Carbon dioxide output in laparoscopic cholecystectomy

T. KAZAMA, K. IKEDA, T. KATO AND M. KIKURA

Summary

In pneumoperitoneum, carbon dioxide eliminated in expired gas (carbon dioxide output) contains both metabolic and absorbed carbon dioxide from the peritoneal cavity. When elimination of carbon dioxide is much higher than carbon dioxide output, storage of tissue carbon dioxide and arterial carbon dioxide concentrations change. Finally, the rate of carbon dioxide eliminated in expired gas is not a match for the real rate of metabolic production and absorbed carbon dioxide from the peritoneal cavity. During and after insufflation of carbon dioxide, changes in carbon dioxide output were elucidated under constant arterial carbon dioxide pressure ($P_{a_{CO_2}}$) the same as the preinduction level. We studied patients undergoing elective laparoscopic cholecystectomy. Carbon dioxide output, oxygen uptake, respiratory exchange ratio (RER), expired minute ventilation ($V_e$), deadspace to tidal volume ratio ($V_D/V_T$ ratio) and arterial to end-tidal carbon dioxide partial pressure difference ($P_{a_{CO_2}} - P_{E_{CO_2}}$) were determined before induction, and during anaesthesia, pneumoperitoneum and recovery. By controlling ventilatory frequency ($f$) every 1 min, $P_{a_{CO_2}}$ was adjusted to concentrations before induction. Constant monitoring of arterial carbon dioxide partial pressure ($P_{E_{CO_2}}$) and intermittent measurement of ($P_{a_{CO_2}} - P_{E_{CO_2}}$) (15-min intervals) were conducted to predict $P_{a_{CO_2}}$. Carbon dioxide output and oxygen uptake decreased significantly from mean values of 83.5 (SEM 5.2), 101.6 (5.1) to 68.5 (4.2), 81.1 (4.6) ml min$^{-1}$m$^{-2}$ (ATPS, $P < 0.05$) with sevoflurane anaesthesia, and RER did not change. During carbon dioxide pneumoperitoneum (intra-abdominal pressure 8 mm Hg), carbon dioxide output increased by 49% (102.4 (5.0) ml min$^{-1}$m$^{-2}$ ($P < 0.05$) while oxygen uptake remained stable and RER increased from 0.84 (0.02) to 1.16 (0.03) ($P < 0.05$). It was necessary to increase $V_e$ during pneumoperitoneum by 1.54 times that during anaesthesia to maintain individual $P_{a_{CO_2}}$ values constant. After removal of carbon dioxide from the abdominal cavity, the regression equation of excess carbon dioxide output/BSA best fitted a two-compartment model. The time constants of the rapid and slow compartments were 8.2 and 990 min, respectively. Excess carbon dioxide output/BSA was still 5.5 ml min$^{-1}$m$^{-2}$, 30 min after pneumoperitoneum. (Br. J. Anaesth. 1996; 76: 530–535)

Key words


Laparoscopic gynaecological procedures involve a short duration of intraperitoneal carbon dioxide insufflation and are performed usually in young or otherwise healthy female patients. Changes in haemodynamic state and arterial blood-gas tensions with insufflation of carbon dioxide have been studied extensively and found to be relatively insignificant [1–6]. However, peritoneal insufflation for laparoscopic cholecystectomy may be longer than that for gynaecological procedures.

Insufflation of the abdominal cavity with carbon dioxide may be associated with pulmonary atelectasis, decreased functional residual capacity and high peak airway pressures. Absorption of carbon dioxide via the peritoneum causes hypercapnia but not impaired ventilation in healthy patients [7, 8]. Significant carbon dioxide retention has been demonstrated in patients with cardiopulmonary impairment during carbon dioxide pneumoperitoneum for extended procedures such as laparoscopic cholecystectomy [7, 9], with possibly consequent cardiac arrhythmias [10]. In pneumoperitoneum, carbon dioxide eliminated in expired gas (carbon dioxide output) contains both carbon dioxide of metabolic production and also absorbed carbon dioxide from the peritoneal cavity. Although there has long been interest in the rate of carbon dioxide output during long-lasting laparoscopic procedures, the reported data [5, 10–12] are not consistent, possibly because storage of carbon dioxide may be variable.

This study was conducted to assess excess carbon dioxide output evoked by pneumoperitoneum with stable carbon dioxide storage maintained by keeping arterial $P_{a_{CO_2}}$ constant at preinduction levels and to investigate continued carbon dioxide load after pneumoperitoneum using a pharmacokinetic model.

Patients and methods

We studied 12 consenting, ASA I or II patients, undergoing elective laparoscopic cholecystectomy.

TOMMI KAZAMA, MD, KAZUYUKI IKEEM, MD, TAKASUMI KATO, MD, MUTSUHIITO KIKURA, MD, Department of Anaesthesiology and Intensive Care, Hamamatsu University School of Medicine, 3600 Handsa-cho, Hamamatsu, Japan 431-31. Accepted for publication: October 27, 1995.

Correspondence to T.K.
Approval was obtained from the Human Studies Committee at Hamamatsu University Hospital. Patients were in good general health, with no signs or laboratory findings of renal, pulmonary or hormonal disease, or obesity (defined as a body mass index > 29). All patients fasted overnight and were premedicated with hydroxyine 50 mg and atroine 0.5 mg 1 h before induction of anaesthesia. An i.v. cannula was inserted during local anaesthesia. i.v. infusion of sodium lactate solution was started, and 0.5 mg 1 h before induction of anaesthesia. An i.v. medicated with hydroxyine 50 mg and atroine 1.0 mg. The trachea was then extubated. Inspired concentrations of nitrogen, oxygen and nitrous oxide were adjusted to 30 %, 20 % and 50 %, respectively, during anaesthesia.

Before induction of anaesthesia, all subjects were permitted to breathe room air through the anaesthesia mask for 20 min and mean expired and inspired concentrations of oxygen, carbon dioxide, nitrogen and expiratory minute volume were measured to obtain baseline carbon dioxide output and oxygen uptake. Anaesthesia was induced with thiopentone 5 mg kg\(^{-1}\) i.v. and non-depolarizing neuromuscular blocker (vecuronium 0.1 mg kg\(^{-1}\)). Tracheal intubation was performed orally using auffed tracheal tube. Inspired concentrations of oxygen, nitrogen and nitrous oxide were adjusted to 30 %, 20 % and 50 %, respectively, during anaesthesia. The inspired sevoflurane mixture was adjusted to give an end-tidal sevoflurane concentration of 1.37 % (0.8 MAC). The fresh gas flow rate was 6–7 litre min\(^{-1}\). The lungs of all patients were ventilated mechanically with the same ventilator equipped with an anaesthesia machine (Narcomed3, North American Drager, USA). Tidal volume was set at 10 ml kg\(^{-1}\). Ventilatory frequency \((f)\) was adjusted mainly each minute to maintain \(P_{a\,CO_2}\) at preinduction levels with continuous monitoring of end-tidal carbon dioxide pressure \((P_{E\,CO_2})\) and intermittent measurement of arterial to end-tidal carbon dioxide partial pressure difference \((P_{a\,CO_2} - P_{E\,CO_2})\) Arterial blood samples were obtained every 15 min after stabilization of the ventilator settings and analysed for pH, \(P_{a\,CO_2}, P_{aO_2}\), and base excess. Before skin incision, baseline carbon dioxide output and oxygen uptake were obtained after they reached steady state. Neuromuscular block was maintained with additional increments of vecuronium 0.025 mg kg\(^{-1}\) when the train-of four ratio exceeded 75 %. Carbon dioxide was introduced into the peritoneal cavity by a carbon dioxide Pneu (Wisap, Germany) pressure limiting automatic insufflation apparatus and abdominal pressure was maintained at 8 mm Hg in all patients. After insufflation, multiple incremental changes in minute volume were made to maintain \(P_{a\,CO_2}\) at preinduction levels. The table was tilted about 5° of the reverse. Trendelenburg position and then slightly to the left lateral position. Laparoscopic cholecystectomy was performed by a standard procedure. Intrapertoneal gas was evacuated after cholecystectomy and regression of carbon dioxide output in the post-insufflation state was measured 30 min under stable \(P_{a\,CO_2}\) every 1 min by manual control of ventilatory frequency. After carbon dioxide output returned to control level, neuromuscular block was antagonized with neostigmine 2.0–2.5 mg i.v. and atroine 1.0 mg i.v. The trachea was then extubated.

Anaesthesia was divided into five periods: (1) preinduction phase, (2) anaesthesia phase (control period of anaesthesia before skin incision), (3) pneumoperitoneum phase (during laparoscopy at intra-abdominal pressure of 8 mm Hg), (4) post-pneumoperitoneum phase (0–30 min after evacuation of carbon dioxide from the peritoneal cavity), and (5) recovery phase (40 min after extubation).
To fit the regression curve for carbon dioxide output during the post-pneumoperitoneum phase to multicompartiment models, the least squares method was used and the number of compartments was determined by minimum AIC (an information criterion) based on the maximum likelihood estimation method [20].

Statistical analysis was carried out using analysis of variance (ANOVA), Fisher’s test and Student’s t test, where appropriate. \( P < 0.05 \) was considered statistically significant. All values are expressed as mean (SEM).

**Results**

We studied 12 premedicated patients, who were essentially normal in the pre-anaesthesia state (table 1). Steady states for \( \dot{V}_{\text{CO}_2}/\text{BSA} \) and \( \dot{V}_{\text{O}_2}/\text{BSA} \) were obtained during the following phases: preinduction, anaesthesia, pneumoperitoneum and recovery. Although it was difficult to maintain \( P_{\text{aCO}} \) constant during the 10 min after tracheal intubation and the start of pneumoperitoneum surgery, concentrations were maintained at 5.0–5.4 kPa.

Compared with the preinduction phase, minute ventilation (\( \dot{V} \)) decreased from 5.26 (0.33) to 3.33 (0.27) litre min \(^{-1} \) (\( P < 0.05 \)) in the anaesthetic phase and increased to 5.14 (0.30) litre min \(^{-1} \) in the pneumoperitoneum phase (\( P < 0.05 \)). Respiratory minute volume during pneumoperitoneum thus had to be made 1.54 times that in the anaesthesia phase to maintain \( P_{\text{aCO}} \) constant (table 2). Carbon dioxide output and oxygen uptake decreased, respectively, from 83.5 (5.2), 101.6 (5.1) to 68.5 (4.2), 81.1 (4.6) ml min \(^{-1} \) m \(^{-2} \) (ATPS, \( P < 0.05 \)) with sevoflurane anaesthesia and RER did not change. During pneumoperitoneum, carbon dioxide output increased 49 % (102.4 (5.0) ml min \(^{-1} \) min \(^{-1} \), \( P < 0.05 \)) while oxygen uptake remained stable and RER increased from 0.84 (0.02) to 1.16 (0.03) (\( P < 0.05 \), table 2, figs 1, 2). These variables returned to preinduction levels during recovery. \( P_{\text{aCO}_2} \), pH, base excess and \( S_{\text{aO}_2} \) in the preinduction phase were normal (table 2) and were maintained throughout the experiment.

**Figure 1** Changes in carbon dioxide output (□) and oxygen uptake (●) in the pre-induction (Pre.) anaesthesia (Anaes.) and pneumoperitoneum (Pneumo.) phases while maintaining \( P_{\text{aCO}} \) constant at the normal value for the preinduction phase (mean, SEM, \( n = 12 \)). I = Intubation, SI = skin incision.

**Table 1** Characteristics of patients, pneumoperitoneum (pneumo.) and anaesthesia (mean (SEM or range))

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Sex (M : F)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Duration of anaesthesia (min)</th>
<th>Duration of pneumo. (min)</th>
<th>CO(_2) volume for insufflation (litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.5 (37–69)</td>
<td>5 : 7</td>
<td>57.1 (16.7)</td>
<td>154.1 (11.0)</td>
<td>196.2 (5.4)</td>
<td>89.3 (4.4)</td>
<td>77.2 (5.1)</td>
</tr>
</tbody>
</table>

**Table 2** Metabolic and respiratory variables during the four phases of the procedures (mean (SEM)). \( P_{\text{aCO}_2} \) = end-tidal carbon dioxide pressure; \( \dot{V} \) = expired minute volume; \( \overline{\dot{V}}_{\text{CO}_2}/\text{BSA} \) = carbon dioxide output/body surface area; \( \dot{V}_{\text{O}_2}/\text{BSA} \) = oxygen uptake/body surface area; RER = respiratory exchange ratio; \( \overline{\dot{V}}_{\text{ET}}/\text{ET} \) = deadspace to tidal volume ratio; \( (P_{\text{aCO}_2} - P_{\text{ETCO}_2}) \) = arterial to end-tidal carbon dioxide tension. * Significant difference from pre-induction, ** significant difference from anaesthesia.
The results for haemodynamic state and temperature are summarized in table 3. After induction of anaesthesia there were decreases in heart rate, systolic arterial pressure, mean arterial pressure and diastolic arterial pressure. Significant increases in arterial pressure in the pneumoperitoneum phase were noted, but no cardiac arrhythmia was detected during induction, pneumoperitoneum or after pneumoperitoneum.

The regression equation for excess $\dot{V}_{CO_2}/BSA$ after removal of carbon dioxide from the abdominal cavity is shown in figure 3. $\dot{V}_O_2$ and $P_{\text{a}CO_2}$ were stable. A two-compartment model was judged to give the best fit by AIC. Excess carbon dioxide output pharmacokinetic variables and AIC values in each model are shown in table 4. Time constants of the first (rapid) and second (slow) compartments were 8.2 and 990 min, respectively. At the end of pneumoperitoneum, the rapid compartment was thought to be equilibrated, as $T_1$ was short (5.7 min) and carbon dioxide output was constant. The excess rate of carbon dioxide output/BSA was still 5.5 ml min$^{-1}$ m$^{-2}$, 30 min after removal of carbon dioxide from the peritoneal cavity.

There was no clinical evidence of hypoxaemia, no change in standard bicarbonate before and after peritoneal insufflation, and no postoperative complications.

**Discussion**

During laparoscopy, the large volume of carbon dioxide for pneumoperitoneum is passively absorbed from the peritoneal cavity into the blood and most of it is removed from the circulation by hyperventilation. The respiratory effects of carbon dioxide absorbed from the peritoneal cavity into the blood have been studied previously [7, 21–27]. The quantity of carbon dioxide and bicarbonate ion in the body is large. When ventilation is not in accord with carbon dioxide output, hypercapnia continues. Sustained elevation in $P_{\text{a}CO_2}$ typical of that associated with pneumoperitoneum, probably recruits whole-body storage depots, such as skeletal muscle and bone [28], in addition to intraperitoneal organs. Thus to study carbon dioxide output during laparoscopic cholecystectomy, the body storage of carbon dioxide must not be allowed to change. Although it is not certain that a constant $P_{\text{a}CO_2}$ necessarily implies constant storage, it is a reasonable assumption.

In the present study, $\dot{V}_E$ was adjusted to maintain $P_{\text{a}CO_2}$ constant at the preinduction level with constant monitoring of $P_{\text{ET}CO_2}$ and intermittent measurement of $(P_{\text{a}CO_2} - P_{\text{ET}CO_2})$. This method for estimating $P_{\text{a}CO_2}$ is invalid if the alveolar deadspace increases with $(P_{\text{a}CO_2} - P_{\text{ET}CO_2})$, a situation that may occur during the period of carbon dioxide insufflation. Bramton

**Table 3** Haemodynamic variables and temperatures during the four phases of the procedures (mean (SEM)). SAP = systolic arterial pressure; MAP = mean arterial pressure; DAP = diastolic arterial pressure; HR = heart rate. * Significant difference from preinduction; ** significant difference from anaesthesia

<table>
<thead>
<tr>
<th></th>
<th>Preinduction</th>
<th>Anaesthesia</th>
<th>Pneumoperitoneum</th>
<th>Recovery (40 min after extubation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP (mm Hg)</td>
<td>138.9 (4.0)</td>
<td>106 (1.7)*</td>
<td>130.9 (5.1)**</td>
<td>132.8 (3.7)**</td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>102 (3.7)</td>
<td>76.7 (1.4)*</td>
<td>101.9 (3.9)**</td>
<td>96.0 (3.5)**</td>
</tr>
<tr>
<td>DAP (mm Hg)</td>
<td>79.8 (3.5)</td>
<td>58.8 (1.3)*</td>
<td>73.9 (3.2)**</td>
<td>76.1 (3.2)**</td>
</tr>
<tr>
<td>HR (beat min$^{-1}$)</td>
<td>75.5 (3.7)</td>
<td>67.6 (1.9)</td>
<td>76.0 (2.8)</td>
<td>70.1 (2.7)</td>
</tr>
<tr>
<td>Rectal temp. (°C)</td>
<td>36.48 (0.08)</td>
<td>36.49 (0.09)</td>
<td>36.46 (0.09)</td>
<td>36.45 (0.08)</td>
</tr>
<tr>
<td>Room temp. (°C)</td>
<td>26.2 (0.6)</td>
<td>25.9 (0.7)</td>
<td>25.5 (0.4)</td>
<td>25.4 (0.6)</td>
</tr>
</tbody>
</table>
and Watson reported that monitoring of $P_{E\text{CO}_2}$ during laparoscopy could be used to reflect $P_{a\text{CO}_2}$, except at the start of pneumoperitoneum [29]. Fitzgerald and colleagues demonstrated that there were no changes in $(P_{a\text{CO}_2} - P_{e\text{CO}_2})$ during He pneumoperitoneum in mechanical ventilation [7]. In the present study, $V_d/V_T$ was almost constant except during preinduction when an anaesthesia mask was used for ventilation. $P_{a\text{CO}_2}$ during pneumoperitoneum was thought to be nearly constant, since $P_{E\text{CO}_2}$ and $(P_{a\text{CO}_2} - P_{E\text{CO}_2})$ were nearly constant (table 2, fig. 2).

During anaesthesia, the metabolic rate is reduced by about 15–30 % below that of the awake state [16, 30]. In this study, oxygen uptake and carbon dioxide output decreased 20.2 % and 18.0 % respectively. Thus RER remained constant, even during anaesthesia. Surgical stimulation may alter carbon dioxide output and oxygen uptake by increasing metabolic rate. End-tidal total MAC multiples of sevoflurane and nitrous oxide during pneumoperitoneum were maintained at 1.39, which was sufficient to prevent the effect of surgical stimulation on metabolism, as oxygen uptake did not change during surgery. The increased intra-abdominal pressure may have interfered with the elimination of carbon dioxide from abdominal organs and lower extremities by causing the veins to collapse. Carbon dioxide output and oxygen uptake increase after completion of pneumoperitoneum in this situation. However, an intra-abdominal pressure of 8 mm Hg, which was maintained automatically, did not hinder elimination of carbon dioxide, as oxygen uptake during and after pneumoperitoneum remained stable.

Marked increases in $P_{a\text{CO}_2}$ and excess carbon dioxide output, 66.9 mm Hg and 41 ml min$^{-1}$, respectively, 12 min after pneumoperitoneum were reported by Lewis and co-workers in young gynaecological patients anaesthetized with halothane during spontaneous ventilation [10]. Mullet and colleagues reported excess carbon dioxide output to be 32 ml min$^{-1}$ with a 25 % increase in $P_{a\text{CO}_2}$ [12]. Wurst, Schulte-Steinberg and Finsterer noted a 30–40 % increase in carbon dioxide output during pneumoperitoneum [11]. These values are less than the carbon dioxide output of 102.4 (5.0) ml min$^{-1}$ m$^{-2}$ and excess carbon dioxide output of 34.1 (3.9) ml min$^{-1}$ m$^{-2}$ (54.0 (4.6) ml min$^{-1}$) observed in the present study, possibly because of the following three factors: a decrease in tissue storage of carbon dioxide as a result of hyperventilation before insufflation of carbon dioxide, hypoventilation after insufflation and unstable conditions for measuring carbon dioxide output. Viale and colleagues demonstrated that the transient increase in RER at the start of anaesthesia was caused by increased carbon dioxide output during mechanical ventilation, as the standard controlled ventilation used (tidal volume = 10 ml kg$^{-1}$, ventilatory rate = 12 b.p.m.) may have caused alveolar hyperventilation. They found that 60 min was necessary to attain steady state after starting mechanical ventilation [15].

The regression equation for excess $V_{\text{CO}_2}/\text{BSA}$ showed the best fit with the two-compartment model (rapid and slow compartments) after removing carbon dioxide from the abdominal cavity. The half-times of the rapid and slow compartments were 5.7 and 686 min, respectively. A very small pressure difference causes carbon dioxide diffusion because carbon dioxide diffuses rapidly into the tissues. $P_{\text{CO}_2}$ of arterial blood entering the tissues is 5.3 kPa; tissue capillary blood reaches almost complete equilibrium with interstitial $P_{\text{CO}_2}$ when venous blood leaves the tissues [31]. The carbon dioxide insufflated to establish pneumoperitoneum diffuses into the abdominal organs and abdominal wall through the peritoneum, partly accumulates in tissue, and is then carried by the blood to the lungs. Therefore, the rapid compartment represents abdominal circulatory blood, liver, kidneys and other well-perfused tissues. The slow compartment represents tissues with low blood flow. Although the carbon dioxide load in the present study was clinically safe in patients without cardiac or pulmonary disease with controlled ventilation during and after pneumoperitoneum, excess $V_{\text{CO}_2}/\text{BSA}$ was still 5.5 ml min$^{-1}$ m$^{-2}$, 30 min after pneumoperitoneum. Therefore, patients receiving sedative drugs, patients with significant cardiac or pulmonary disease, or those with impaired ventilation in the pneumoperitoneum phase may be adversely affected by hypercapnia associated with carbon dioxide insufflation, even in the postoperative phase [9, 7].

**Acknowledgments**

We thank Koji Morita, PhD, and Yoshimitsu Sanjo, PhD for help and advice.

<table>
<thead>
<tr>
<th>Time constant 1 (min)</th>
<th>Time constant 2 (min)</th>
<th>Time constant 3 (min)</th>
<th>AIC</th>
<th>$V_1$ (ml m$^{-2}$)</th>
<th>$V_2$ (ml m$^{-2}$)</th>
<th>$V_3$ (ml m$^{-2}$)</th>
<th>$V^*$ (ml m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 41.1</td>
<td>39.4</td>
<td>39</td>
<td></td>
<td>151.6</td>
<td>323</td>
<td>1178</td>
<td>2172</td>
</tr>
<tr>
<td>A2 6.1</td>
<td>8.2</td>
<td>111</td>
<td></td>
<td>155.6</td>
<td>320</td>
<td>1067</td>
<td>2565</td>
</tr>
<tr>
<td>A3 4.6</td>
<td>8.2</td>
<td>111</td>
<td></td>
<td>1006</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Excess carbon dioxide output pharmacokinetic variables and AIC values in each model. AIC = An information criterion [20]. $V_1, V_2, V_3$ = volumes of each compartment, $V^*$ = total volume of distribution.
CO₂ output in laparoscopic cholecystectomy

References


