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End-tidal CO_2 Should not be a Parameter for Ventilatory Adjustment during Low Cardiac Output States Like Off-pump Coronary Artery Bypass Grafting

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Abstract

Background: Capnography is widely used as a non-invasive monitoring technique for intra-operative and postoperative mechanically ventilated patients.

Aim: To study whether the $EtCO_2$ values should be used to adjust mechanical ventilation during low cardiac output states such as off pump cardiac bypass surgery (OPCABG).

Setting and design: Prospective study in 50 patients undergoing OPCABG.

Material and Methods: The values of cardiac index (CI), $EtCO_2$, $PaCO_2$ and $P(a\text{-}Et)CO_2$ gradient were compared at two time points during OPCABG: immediately before skin incision and during grafting of obtuse marginal artery, as usually OM grafting is considered to be associated with low cardiac output.

Statistics: Data was analysed using student's t-test.

Results: There was a significant decrease in the value of CI from point A to point B (2.33 vs. 1.75 L/min/m^2, $p<0.001$), significant decrease in $EtCO_2$ from 25.28 to 21.88mmHg ($p<0.001$) and statistically significant increase in $P(a\text{-}Et)CO_2$ gradient 4.39 at point A to 9.18 mmHg at point B ($p<0.003$).

Conclusion: The decrease in $EtCO_2$ had a positive correlation with the decrease in cardiac index. So during the low flow periods as found in OPCABG, $EtCO_2$ cannot reliably estimate the adequacy of ventilation.

Keywords: End-tidal CO_2; Capnography; $PaCO_2$; Off-pump coronary artery bypass grafting; Mechanical ventilation

Introduction

Capnography is routinely used in monitoring of intra-operative and postoperative mechanically ventilated patients [1]. It is a non-invasive technique used for continuous measurement of exhaled carbon dioxide (CO_2) throughout the respiratory cycle, commonly referred to as end-tidal CO_2 ($PEtCO_2$ or $EtCO_2$) [2]. $EtCO_2$ is a measure of alveolar partial pressure of CO_2 ($PACO_2$), which in turn is a measure of arterial CO_2 ($PaCO_2$). It is commonly used to assess the correct placement of endotracheal tube, to monitor the integrity of mechanical ventilation equipment, weaning from mechanical ventilation and monitoring quality of resuscitation [2-4]. $PEtCO_2$ is governed by metabolism, ventilation and circulation [2,5]. When the first two factors are controlled, $PEtCO_2$ reflects the pulmonary blood flow and therefore cardiac output (CO) [3]. Attempts have been made to use $PEtCO_2$ measurement as an alternative to thermo-dilution technique for determining CO in various cardiac surgical settings [3,6,7]. The normal gradient between $PaCO_2$ and $EtCO_2$ [$P(a\text{-}Et)CO_2$] is approximately 4-5 mmHg which represents the normal dead space ventilation [2]. But as $PEtCO_2$ is governed by pulmonary blood flow, it may not be true in conditions with acutely low CO [1,8]. In these situations, there is an increase ventilation-perfusion ratio (V/Q), which decreases $PEtCO_2$ and increases $P(a\text{-}Et)CO_2$ [1]. Applying this principal in clinical scenario means that the ventilatory settings should not be adjusted taking into account the low values of $EtCO_2$ in different low output states.

Off-pump coronary artery bypass grafting (OPCABG) is a complex procedure with abrupt hemodynamic alterations and periods of low CO as a result of surgical manipulations, unprotected myocardial ischemia and use of stabilisers on the beating heart [9,10]. We wanted to study the changes in $EtCO_2$ values during the cardiac output period in OPCABG and whether the $EtCO_2$ can be relied upon as a marker of adequacy of ventilation during such low cardiac output states. For this, we assessed and compared the values of cardiac index (CI), $EtCO_2$, $PaCO_2$ and P(a-Et)CO_2 gradient immediately before skin incision and during grafting of obtuse marginal artery (OM), as OM grafting is usually associated with a period of low CO [9].

Material and Methods

The study was approved by the hospital ethics committee. 50 patients planned for OPCABG with OM grafting were enrolled in the study. Written informed consent was taken from all patients preoperatively. On arrival in the operating room, monitoring was done in the form of continuous ECG with 5-electrodes and pulse oximetry. Under local anaesthetic infiltration, a 16-G cannula was inserted in antecubital vein and right radial artery was cannulated with 20-G cannula that was connected to a pressure transducer for arterial blood pressure (ABP) monitoring. After preoxygenation, general anaesthesia was induced with midazolam (0.03-0.05 mg/kg BW), fentanyl (3-5 mcg/kg BW) and propofol (1.5-2 mg/kg BW). Endotracheal intubation was facilitated with rocuronium (0.6 mg/kg BW) and mechanical ventilation was initiated after confirming the ET placement using 5-point auscultation and $EtCO_2$ using side-stream capnography. All the patients were ventilated with a tidal volume of 6 mL/kg and a respiratory rate of 15/minute. After induction of anaesthesia, 7.5 Fr thermodilution pulmonary artery catheter (PAC) was inserted into right internal jugular vein. Other intra-operative monitoring included nasopharyngeal temperature and urine output. Anaesthesia was maintained with isoflurane in air-oxygen mixture, fentanyl and rocuronium. Normothermia was maintained using warm intravenous fluids and circulating warm water mattress under the patients. Medtronic octopus stabiliser was used for positioning of heart during beating heart surgery.

For study purpose, CI, $EtCO_2$, $PaCO_2$ and P(a-Et)CO_2 values were recorded at two time points: immediately before skin incision (A) and during OM grafting (B). CI was calculated using thermodilution method by PAC (10 mL of saline at room temperature, at end expiration in triplicate). $EtCO_2$ value was directly recorded from the side-stream capnograph monitor. Arterial blood gas sample from radial artery was withdrawn for estimation of $PaCO_2$ values. During OM grafting, these parameters were recorded after arteriotomy and placement of shunt. P(a-Et)CO_2 gradient was calculated as difference between $PaCO_2$ and $EtCO_2$.

Statistical analysis

The collected data is expressed as mean ± standard deviation. All data was analysed using SPSS 17.0 software. Student's t-test was applied for statistical analysis. A p-value of <0.05 was considered significant.

Results

Out of the 50 study patients, there were 40 males and 10 females. Mean age of the study patients was 63.54 ± 9.27 years. Mean left ventricular ejection fraction was 47.76 ± 9.67%. The average grafting time of OM artery was 10.72 ± 1.88 mins. The demographic profile of the patients is shown in Table 1.

Table 2 shows the mean values of the parameters studied at two time points and their statistical relationship. There was a significant decrease in the value of CI from point A to point B (2.33 vs. 1.75 L/min/m^2, $p<0.001$). A significant decrease was also found in the values of $EtCO_2$ from 25.28 to 21.88 mmHg at both these time points ($p<0.001$). $PaCO_2$ values increased significantly from 29.68 to 31.06 mmHg ($p<0.003$). A statistically significant difference was also noted in P(a-Et)CO_2 gradient. The gradient changed from 4.39 at point A to 9.18 at point B, showing an increase of more than 100% ($p<0.000$). Thus as the CI decreased from point A to point B, there was a significant reciprocal increase in P(a-Et)CO_2 gradient.

	Mean ± S.D
Age (yr)	63.54 ± 9.27
Weight (Kg)	69.14 ± 9.51
Height (cm)	168.16 ± 7.31
BSA (m^2)	1.79 ± 0.14
LVEF (%)	47.76 ± 9.67
OM Graft Time (min)	10.72 ± 1.88
Sex Ratio (M:F)	40:10

Table 1: Demographic profile. BSA: Body Surface Area; LVEF: Left Ventricular Ejection Fraction.

	A	B	p - value
CI (L/min/m^2)	2.33 ± 0.54	1.75 ± 0.43	0.000
$EtCO_2$ (mmHg)	25.28 ± 2.57	21.88 ± 3.00	0.000
$PaCO_2$ (mmHg)	29.68 ± 2.92	31.06 ± 3.96	0.003
P(a-Et)CO_2 (mmHg)	4.40 ± 2.44	9.18 ± 3.46	0.000

Table 2: Comparison of study parameters. A-immediately before skin incision, B-during OM grafting.

Discussion

Arterial blood gas sampling is conventionally used for estimation of $PaCO_2$ and optimizing ventilatory strategies in mechanically ventilated patients. However the appeal for this technique is blunted clinically because it is invasive, labor intensive and expensive and it generally offers only intermittent measure of $PaCO_2$ [11]. Time based capnography, best known as $EtCO_2$ monitoring, provides valuable qualitative information on the waveforms associated with mechanical ventilation and a quantitative indirect estimation of $PaCO_2$ [12]. CO_2 is a product of organic cell metabolism which is uptaken and transported by venous circulation to the lungs where it is excreted by the alveolo-capillary membrane and thus, in normal ventilation/perfusion conditions, $EtCO_2$ is an approximate measure of $PaCO_2$ [5].

Various researchers have studied the efficacy of $EtCO_2$ as a monitoring tool for adjustment in mechanical ventilation. Eun found a positive correlation between $EtCO_2$ and $PaCO_2$ in 24 critically ill neurological patients [2]. Similar findings were observed by McDonald in 129 children receiving mechanical ventilation who concluded that $EtCO_2$ reliably estimates ventilation [12]. Russell in 59 postoperative cardiac surgery patients also observed a good correlation between $PaCO_2$ and $EtCO_2$ throughout the period from ICU admission to extubation [1]. On the contrary, a meta-analysis by Wahba concluded that changes in $EtCO_2$ do not always indicate the direction and extent of change in $PaCO_2$ [13]. Belpomme also found an inconsistent relationship between $EtCO_2$ and $PaCO_2$ during prehospital transport of 100 mechanically ventilated patients [14]. Prause also could not establish any correlation in 27 emergency patients and concluded that ventilation of emergency patients can only be correctly adjusted according to values from arterial blood gas [15]. Khan in 50 patients for craniotomy has also reported similar findings [16].

When metabolism and ventilation are constant, $EtCO_2$ is largely determined by pulmonary blood flow and hence the CO. Many studies have been published that demonstrate the correlation between $EtCO_2$ and CO in different clinical settings. Jin studied the relationship between cardiac index (CI) and $EtCO_2$ in 16 pigs by inducing low flow states in the form of hemorrhagic, septic and cardiogenic shock and found $EtCO_2$ as a good non-invasive alternative for continuous measurement of CO [17]. Feng, in 1994 had proposed that there exists a good correlation between pulmonary blood flow and $EtCO_2$ while coming off cardiopulmonary bypass (CPB) in cardiac surgical patients. 3 In another study by Baraka in 32 patients for CABG on CPB, a positive correlation was observed between adequacy of CO at $EtCO_2$ values>30 mmHg [18]. Maslow also found that $EtCO_2$ is a useful index of pulmonary arterial blood flow during separation from CPB [19]. Isserles, by inflating venacaval balloon to impede venous return in pentobarbital anaesthetised dogs, found that percentage decrease in $EtCO_2$ is directly correlated to percentage decrease in CO [6]. However sustained decrease in CO led to accumulation of CO_2 in peripheral tissues, leading to return of $EtCO_2$ values towards baseline [3,6].

Hemodynamic changes are an important challenge during off-bypass procedures [9,20,21]. These may be secondary to the heart positioning or stabilization techniques. In order to work on the posterior or lateral walls, the heart must be lifted and tilted out of the pericardial cradle which results in a significant increase in atrial pressures, and a marked decrease in cardiac output [9]. Saleh observed in OPCABG surgery that during grafting on lateral wall, there is a decrease in $EtCO_2$ values usually preceding major hemodynamic upset and dysrhythmias [7].

We aimed to study the appropriateness of $EtCO_2$ monitoring during OPCABG surgery. Thus, we compared CI, $EtCO_2$, $PaCO_2$ and $P(a\text{-}Et)CO_2$ gradients at two time points, before skin incision and during OM grafting. We observed a statistically significant correlation in CI, $EtCO_2$, $PaCO_2$ values and the $P(a\text{-}Et)CO_2$ gradients at both these time points. Thus, we observe that similar to the findings in many studies, there exists a positive correlation between the values of $EtCO_2$ and CO in our study. So whenever there is a decrease in CO, there is concomitant decrease in $EtCO_2$ values, but there is an increase in the $P(a\text{-}Et)CO_2$ gradient. Considering the OM grafting period to be a low cardiac output state, we can extrapolate our results to low cardiac output conditions. Thus we propose that the changes in $EtCO_2$ values and $P(a\text{-}Et)CO_2$ gradient is related to the low CO and no attempts should be made to alter the ventilatory settings during this period to normalize the $EtCO_2$. Instead attempts should be made to increase the cardiac output.

Limitations

Several limitations of our study warrant further investigations. Firstly, the small sample size of our study limited our generalization of results. Secondly, use of side-stream capnometer might have led to under-estimation of the $PEtCO_2$ values as with this, a sample of exhaled air drawn through a sampling tube was sent to an analyzer placed at a distance away.

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