreement with ABG intensive care unit, and to answer how far it can replace the ABG test, Bilan and his coworkers analyzed blood gas of 200 patients in diverse diagnoses. The researcher concluded that, VBG can be used instead of ABG in some diseases such as respiratory distress syndrome, sepsis, renal failure, pneumonia, diabetic ketoacidosis and status epilepticus, but in other diseases such as shock (hypoperfused patients), ABG is preferable and must not be replaced by VBG (Bilanet al.,2008). The same result was reported by Kelly and coworkers. They described the agreement between variables on arterial and venous blood gas analysis (in particular pH, pCO2, bicarbonate and base excess) and they concluded that, for patients who are not in shock, venous pH, bicarbonate and base excess have sufficient agreement to be clinically interchangeable for arterial values. Agreement between arterial and venous pCO2 is too poor and unpredictable to be clinically useful as a one-off test but venous pCO2 might be useful to screen for arterial hypercarbia or to monitor trends in pCO2for selected patients (Kelly et al., 2004).

On the similar vein, Khan and his coworkers studied 100 patients in order to determine a correlation between arterial and venous blood gas values. Patients undergoing lumbar disc surgery. Two blood samples were drawn from each patient 2 hours after induction of anesthesia for ABG and VBG analyses. The result revealed that, there was good correlation between arterial and venous blood samples with regard to pH, PCO2, HCO3-, BE and BB (Khan Z.H. et al., 2010).

Similar result has been reported by Malatesha and her coworker. They aimed to determine the agreement between arterial and venous samples in a pathologically diverse patient population presenting at an emergency department (ED) with a view to obviating the need for arterial blood gas (ABG) analysis in initial ED evaluation. The data were analyzed for agreement between pH, PCO2, PO2 and bicarbonate using the Bland–Altman method. As the results shown, agreement was excellent in pH values (95% limits of agreement 0.13 to 20.1), and acceptably narrow in PCO2 and bicarbonate values and venous PO2 and arterial PO2 did not show good agreement in our study. In conclusion, venous pH, bicarbonate and PCO2 estimation can replace ABGs in initial ED assessment (Malatesha et al., 2007).

In addition, Darren and her coworkers approved the hypothesis that, central venous blood gas (VBG) measurements of pH, PCO2, and base excess can be substituted for the same values obtained from an arterial blood gas (ABG) analysis in mechanically ventilated trauma patients, obviating the need for arterial puncture. They concluded that, Central venous and arterial PCO2, pH, and base excess values correlate well. They mentioned that, although VBGs cannot be substituted for ABGs in mechanically ventilated trauma patients during the initial phases of resuscitation, clinically reliable conclusions could be reached with VBG analysis (Darren et al., 2005).

Although the results of the current study have demonstrated a high degree of support and agreement with the previously mentioned studies, some of the other studies did not support the positive correlation or agreement between arterial and venous PCO2. In a review article that was done by Anne Marie in order to describe the agreement between variables on arterial and venous blood gas analysis (in particular pH, PCO2, bicarbonate and base excess) and answer the question: can venous blood gas analysis replace arterial in emergency medical care. She searched the papers published from 1966 to January 2010 for studies comparing arterial and venous blood gas values for any of pH, PCO2, bicarbonate base excess and PO2 in adult patients with any condition in an emergency department setting. The results of these revised articles were claimed that; for patients who are not in shock, venous pH, bicarbonate and base excess have sufficient agreement to be clinically interchangeable for arterial values. Agreement between arterial and venous PCO2 is too poor and unpredictable to be clinically useful as a one-off test but venous PCO2 might be useful to screen for arterial hypercarbia or to monitor trends in PCO2 for selected patients. (Marie et al., 2010).

Poor correlation between arterial and venous PCO2 was also claimed by Parvizi. His study aimed to determine whether venous blood gas values can replace arterial gas values during cardiac surgery. He investigated the correlation of pH, Po2, Base Excess and HCO3 in arterial and venous blood gases. A prospective study was performed on 150 patients undergoing cardiac surgery. Their searcher measured of the arterial and venous blood gases perioperative phase of cardiac surgery. There were considerable correlations between pH and HCO3 but not in PCO2, and PO2. The researcher did not recommend venous blood gas for determining PO2, PCO2 (Parvizi et al., 2008).

Limitations of the study:

The study was covered a relatively large, pathological diversity of diagnoses; practically its results could not be generalized to every disease category because of the inappropriate distribution of studied patients and their small number in each disease group.

Conclusions:

There is a perfect correlation between the arterial and central venous measurements of acid – base (pH, PCO2, HCO3-) levels in the critically ill patients. While, it is difficult to conclude at least a basic agreement between the arterial and central venous measurement of oxygenation (PO2 & SO2).

Recommendations:

Because of central venous blood gas measurements of acid – base balance (pH, PCO2, HCO3-) have been representing a perfect agreement with the same measurements obtained from arterial blood gas, the researcher recommended the following:

VBG with pulse oximetry can be used to monitor and frequently check the acid –base status and oxygenation values in the critically ill – hemodyamically stable patients.

Although VBG can accurately replace the ABG, obviate the need for continues arterial sampling and reduce the risk of arterial puncture and arterial cannulation complications, all the patients were normotensive with adequate perfusion, so the researcher recommend to repeat the same study on hemodyamically – unstable patients such as patients in shock.

Although central venous and arterial PCO2, pH, and bicarbonate (but not for PO2and SaO2) values correlate well, VBG can be used for continuous assessment but initial adjustment and resuscitation of patients needed for MV, it is preferable to depend on the result of ABG.

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