Original Article

Anaesthesia for laparoscopic nephrectomy: Does end-tidal carbon dioxide measurement correlate with arterial carbon dioxide measurement?

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ABSTRACT

Background and Aims: Not many studies have explored the correlation between arterial carbon dioxide tension ($PaCO_2$) and end-tidal carbon dioxide tension ($ETCO_2$) in surgeries requiring pneumoperitoneum of more than 1 hour duration with the patient in non-supine position. The aim of our study was to evaluate the correlation of $ETCO_2$ with $PaCO_2$ in patients undergoing laparoscopic nephrectomy under general anaesthesia. **Methods:** A descriptive study was performed in thirty patients undergoing laparoscopic nephrectomy from September 2014 to August 2015. The haemodynamic parameters, minute ventilation, $PaCO_2$ and $ETCO_2$ measured at three predetermined points during the procedure were analysed. Correlation was checked using Pearson's Correlation Coefficient Test. P <0.05 was considered statistically significant. **Results:** Statistical analysis of the values showed a positive correlation between $ETCO_2$ and $PaCO_2$ (P < 0.05). Following carbon dioxide insufflation, both $ETCO_2$ and $PaCO_2$ increased by 5.4 and 6.63 mmHg, respectively, at the end of the 1st hour. The $PaCO_2$-$ETCO_2$ gradient was found to increase during the 1st hour following insufflation (4.07 ± 2.05 mmHg); it returned to the pre-insufflation values in another hour (2.93 ± 1.43 mmHg). **Conclusion:** Continuous $ETCO_2$ monitoring is a reliable indicator of the trend in arterial CO_2 fluctuations in the American Society of Anesthesiologists Grades 1 and 2 patients undergoing laparoscopic nephrectomy under general anaesthesia.

Key words: Blood gas monitoring, capnography, carbon dioxide partial pressure determination, pneumoperitoneum

INTRODUCTION

Arterial blood gas analysis is the gold standard for assessing the adequacy of ventilation. Peripheral arterial catheters are commonly used for this purpose but may be associated with complications ranging from temporary occlusion of the artery to distal ischaemia, pseudoaneurysm formation and sepsis.[1] Apart from the blood loss due to recurrent sampling, a further disadvantage of arterial blood analysis is that it only reflects homoeostasis at the time of sampling, which can change considerably within a short period of time. End-tidal carbon dioxide ($ETCO_2$) measurements may be satisfactory surrogate measures of arterial carbon dioxide ($PaCO_2$) in select patients obviating the need for serial arterial blood gas determination. Under normal circumstances, a gradient of approximately 4–5 mmHg exists between the two.[2] There can be wide variations in this gradient between $PaCO_2$ and $ETCO_2$ depending on the patient's condition, the position adopted for surgery and the surgery itself – this relationship does not remain constant over time.

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Capnoperitoneum is associated with CO_2 absorption and an increase in CO_2 concentration in the bloodstream, leading to a rise in the $ETCO_2$ and $PaCO_2$. The rise in $ETCO_2$ is initially sharp, followed by a plateau as equilibrium is achieved.[3]

Few studies have explored the correlation between $ETCO_2$ and $PaCO_2$ in surgeries requiring pneumoperitoneum for a long duration with the patient in non-supine position. Laparoscopic nephrectomy requires pneumoperitoneum of at least 120 min duration with the patient maintained in lateral decubitus position. Under anaesthesia, the lateral decubitus position is itself associated with ventilatory compromise.[4] Overinflation and underperfusion of non-dependent lung and gravity favoured perfusion of the dependent underventilated lung leads to ventilation-perfusion mismatch affecting both oxygenation and elimination of carbon dioxide. Hence, measuring $PaCO_2$ in addition to $ETCO_2$ might be a more accurate reflection of the adequacy of ventilation.

In our study, we aimed to determine if the $ETCO_2$ values correlate with $PaCO_2$ during anaesthesia for laparoscopic nephrectomy.

METHODS

After obtaining Institutional Ethics Committee approval, a prospective observational study was conducted in thirty individuals undergoing laparoscopic nephrectomy in the period between September 2014 and August 2015. The sample size was calculated to be 30 so as to have a power of 90%; this was based on the information obtained from the study by Hu *et al*. which found a correlation coefficient of 0.579 between $ETCO_2$ and $PaCO_2$.[5] Written informed consent was obtained from patients undergoing laparoscopic nephrectomy who satisfied the inclusion criteria of age group between 20 and 50 years and surgeries requiring a duration of pneumoperitoneum of >120 min.

The exclusion criteria included patients belonging to the American Society of Anaesthesiologists (ASA) grades ≥3, patients with significant cardiovascular disease (New York Heart Association classes III and IV) and established chronic obstructive pulmonary disease (COPD), a negative Allen's test during the preoperative evaluation, and patients with a body mass index >30 kg/m^2. We excluded data if the surgery was converted to open nephrectomy.

The patients underwent pre-operative anaesthetic evaluation on the day before surgery during which they were explained about the ongoing study and consent obtained. Modified Allen's test was done to ensure patency of collateral circulation of the hand. As per institutional practice, solid food was withheld for 6 hours while clear fluids were allowed up to 2 hours before surgery. All patients received premedication in the form of tablet lorazepam 2 mg and tablet ondansetron 8 mg, 2 hours before surgery.

On arrival in the operation theatre (OT), all patients were pre-oxygenated with 100% O_2 for 3 minutes using a semi-closed breathing circuit. Anaesthesia was induced with 2 mcg/kg fentanyl and 2 mg/kg propofol. Intubation was performed 90 seconds after administration of 0.9 mg/kg rocuronium. Intermittent positive pressure ventilation mode was used with a tidal volume of 8 ml/kg and an initial respiratory rate of 12 breaths/min. The lungs were ventilated with air-oxygen mixture (FiO_2 0.5) and sevoflurane (end tidal concentration: 1.5- 2.0%) using Dräger Fabius® GS premium Anaesthesia workstation. A 20/22 G 4 cm long BD Insyte™ (BD, USA) -WTM cannula was inserted into the radial artery under aseptic precautions.

Pneumoperitoneum was created by insufflation with CO_2 after positioning the anaesthetised patient in lateral position. Intra-abdominal pressure was monitored and maintained below 12 mmHg. Expired tidal volumes, airway pressure and minute ventilation were monitored continuously throughout the surgery on the anaesthesia workstation. $ETCO_2$ was monitored using mainstream capnography (GE CAPNOSTAT™ CO_2 module) and minute ventilation was adjusted to maintain the $ETCO_2$ between 30 and 35 mmHg.

Maintenance of anaesthesia was with air-oxygen mixture (FiO_2 0.5) and sevoflurane (end tidal concentration: 1.5- 2.0%). Muscle relaxation was ensured with bolus doses of short-acting neuromuscular blockers (atracurium) at the discretion of the anaesthesiologist; additional analgesics used included intravenous fentanyl or morphine, and paracetamol.

The patients were monitored with ECG, pulse oximetry, intermittent non-invasive blood pressure monitoring, nasopharyngeal temperature probe and mainstream capnography (GE Dash 4000™ monitor). In addition, the breathing circuit had an oxygen sensor in the inspiratory limb to determine the fraction

of inspired oxygen concentration delivered to the patient. As per our department protocol for patients undergoing laparoscopic nephrectomy, arterial blood gas sampling was done at definite points (following lateral positioning, at 60 min of pneumoperitoneum and 120 min of pneumoperitoneum) during the surgery.

For the current study, the haemodynamic parameters, minute ventilation, $PaCO_2$ and $ETCO_2$ at the same three predetermined points during the surgery were analysed.

The time points analysed were: Baseline, T1: After induction and lateral positioning of the patient, while the surgical site was prepared and draped; 1 h after insufflation of pneumoperitoneum, T2; After 2 h of pneumoperitoneum, T3.

Data were entered in Excel sheet after coding. SPSS version 16.0 (trial version) was used for analysis of the data. Qualitative variables were summarised using proportion; quantitative variables were summarised using mean with standard deviation. Statistical analysis was done using Pearson correlation coefficient test and paired *t*-test. $P < 0.05$ was considered statistically significant.

RESULTS

The mean age of the patients was 42.87 ± 7.26 years. Twenty five male and five female patients participated in our study. Statistical analysis of the values showed a positive correlation between $ETCO_2$ and $PaCO_2$ ($P < 0.05$). Following laparoscopic insufflation, both $ETCO_2$ and $PaCO_2$ increased by 5.4 and 6.63 mmHg, respectively, by the end of the 1st hour [Tables 1 and 2]. The $PaCO_2$-$ETCO_2$ gradient was found to increase during the 1st hour following insufflation (4.07 ± 2.05 mmHg); it returned to the pre-insufflation values in another hour (2.93 ± 1.43 mmHg) [Figure 1].

Table 1: Paired sample statistics

Time	Mean±SD			*P*
	$ETCO_2$	$PaCO_2$	Difference	
Baseline	28.50±3.037	31.37±2.684	2.867±1.961	<0.001
1 h	33.93±4.135	38.00±4.218	4.067±2.050	<0.001
After 2 h	31.37±2.846	34.30±3.229	2.933±1.437	<0.001

SD – Standard deviation; $ETCO_2$ – End-tidal carbon dioxide; $PaCO_2$ – Arterial carbon dioxide

Table 2: Correlation

Time	Correlation coefficient (*r*)	*P*
Baseline	0.772	<0.001
1 h	0.880	<0.001
After 2 h	0.896	<0.001

DISCUSSION

From our study, we have been able to demonstrate a positive correlation between $ETCO_2$ and $PaCO_2$ in healthy patients undergoing laparoscopic nephrectomy.

The $PaCO_2$-$ETCO_2$ gradient varies with various patient positions adopted for surgery: it decreases slightly in prone position and increases significantly in the lateral decubitus position.[6] Our study revealed a mean $PaCO_2$-$ETCO_2$ gradient of 2.67 mmHg in patients in the lateral decubitus posture. The effect of lateral decubitus positioning on the gradient was not assessed since samples were not drawn before lateral positioning.

The samples drawn 1 hour post-insufflation showed that both arterial and $ETCO_2$ values increased – the mean $PaCO_2$-$ETCO_2$ gradient increased to 4.07 ± 2.05 mmHg. This is consistent with the findings of other researchers such as Tanaka *et al*.[7] Seed *et al*. proposed that during laparoscopy absorption of CO_2 occurs from the peritoneum.[8] The elimination of absorbed CO_2 depends on cardiac output, ventilation: perfusion ratios and alveolar ventilation.[2] Over a short period of time, CO_2 is buffered in the alveolar-arterial interface of the lung and in visceral stores and it is ultimately expired by the lung.[8] Absorption of CO_2 from the peritoneal cavity may be poor and inconsistent because of a reduction of capillary blood flow caused by increased

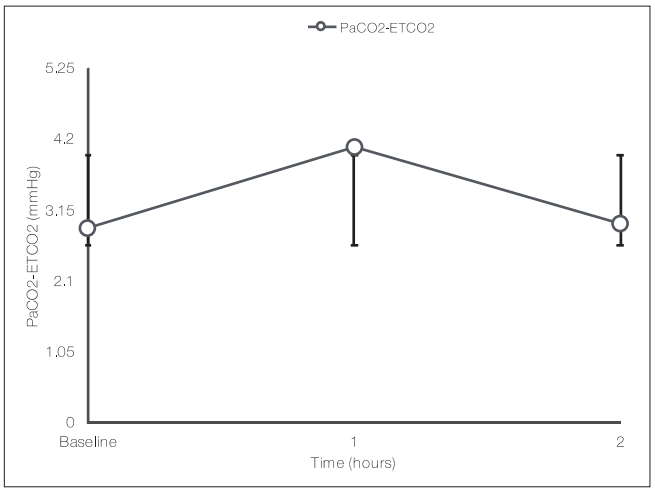

Figure 1: Change in the arterial carbon dioxide-end-tidal carbon dioxide difference over time

intra-abdominal pressure and general anaesthesia.[9] Analysis of the third arterial blood sample in our study seems to confirm this hypothesis – the $PaCO_2$-$ETCO_2$ gradient returned to the pre-insufflation values in the second hour (2.93 ± 1.43 mmHg) despite ongoing capnoperitoneum.

Capnographs measure CO_2 concentration using mainstream or sidestream configurations. Mainstream end-tidal CO_2 measurement, as used in our study, provides a more accurate estimation of arterial CO_2 as compared to sidestream measurement. Fresh gas entrainment during sidestream sampling can dilute expired CO_2 tension and contribute to the underestimation of $PaCO_2$.[10]

Prolonged intra-abdominal insufflation with CO_2 in anaesthetised and mechanically ventilated patients during abdominal laparoscopic surgery does not significantly affect the reliability of $ETCO_2$ monitoring in predicting $PaCO_2$ in healthy ASA grades 1 and 2 participants.[2,9,11] Our results confirmed the same. However, this may not be the case in patients with pre-existing pulmonary disease or moderate-to-severe cardiac compromise. An increasing number of patients requiring renal surgery are presenting with substantial comorbidities such as diabetes mellitus, COPD and cardiovascular disease. Most of the patients undergoing partial or radical nephrectomies for renal cell carcinoma are of advanced age and belong to ASA grade 3.[12] The changes produced during lateral positioning and CO_2 pneumoperitoneum may be varied in this category of patients owing to the altered physiology. These patients may benefit from direct arterial $PaCO_2$ monitoring in addition to continuous $ETCO_2$ monitoring.

Since continuous $ETCO_2$ monitoring serves as a reliable indicator of the trend in arterial CO_2 fluctuations, this would facilitate timely adjustments in ventilatory parameters to maintain homoeostasis and avoid complications of hypercapnia. Capnography being a non-invasive and continuous monitoring modality is advantageous in that it obviates the need for multiple arterial punctures (in healthy patients). Arterial blood sampling, on the other hand, is invasive and reflects the CO_2 values at the particular time when the sample is drawn. In our study, we found that $ETCO_2$ monitoring correlates with $PaCO_2$ in patients during anaesthesia for laparoscopic nephrectomy. Considering the adverse events and expenses associated with repeated arterial blood sampling, we recommend that observation of the trends in $ETCO_2$ would suffice to monitor ventilation in patients belonging to ASA grades 1 and 2 undergoing laparoscopic nephrectomy. High-risk patients may require invasive arterial $PaCO_2$ monitoring in addition.

Our study has a number of limitations: we included only healthy patients belonging to ASA grades 1 and 2, the effect of lateral positioning *per se* on the $ETCO_2$-$PaCO_2$ gradient was not assessed, specific time points for drawing blood samples were chosen. Hence we cannot authoritatively conclude that the same correlation exists at all times during the surgical period. Further studies involving diverse patient populations undergoing laparoscopic nephrectomies are required to conclusively establish the correlation.

CONCLUSION

Continuous $ETCO_2$ monitoring is a reliable indicator of the trend in arterial CO_2 fluctuations in the American Society of Anaesthesiologists Grades 1 and 2 patients undergoing laparoscopic nephrectomy under general anaesthesia.

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Conflicts of interest

There are no conflicts of interest.

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