End-tidal CO₂ 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 EtCO₂ 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), EtCO₂, PaCO₂ and P(a-Et)CO₂ 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/m², p<0.001), significant decrease in EtCO₂ from 25.28 to 21.88 mmHg (p<0.001) and statistically significant increase in P(a-Et)CO₂ gradient 4.39 at point A to 9.18 mmHg at point B (p<0.003).

Conclusion: The decrease in EtCO₂ had a positive correlation with the decrease in cardiac index. So during the low flow periods as found in OPCABG, EtCO₂ cannot reliably estimate the adequacy of ventilation.

Keywords: End-tidal CO₂; Capnography; PaCO₂; 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 (CO₂) throughout the respiratory cycle, commonly referred to as end-tidal CO₂ (PETCO₂ or ETCO₂) [2]. ETCO₂ is a measure of alveolar partial pressure of CO₂ (PACO₂), which in turn is a measure of arterial CO₂ (PaCO₂). 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]. PETCO₂ is governed by metabolism, ventilation and circulation [2,5]. When the first two factors are controlled, PETCO₂ reflects the pulmonary blood flow and therefore cardiac output (CO) [3]. Attempts have been made to use PETCO₂ measurement as an alternative to thermo-dilution technique for determining CO in various cardiac surgical settings [3,6,7]. The normal gradient between PaCO₂ and EtCO₂ [P(a-Et)CO₂] is approximately 4-5 mmHg which represents the normal dead space ventilation [2]. But as PETCO₂ 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 PETCO₂ and increases P(a-Et)CO₂ [1]. Applying this principal in clinical scenario means that the ventilatory settings should not be adjusted taking into account the low values of EtCO₂ 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 EtCO₂ values during the cardiac output period in OPCABG and whether the EtCO₂ 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 thermochillation 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.

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

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of change in PaCO₂ [13]. Belpomme also found an inconsistent relationship between ETCO₂ and PaCO₂ 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, EtCO₂ is largely determined by pulmonary blood flow and hence the CO. Many studies have been published that demonstrate the correlation between EtCO₂ and CO in different clinical settings. Jin studied the relationship between cardiac index (CI) and EtCO₂ in 16 pigs by inducing low flow states in the form of hemorrhagic, septic and cardiogenic shock and found EtCO₂ 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 EtCO₂ 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 EtCO₂ values>30 mmHg [18]. Maslow also found that EtCO₂ 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 EtCO₂ is directly correlated to percentage decrease in CO [6]. However sustained decrease in CO led to accumulation of CO₂ in peripheral tissues, leading to return of EtCO₂ 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 EtCO₂ values usually preceding major hemodynamic upset and dysrhythmias [7].

We aimed to study the appropriateness of EtCO₂ monitoring during OPCABG surgery. Thus, we compared CI, EtCO₂, PaCO₂ and P(a-Et)CO₂ gradients at two time points, before skin incision and during OM grafting. We observed a statistically significant correlation in CI, EtCO₂, PaCO₂ values and the P(a-Et)CO₂ 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 EtCO₂ and CO in our study. So whenever there is a decrease in CO, there is concomitant decrease in EtCO₂ values, but there is an increase in the P(a-Et)CO₂ 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 EtCO₂ values and P(a-Et)CO₂ gradient is related to the low CO and no attempts should be made to alter the ventilatory settings during this period to normalize the EtCO₂. 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 PETCO₂ values as with this, a sample of exhaled air drawn through a sampling tube was sent to an analyzer placed at a distance away.

References