Effect of Small Bowel Perforation During Laparoscopy on End-Tidal Carbon Dioxide: Observation in a Small Animal Model

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Introduction. There are currently no reports in the literature regarding changes in end-tidal carbon dioxide (ETCO₂) when the small bowel is deliberately or inadvertently perforated during laparoscopic surgery. The aim of this study was to assess the influence of small bowel perforation during laparoscopy on ETCO₂ in a rat model.

Materials and methods. Two groups of Wistar rats (n = 8/group) were anesthetized, tracheostomized, and mechanically ventilated at a fixed tidal volume and respiratory rate. After a stabilization phase of 30 min, CO₂ pneumoperitoneum was established to 5 mmHg in one group and 12 mmHg in the other group, and maintained for 30 min. A small bowel perforation was then created and pneumoperitoneum was reestablished for another 30 min. Blood pressure, heart rate, peak ventilatory pressure, and ETCO₂ were recorded throughout the experiment.

Results. No significant changes in blood pressure throughout the experiment were noted in either group. The ventilatory pressure increased in both groups after the induction of pneumoperitoneum. In the 5 mmHg group, there was a modest increase in ETCO₂ following the induction of pneumoperitoneum (from 39.4 ± 1.9 to 41.1 ± 1.4, P = 0.014), and a further increase following the small bowel perforation (from 41.1 ± 1.4 to 42 ± 0.8, P = 0.007). In the 12 mmHg group, there was no change in ETCO₂ after the induction of pneumoperitoneum; however, there was a substantial increase in ETCO₂ following bowel perforation (35.0 ± 2.0 to 49.8 ± 7.1, P = 0.002).

Conclusions. ETCO₂ increases when the small bowel is perforated during CO₂ pneumoperitoneum. This increase seems more substantial under higher pneumoperitoneal pressures. Small bowel injury may enable the diffusion of CO₂ through the bowel mucosa, causing ETCO₂ elevation. Therefore, an abrupt increase in ETCO₂ observed during laparoscopy may indicate small bowel injury. © 2007 Elsevier Inc. All rights reserved.

Key Words: laparoscopy; small bowel perforation; end-tidal carbon dioxide; carbon dioxide absorption.

INTRODUCTION

Carbon dioxide (CO₂) is currently the most widely used gas to establish pneumoperitoneum in laparoscopic surgery because it is noncombustible, inexpensive, and least likely to cause embolism [1, 2]. CO₂ is absorbed through the peritoneal surface into the bloodstream, leading to elevation of arterial CO₂, and is eliminated by ventilation in the expired gas [3, 4]. This release causes an increase in the measured end-tidal CO₂ (ETCO₂), which can roughly indicate CO₂ blood level. Thus, ETCO₂ elevation during laparoscopic surgery represents hypercarbia and is treated by an increase of minute ventilation [5, 6].

Currently, there are no reports in the literature regarding changes in ETCO₂ absorption and/or its respiratory release when the small bowel is deliberately or inadvertently opened during laparoscopic surgery. In our anecdotal experience, small bowel injury during laparoscopy was associated with an immediate increase in ETCO₂ observed by the anesthesiologist. The aim of this study was to assess possible changes in ETCO₂ associated with small bowel perforation during laparoscopy in a rat model.

MATERIALS AND METHODS

Sixteen adult male Wistar rats (weight 350 to 420 g) were kept in accordance with the guidelines of the Committee on Animal Re-
search of the Tel Aviv Sourasky Medical Center and the Tel Aviv University, which also approved this study.

Surgical Procedure

All animals were anesthetized with intraperitoneal ketamine 5 mg/kg and diazepam 1 mg/kg. A tracheostomy was performed and the rats were mechanically ventilated with room air, using a piston-type rodent ventilator set to deliver 10 mL/kg body weight tidal volume at 45 breaths/min. Continuous positive airway pressure was maintained at 4 mmHg. The femoral artery was cannulated with an 18-gauge catheter for invasive blood pressure monitoring. ETCO2, peak ventilatory pressure (PVP), and other hemodynamic parameters were continuously monitored and recorded (Capnomac Ultima; Datex, Helsinki, Finland) every 10 min throughout the experiment.

Experimental Protocol

The rats were divided into two groups (n = 8/group) and the experiment was conducted in three 30-min phases. Each animal served as its own control.

Stabilization Phase (Phase I)

After all cannulations had been performed, the rats were allowed to stabilize.

Pneumoperitoneum Phase (Phase II)

Pneumoperitoneum was established with a CO2 insufflator (Olympus OTV-S7; Olympus Corporation, Tokyo, Japan) connected to a 21-gauge needle by peritoneal penetration. The set pressure was 12 mmHg in Group I and 5 mmHg in Group II.

Pneumoperitoneum with Small Bowel Perforation (Phase III)

Following the pneumoperitoneum phase (II), the abdomen was desufflated and a 2 cm laparotomy was performed. The proximal jejunum was identified and a cross incision, 5 mm in length in each arm, was made on the bowel wall. The bowel was left in situ and the abdominal wall incision was sutured closed with 2-0 Vicryl. Pneumoperitoneum was then reestablished to the previous pressures and all parameters were remonitored and recorded.

Validating Experiments

During the validation process of the model, we ascertained that the incisional laparotomy itself did not affect the ETCO2 levels, possibly due to CO2 diffusion through the sutured peritoneal incision. In a separate set of experiments of CO2 pneumoperitoneum, we compared ETCO2 levels both before and after performing a 2 cm laparotomy incision without the intestinal injury. Specifically, 7 rats/pressure level (i.e., 5 and 12 mmHg) were subjected to pneumoperitoneum before and after a 2 cm midline laparotomy that was sutured closed. We found no significant differences between ETCO2 measured before and after the laparotomy in each of the pressure group (5 and 12 mmHg) (Average delta pressure of −0.28 mmHg in the 5 mmHg [P = 0.9]; 3 mmHg in the 12 mmHg group [P = 0.5]). These results validated the methodology we used (i.e., the creation of a small bowel injury using a small laparotomy incision and then the reinsufflating the abdominal cavity) and demonstrated that the laparotomy itself had no impact on the experimental process, especially on ETCO2 changes.

Statistical Analyses

Data were summarized as means ± SD. Differences in variables were analyzed by ANOVA with repeated measures test; P < 0.05 was considered statistically significant.

RESULTS

There were no significant changes in blood pressure among the three phases in either group. Ventilatory pressure increased significantly in both groups following the induction of pneumoperitoneum, and remained elevated during the time pneumoperitoneum was applied. Phases II and III PVP were higher in the 12 mmHg group compared with the 5 mmHg group (P = 0.008) (Fig. 1).

In the 5 mmHg group, there was a statistically significant though modest increase in ETCO2 in Phase II (pneumoperitoneum) and a further modest increase following the small bowel perforation (Phase III) (Table 1). In the 12 mmHg group, there was no change in ETCO2.

<table>
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<th>Table 1</th>
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<td>ETCO2 Changes Between Phase I and II and Between Phase II and III (means ± SD)</td>
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<tr>
<th>ETCO2 (mean ± SD)</th>
<th>Stabilization phase (Phase I)</th>
<th>Pneumoperitoneum phase (Phase II)</th>
<th>P-value</th>
<th>Pneumoperitoneum phase (Phase II) + Small bowel perforation phase (Phase III)</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Group 1</td>
<td>39.4 ± 1.95</td>
<td>41.1 ± 1.4</td>
<td>0.014</td>
<td>41.1 ± 1.4</td>
<td>0.007</td>
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<tr>
<td>Group 2</td>
<td>35.6 ± 1.6</td>
<td>35 ± 2.0</td>
<td>NS</td>
<td>35 ± 2.0</td>
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after the induction of pneumoperitoneum (Phase II). However, there was a significant increase in ETCO$_2$ immediately upon starting pneumoperitoneum that followed bowel perforation ($P = 0.002$) (Table 1 and Fig. 2). ETCO$_2$ level remained elevated throughout the perforation-associated pneumoperitoneal phase.

**DISCUSSION**

The results of the present study indicate that, presumably, small bowel perforation during laparoscopy allows for intraperitoneal CO$_2$ to enter the small bowel lumen, which could then be rapidly absorbed through the small bowel mucosa.

The current experimental method (i.e., the creation of a small bowel injury after desufflation via a small laparotomy incision, and then the reinsufflation of the abdominal cavity) was chosen because of technical constraints. The main concern in this design is that the rat had a sutured incision with violation of the peritoneum, which could have potentially biased the results. We prevailed over this issue by conducting a preliminary study that demonstrated no impact of this method on ETCO$_2$ (as was detailed in the Materials and Methods section).

We did not directly measure mucosal CO$_2$ absorption; however, based on studies demonstrating a quick disappearance of CO$_2$ from the bowel lumen [7], we assume that this is the explanation for our study results. Indeed, Silva et al. [7] demonstrated a rapid absorption of CO$_2$ through the small bowel mucosa when comparing small bowel endoscopy with air insufflation to CO$_2$ endoscopy performed during laparoscopy. They found that CO$_2$ was more rapidly eliminated from the small bowel lumen within 15 min, compared with several hours in the air insufflation group.

Rapid mucosal absorption of CO$_2$ is not unique to the small bowel. Nakajima et al. [8] performed intraoperative CO$_2$ colonoscopy in patients undergoing laparoscopy and also demonstrated a rapid absorption of CO$_2$ through the colonic mucosa. They reported a rather rapid increase in ETCO$_2$ during the procedure. A rapid decrease in bowel distension associated with a decrease in ETCO$_2$ was reported following the cessation of CO$_2$ insufflation. Based on this data, we hypothesize that colonic perforation during laparoscopy may also result in an increased ETCO$_2$. This contention is currently under investigation.

In our study, the increase in ETCO$_2$ following small bowel perforation was more considerable in the higher pneumoperitoneum pressure group (12 mmHg). Interestingly, the ETCO$_2$ did not increase following induction of Phase I pneumoperitoneum in the 12 mmHg group, as would be expected. This phenomenon is most likely due to the physiology of CO$_2$ absorption through the peritoneum. Specifically, Blobner et al. [9] demonstrated in a porcine model that the peritoneal absorption rate of CO$_2$ increases in a direct correlation to the intra-abdominal pressure, however, only to a maximum pressure level of 16 mmHg. Higher intra-abdominal pressure caused a steep reduction in the CO$_2$ absorption rate. This occurrence was explained by pressure occlusion gradient of the peritoneal capillaries. Thus, in lower pneumoperitoneum pressures, these capillaries enable CO$_2$ absorption; conversely, in higher pressures, the capillaries are compressed, thereby preventing CO$_2$ peritoneal diffusion to the blood. The same authors also demonstrated that peritoneal CO$_2$ absorption starts to decline at intra-abdominal pressures ranging between 14 and 20 mmHg in humans [10].

Despite the results of our study, we are uncertain as to the degree of pneumoperitoneum used in rats and how it compares clinically with humans as it may affect the significance of our findings.

Many studies on pneumoperitoneum and its effects have used a rat model, using pressures ranging between 4 and 12 mmHg [11, 12]. The correlation between pressures in rodents and human may possibly be evaluated from the relationship between CO$_2$ pressure and CO$_2$ peritoneal diffusion. In humans, as we increase intra-abdominal pressure the CO$_2$ diffusion increases but only until a certain point (14 to 20 mmHg) at which the CO$_2$ diffusion declines [10]. In this study, we demonstrated an increase in ETCO$_2$ in the 5 mmHg group, suggesting CO$_2$ diffusion from the peritoneum as occurs in humans. Since no diffusion of CO$_2$ (as reflected by ETCO$_2$) was demonstrated when pneumoperitoneum pressure was increased to 12 mmHg, it is credible that this may correlate to high pressure levels in humans (14 to 20 mmHg), where CO$_2$ diffusion from the peritoneum is also known to be minimal [10]. However, this correlation has not been validated and to confirm the significance of our results in humans, it is our future investigational step to study ETCO$_2$ changes in a large animal model, which may better simulate conditions in humans. Additionally, ETCO$_2$
changes may be studied in operations in humans
where the bowel is intentionally opened during laparoscopic surgery.

We contend that a 12 mmHg intraperitoneal pressure in the rat is above the peritoneal capillary occlusion pressure at which point peritoneal CO2 absorption is unlikely to occur. Furthermore, since the intraabdominal volume in the rat is minimal, the 12 mmHg pressure level was achieved in a matter of seconds; therefore no change in ETCO2 could have taken place following this CO2 insufflation. However, the small bowel perforation served as the entry port for CO2 into the bloodstream, causing an abrupt increase in ETCO2. Thus, the higher increase in ETCO2 following small bowel injury in the higher abdominal pressure in the rat is attributable to a lower peritoneal absorption, coupled with a higher pressure-related mucosal CO2 absorption. Comparably, a more pronounced elevation in ETCO2 should be anticipated in humans following small bowel perforation in high laparoscopic pneumoperitoneal pressures. Clinically, this finding should alert the surgeon to the possibility of an inadvertent small bowel injury during laparoscopy.

Noteworthy, the initial purpose of our study was to generally determine whether small bowel perforation would be accompanied by an increase in ETCO2. We believe that further studies evaluating different sites of perforation in the gastrointestinal tract are important as well.

The size of the small bowel injury that causes ETCO2 elevation might also be of clinical importance. It would be of value to assess whether a very small hole that may not be detected by the surgeon would create similar changes in ETCO2 as those following a larger damage. This and similar queries may be assessed in a large animal model, to better correlate the results to accidents occurring in humans.

CONCLUSIONS

This study has demonstrated that small bowel injury during laparoscopy in a rat model is associated with an increase in ETCO2, which is more pronounced under high pressure pneumoperitoneum. We argue that although proven in a murine model, surgeons should be aware of changes in CO2 during laparoscopic surgery, as an unexpected increase in ETCO2 may indicate bowel injury. Clinical studies should be undertaken in the future to assess the validity of the present findings in humans as well, during procedures that may lead to inadvertent small bowel injury.

REFERENCES