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Application value of monitoring of percutaneous partial pressure of carbon dioxide/oxygen for patients in ICU after general anesthesia

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For patients in ICU under mechanical ventilation, monitoring of percutaneous partial pressure of CO_2 and O_2 after general anesthesia is crucial as excessive or insufficient ventilation may prove to be fatal. However, the correlation between percutaneous monitoring and arterial blood gas analysis still remains unclear. Here, we studied the application value of monitoring of $PtcCO_2/PtcO_2$ for patients in ICU after general anesthesia for better management of patients in ICU on ventilation. A total of 195 eligible patients were selected. After transfer, when $PtcCO_2$ and $PtcO_2$ were stable (10-15 min), they were recorded as transfer-in values. Partial pressure of carbon dioxide ($PaCO_2$), partial pressure of oxygen (PaO_2), lactate, $PtcO_2$ and $PtcCO_2$ were recorded. Vital signs and hemodynamics data were also recorded. There were significant positive correlations between $PtcCO_2$ and $PtcO_2$ ($r = 0.876$), and between $PtcO_2$ and $PaCO_2$ ($r = 0.817$) ($P < 0.01$). PaO_2 was higher than $PtcO_2$ ($P < 0.01$). There were significant positive correlations between $PtcCO_2/PtcO_2$ and $PaCO_2/PaO_2$ at different time points (T0: upon transfer-in; T1: before extubation; T2: upon transfer-out, $P < 0.01$). At different oxygen inhalation concentrations (21, 40 and 50%), $PtcCO_2$ and $PtcO_2$ were all well linearly correlated. The overall $PtcO_2/PaO_2$ was (0.75±0.12). When FIO_2 values were 21, 40 and 50%, $PtcO_2/PaO_2$ values were similar ($P > 0.05$). $PtcCO_2$ and $PtcO_2$ or $PtcO_2$ and $PaCO_2$ are significantly positively correlated, without significant differences between different time periods or oxygen concentrations. $PtcCO_2$ and $PtcO_2$ can predict the changes of $PtcO_2$ and $PaCO_2$, which is of great significance to the early observation of oxygenation changes, adjustment of ventilator parameters and improvement of prognosis. $PtcCO_2/PaO_2$ values are similar at different oxygen concentrations, as an eligible index for the postoperative evaluation of tissue perfusion status and hemodynamic level.

Keywords: Blood gas analysis, Ventilation

Mechanical ventilation is a common treatment for critical patients. However, excessive or insufficient ventilation during mechanical ventilation may have serious clinical consequences. Therefore, it should be routinely avoided for ICU patients, especially for those after surgery[1]. Dynamic monitoring of the changes in partial oxygen pressure (PaO_2), partial carbon dioxide pressure ($PaCO_2$) and lactate (Lac) level of patients is crucial for understanding the lung gas exchange and acid-base status of the whole body and tissues, adjusting the ventilator parameters in time and improving the prognosis. At present, monitoring of $PaCO_2$ through intermittent arterial blood gas analysis has become a routine examination in ICU[2]. However, for critical patients, frequent arterial blood sampling not only increases their pain, but also contributes to the loss of blood volume. Besides, $PaCO_2$ can also be evaluated by measuring percutaneous partial pressure of carbon dioxide ($PtcCO_2$) and end-expiratory partial pressure of carbon dioxide[3].

Percutaneous blood gas monitoring is a potentially non-invasive and continuous method for detecting $PaCO_2$ and PaO_2[4]. It was first performed in a neonatal care unit in the 1970s to reduce the frequency of arterial blood sampling[5]. Several studies have confirmed the high consistency and correlation between percutaneous blood gas monitoring and arterial blood gas detection in different populations[6], including general wards, sleep centers, respiratory care units using non-invasive ventilation, ICUs and operating rooms. $PtcCO_2$ has considerable clinical value as a monitoring index of tissue perfusion status and oxygenation level for general anesthesia[7]. Therefore, continuous monitoring of $PtcCO_2$ and $PtcO_2$ can reflect the immediate changes of $PaCO_2$

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and PaO_2 in patients. $PtcCO_2$ could be employed to monitor the early changes of $PaCO_2$, and arterial blood $PaCO_2$ changed evidently when $PtcCO_2$ increased by 5.0 mmHg[8].

Here, we monitored $PtcCO_2$ and $PtcO_2$ of patients transferred to ICU of our hospital after general anesthesia to understand the correlation between percutaneous monitoring and arterial blood gas analysis, and confirm whether such transcutaneous blood gas monitoring correctly reflects the changes of arterial blood gas, and provide guidance for early detection of disease progression for timely adjustment of ventilator parameters and improvement of prognosis.

Materials and Methods

Baseline clinical data

A total of 195 patients who were transferred to ICU of our hospital after general anesthesia from January 2016 to December 2019 were selected, including 105 males and 90 females aged from 28 to 89 years old with an average of (65.27 ± 5.18). Exclusion criteria: (i) Pregnant women or cases who were aged <18 years old; (ii) with contraindications for percutaneous partial oxygen pressure monitoring: skin ulceration or severe edema and/or subcutaneous tissue in the interior chest wall; and (iii) patients with severe preoperative lung diseases. This study has been approved by the ethics committee of our hospital, and written informed consents have been obtained from all patients. After patients were transferred to ICU, continuous percutaneous blood gas monitoring ($PtcCO_2$ and $PtcO_2$) was performed on the basis of routine monitoring of blood pressure (BP) and heart rate (HR).

Data collection

After patients were transferred into ICU, a percutaneous blood gas monitoring electrode was placed immediately. When $PtcCO_2$ and $PtcO_2$ were stable (10-15 min), they were recorded as the transfer-in values. Meanwhile, blood gas analysis was carried out, and $PaCO_2$, PaO_2, Lac, $PtcO_2$ and $PtcCO_2$ were recorded. The vital signs and hemodynamics data were also recorded.

Monitoring of $PtcCO_2$ and $PtcO_2$

TCM4 transdermal monitor (Radiometer, Denmark) was used. In strict accordance with the operating specifications, the front chest skin was selected as the monitoring site after calibration with standard gas. After the skin was disinfected with ethanol, a fixed ring was placed, and a sensor was installed. $PtcCO_2$ and $PtcO_2$ were measured at the thin part of the anterior chest skin. The electrode temperature was 44°C, and the electrode was replaced after being utilized continuously for 4 h to prevent skin burn.

Statistical analysis

All data were statistically analyzed by SPSS19.0 software and expressed as mean ± standard deviation. The relationship between $PtcCO_2$ and $PtcO_2$ oraCO_2 and PaO_2 was subjected to the paired t test. Intergroup comparisons were conducted with one-way analysis of variance, and correlations between related indices were subjected to Pearson's analysis. $P<0.05$ was considered statistically significant.

Results

Baseline clinical data

Among the 195 patients, there were 105 males and 90 females, aged 28-89 years old, with a mean of (65.27 ± 5.18) years old. The demographic data and vital signs are shown in Table 1.

Transcutaneous $PtcCO_2/PtcO_2$ and arterial $PaCO_2/PaO_2$ results

There was a significant positive correlation between $PtcCO_2$ and $PaCO_2$ (r=0.876, P <0.01), and a significant positive correlation between PaO_2 and $PtcO_2$ (r=0.817, P <0.01). Moreover, PaO_2 was higher than $PtcO_2$ [(148.89 ± 43.28) mmHg *vs.* (94.87 ± 14.28) mmHg (P <0.01)] (Tables 2 and 3).

Correlations between $PtcCO_2/PtcO_2$ and $PaCO_2/PaO_2$ at different time points after operation

There were significant positive correlations between $PtcCO_2/PtcO_2$ and $PaCO_2/PaO_2$ at different time points after operation (P <0.01) (Table 4).

Table 1 — Demographic data and basic vital signs of patients

		Range
Male	105	
Female	90	
Age	65.27±5.18	28-89
T (°C)	36.96±0.62	35.4-39.1
HR (beat/min)	79.91±5.68	54-112
MAP (mmHg)	84.29±7.28	66-116

Table 2 — Transcutaneous and arterial blood gas monitoring results

		Range
PaO_2 (mmHg)	148.89±43.28	69-568
$PaCO_2$ (mmHg)	38.29±5.34	26-67
$PtcO_2$ (mmHg)	94.87±14.28	45-166
$PtcCO_2$ (mmHg)	38.28±4.39	29-71

Table 3 — Transcutaneous and arterial blood gas monitoring results at different time points after operation

		Range
PaO_2 (mmHg)		
T0	212.43±45.37	126-569
T1	147.28±18.27	106-196
T2	82.39±8.26	69-112
$PaCO_2$ (mmHg)		
T0	35.87±4.59	28-54
T1	38.11±4.12	31-53
T2	38.79±5.98	29-67
$PtcO_2$ (mmHg)		
T0	150.28±45.17	66-362
T1	109.28±23.29	59-166
T2	64.29±12.28	42-93
$PtcCO_2$ (mmHg)		
T0	36.87±4.38	29-54
T1	41.28±4.37	34-58
T2	41.29±5.49	32-71

Table 4 — Correlations between $PtcO_2/PtcCO_2$ and PaO_2 at different time points after operation

		PaO_2 (mmHg)	
		r	P
T0	$PtcO_2$ (mmHg)	0.765	<0.01
T1	$PtcO_2$ (mmHg)	0.776	<0.01
T2	$PtcO_2$ (mmHg)	0.718	<0.01
T0	$PtcCO_2$ (mmHg)	0.798	<0.01
T1	$PtcCO_2$ (mmHg)	0.756	<0.01
T2	$PtcCO_2$ (mmHg)	0.726	<0.01

Table 5 — Transcutaneous and arterial blood gas monitoring results at different oxygen concentrations

		Range
FiO_2 21%		
PaO_2 (mmHg)	84.38±8.28	69-109
$PtcO_2$ (mmHg)	63.29±10.29	42-92
FiO_2 40%		
PaO_2 (mmHg)	148.28±22.28	104-193
$PtcO_2$ (mmHg)	107.28±21.32	59-166
FiO_2 50%		
PaO_2 (mmHg)	183.28±41.24	126-474
$PtcO_2$ (mmHg)	137.26±40.89	69-355

Correlations between $PtcCO_2$ and $PtcO_2$ at different oxygen concentrations

Among all the statistical results, the data with inspired oxygen concentration of 21, 40 and 50% were selected and divided into three groups. It was found through bivariate correlation analysis and linear regression analysis that both of them had a good linear correlation under different inspired oxygen concentrations (Tables 5 and 6).

Overall $PtcO_2/PaO_2$ and values at different oxygen concentrations

The overall $PtcO_2/PaO_2$ was (0.75 ± 0.12). When FiO_2 were 21, 40 and 50%, the $PtcO_2/PaO_2$ values were (0.77 ± 0.10), (0.74 ± 0.11) and (0.71 ± 0.12), respectively, without significant differences (P >0.05) (Table 7).

Table 6 — Correlations between $PtcCO_2$ and $PtcO_2$ at different oxygen concentrations

		PaO_2 (mmHg)	
		r	P
FiO_2 21%	$PtcO_2$ (mmHg)	0.726	<0.01
FiO_2 40%	$PtcO_2$ (mmHg)	0.695	<0.01
FiO_2 50%	$PtcO_2$ (mmHg)	0.674	<0.01

Table 7 — Overall $PtcO_2/PaO_2$ and values at different oxygen concentrations

		Range
Overall	0.75±0.12	0.46-0.94
FiO_2 21%	0.77±0.10	0.46-0.93
FiO_2 40%	0.74±0.11	0.51-0.94
FiO_2 50%	0.71±0.12	0.51-0.94

Discussion

Although mechanical ventilation has shown its powerful therapeutic effect in clinical practice, it will also lead to some negative effects. The aggravation of cell and/or tissue ischemia in hypocapnia is mainly caused by increased cell oxygen demand and/or decreased cell oxygen supply, which affects blood pressure and nervous system function, and can also lead to hypoxemia-induced arrhythmia. Besides, severe hyperventilation can also contribute to respiratory alkalosis. Additionally, hypocapnia is also related to cerebral palsy and periventricular leukomalacia in premature infants[9], and long-term hypocapnia may be associated with hearing loss in premature and full-term infants[10]. Hyperventilation and its subsequent hypocapnia have an association with the severity of lung injury, and are one of the risk factors affecting bronchopulmonary development[11]. Hence, for ICU patients, including those receiving mechanical ventilation after general anesthesia, the ventilation status should be continuously monitored and ventilator parameters should be adjusted at any time to prevent the occurrence of hypoventilation and hyperventilation.

Arterial carbonic acid level is usually determined by arterial blood gas analysis. However, arterial puncture is an invasive and painful process, which may be performed on the same patient for multiple times (e.g. during oxygen therapy or non-invasive ventilation for COPD patients). In addition, although arterial blood gas analysis is necessary, the information obtained is limited. For example, daytime arterial blood gas analysis is a poor predictor for nocturnal hypopnea. Arterial blood gas sampling during sleep can detect nocturnal hypoventilation, but it does not reflect the relationships with sleep stage,

location or mask leakage[12]. Although nocturnal pulse oxygen saturation monitoring is simple, effective and easy to operate, it may underestimate nocturnal hypoventilation and fail to distinguish hypoxemia caused by hypoventilation or other reasons. Hence, the non-invasive alternatives of $PaCO_2$ will be favorably accepted. Currently, several alternative methods have been applied in clinic, including venous blood gas analysis, $PETCO_2$ and transcutaneous blood gas monitoring. $PtcO_2$ monitoring allows non-invasive and continuous measurement of $PaCO_2$. Currently, it has been confirmed in a number of studies that $PtcCO_2$ detection has high accuracy, especially in newborns and infants, where its accuracy in reflecting $PaCO_2$ is higher than that in older people. Moreover, the accuracy of $PtcCO_2$ prediction also depends on the value of $PaCO_2$. When the value of $PaCO_2$ is over 40 mmHg, the difference will be greater[13]. Patients with increased CO_2 level are those with respiratory diseases and need clinical intervention. Although its accuracy has always been controversial, $PtcCO_2$ has been increasingly adopted in clinical practice. Moreover, it has a good consistency with $PaCO_2$ in elderly people and patients with acute dyspnea, amyotrophic lateral sclerosis, and severe obesity, as well as in cardiopulmonary exercise test. On the contrary, $PtcCO_2$ has been designed in few studies in emergency room, during surgery and in ICU. In this prospective study, the predictive value of $PtcCO_2$ for $PaCO_2$ and PaO_2, respectively, at different time points and different oxygen concentrations after operation were compared in patients transferred to ICU after general anesthesia. The results showed that there was a significant positive correlation between $PtcCO_2$ and $PtcO_2$ (r=0.876, P <0.01) and between $PtcO_2$ and $PaCO_2$ (r=0.817, P <0.0l). Besides, PaO_2 was higher than $PtcO_2$ [(148.89±43.28) mmHg *vs.* (94.87±14.28) mmHg, (P <0.01)], probably because the diffusion ability of oxygen is weaker than CO_2, and the skin tissue consumes oxygen.

In this study, the data were also divided into three groups according to different oxygen concentrations detected. It was found that $PtcO_2$ and PaO_2 were well correlated at different oxygen concentrations [(FiO_2=50%, r=0.86, P <0.01), (FiO_2=40%, r=0.63, P <0.01) and (FiO_2=20%, r=0.67, P <0.01)]. When the oxygen concentration was changed, there was no significant difference in the accuracy of $PtcO_2$ in predicting PaO_2, suggesting that transcutaneous monitoring can be used to evaluate the oxygenation status of patients under different oxygen concentrations.

After general anesthesia operation, the systemic or local effective circulating blood volume in the patient is reduced due to various factors, which leads to cell hypoxia, causing metabolic function disorder and cell function damage. Moreover, hypoperfusion in peripheral tissues easily leads to postoperative circulatory disorder (PCD), thus causing dysfunction of one or multiple organs, and resulting in corresponding pathophysiological changes and clinical manifestations. Hypoperfusion caused by PCD can also develop into multiple organ dysfunction syndrome or multiple organ failure. The major causes of PCD included postoperative infection or poisoning, severe hypovolemia, postoperative cardiac insufficiency, allergic factors and neurogenic factors. Therefore, in clinical practice, attention should be paid to the postoperative test indexes of patients, the possibility of potential PCD should be detected as early as possible, and symptomatic treatment should be conducted timely, so as to improve the prognosis of patients. Currently, the typically used routine monitoring methods include monitoring patient's consciousness, colour and temperature of limbs, pulse rate and blood pressure. The special monitoring methods involve monitoring cardiac output (CO) and cardiac index (CI), blood gas analysis, central venous pressure (CVP), pulmonary capillary wedge pressure (PCWP) and gastric intramucosal pH (pHi), and arterial blood lactic acid determination.

Transcutaneous index ($PtcO_2/PaO_2$) can be used to judge the severity of shock in patients with circulatory disorders. Studies have demonstrated that $PtcO_2/PaO_2$ can eliminate the influences of arterial blood gas and oxygen concentration, and has more clinical significance than $PtcO_2$ alone. When the circulation is unstable, the change in $PtcO_2/PaO_2$ can reflect the severity of shock. $PtcO_2/PaO_2$ >0.7 can be taken as an indicator of sufficient tissue perfusion. $PtcO_2/PaO_2$ =0.3-0.7 suggests that the hemodynamic indexes should be further evaluated in the patient and oxygen challenge test (OCT) should be performed. $PtcO_2/PaO_2$ <0.3 suggests that the patient is in severe shock, so OCT should be conducted, and indexes of cardiac function should be further evaluated. 10-min OCT (the growth of $PtcO_2$ at 10 min under oxygen concentration or pure oxygen) can be used to judge the prognosis and resuscitation effect of shock patients and guide the next step of treatment. Studies have revealed that: (i) 10-min OCT >66 mmHg indicates good resuscitation effect and prognosis and (ii) 10-min OCT <66 mmHg suggests that the patient's condition is severe and the

prognosis is poor. If SpO_2 >90% and $PaoO_2$ >60 mmHg, a circulatory problem is considered, so the indexes such as blood pressure, CI and blood volume can be further evaluated, and resuscitation measures can be taken. 1 h later, 10-min OCT is tested again to evaluate whether the patient's condition is improved from severe to mild. (iii) 10-min OCT <21 mmHg manifests that the patient's condition is critical and the mortality rate is high, hence it is strongly recommended to evaluate the related indexes such as cardiac function and blood volume, conduct PICCO catheterization and echocardiography, and implement resuscitation measures at the same time. 1 h later, 10-min OCT is tested again to evaluate whether the patient's condition is improved from severe to mild. There was a certain correlation between $PtcO_2/PaO_2$ and CO[14]. When there was no shock, $PtcO_2/PaO_2$ was (0.79±0.12). When CI was 1.5-2.2, $PtcO_2/PaO_2$ was (0.48±0.12). When CI was <1.5, $PtcO_2/PaO_2$ was (0.12±0.12). The overall $PtcO_2/PaO_2$ was (0.75±0.12). When FiO_2 was 21, 40 and 50%, the $PtcO_2/PaO_2$ was (0.77±0.10), (0.74±0.11) and (0.71±0.12), respectively, showing no statistically significant difference among groups (P >0.05). These suggested that the hemodynamics was stable and the tissue perfusion was good after operation.

Conclusion

Transcutaneous blood gas monitoring, a non-invasive technique for continuous monitoring of PCO_2 and PO_2 *in vivo*, has been increasingly adopted in clinical practice. It was originally designed for use in neonatal and pediatric wards to reduce the number of arterial punctures. In recent years, with the deepening of research, transcutaneous blood gas monitoring and arterial blood gas analysis have exhibited good consistency among different clinical groups, including patients in neonatal ICU, general adult wards, sleep centers, respiratory care units with non-invasive ventilation, ICU and operating room, as well as in evaluation of shock patients. Therefore, continuous monitoring of $PtcO_2$ and $PtcCO_2$ levels by transcutaneous blood gas meter can reflect the immediate changes of PaO_2 and $PaCO_2$ in patients, which provides necessary clinical parameters for early detection of changes in patients' condition and timely treatment, thus having an extensive application prospect in ICU patients.

Conflict of interest

Authors declare no competing interests.

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