Original Research

Relationship between Gastric pH Measurement and Intra-abdominal Pressure in Patients Undergoing Laparoscopic Surgery

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Abstract

Objectives: Laparoscopic surgery (LS) is a safe and widely used technique. During LS, carbon dioxide insufflation may produce significant hemodynamic and ventilatory consequences, such as elevated intra-abdominal pressure (IAP) and hypercarbia. Splanchnic and cardiovascular blood flow can be affected by the elevated IAP, which can result in ischemia in the splanchnic region prior to hemodynamic changes. Changes in gastric pH may be an early precursor of changes in splanchnic blood circulation. This study investigated the relationship between gastric pH measurement and IAP in patients undergoing LS.

Methods: This study included 49 patients aged 18–65 years with American Society of Anesthesiologists (ASA) physical status I – III who were undergoing elective laparoscopic cholecystectomy. A gastric pH tonometer probe was applied using an orogastric catheter. Simultaneously, insufflation pressure, cardiac apex beat (CAB), and mean arterial blood pressure (MAP) values were recorded. Indirect IAP was then measured through the bladder. Measurements were performed at baseline; at 15, 30, and 60 minutes after onset of insufflation (AI 15, AI 30, and AI 60, respectively); and at the end of insufflation (EI). Two pH measurements were obtained with a gastric tonometer pH probe, using an automated function of the gastric tonometer to improve measurement reliability.

Results: IAP was significantly higher than baseline at AI 15, AI 30, AI 60, and EI (p<0.001). The pH_1 and pH_2 levels were significantly lower at AI 15 and AI 30, compared with baseline (p<0.001). There were no significant differences between pH_1 and pH_2 measurements at AI 60 and EI. Compared with baseline, CAB was significantly lower at AI 15, AI 30, AI 60, and EI (p=0.001, p<0.001, p=0.006). There were no statistically significant differences in MAP changes at any time point.

Conclusion: Elevated IAP caused by CO_2 insufflation during LS led to reductions of pH_1 and pH_2. There was a correlation between gastric pH measurement and IAP. Measurement of gastric pH may be useful to assess blood circulation in the splenic area during LS.

Keywords: elevated intra-abdominal pH; gastric pH; laparoscopic surgery.

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Laparoscopic surgery (LS) has become a preferred modality due to its advantages of minimal invasiveness, ability to mobilize the patient within a short time, and reduction of the period of hospitalization.[1] During LS, CO_2 is used for intraperitoneal gas insufflation; high insufflation pressures are needed for good surgical view. However, elevated insufflation pressure and the presence of CO_2 itself may present some problems. Respiratory and cardiovascu-

lar changes caused by elevated IAP are well-known.[1] Although difficult, it is important to identify changes in microcirculation that are caused by elevated IAP, even when hemodynamic parameters are within normal ranges.[2]

Splanchnic and cardiovascular blood flow can be affected by elevated IAP. After insufflation, cardiac output and blood flow in the superior mesenteric artery and portal vein are progressively reduced; they return to pre-insufflation levels following deflation. Hepatic arterial blood flow does not change significantly, possibly due to compensatory mechanisms for the maintenance of hepatic blood flow. Mechanical compression of the splanchnic capillary beds due to elevated IAP may reflect elevated systemic vascular resistance.[2]

The splanchnic circulation receives 30% of cardiac output, resulting in regional storage. Circulation disorder primarily results in vasoconstriction in the splenic area. Thus, splenic circulation and mucosal pH may be impaired, although hemodynamic parameters are within the respective normal ranges.[1–3] Gastric tonometry is a method for indirect measurement of splenic circulatory disorder, based on gastric pH.[2, 3] The present study was performed to investigate the relationship between gastric pH measurement and IAP in patients undergoing LS in our hospital.

Methods

Approval for this prospective study was obtained from the Ethics Committee, formed in conjunction with the Anesthesia and Reanimation Clinic and General Surgery Clinic of Sisli Hamidiye Etfal Training and Research Hospital (approval no. 911-2015). All included patients provided written and verbal informed consent to participate.

Inclusion and exclusion criteria

This study included 50 patients aged 18–65 years with American Society of Anesthesiologists (ASA) physical status I–III, who were undergoing elective laparoscopic cholecystectomy. Patients were excluded from the study if they met any of the following criteria: refusal to participate, pregnancy, advanced cardiac or respiratory disease, alkaline reflux gastritis or gastroesophageal reflux, alcohol or drug dependence, neuropsychiatric disease, metabolic disorders, electrolyte imbalance, severe dehydration or malnutrition, and emergency surgery. Demographic data, including age, sex, weight, height, and ASA physical status were recorded. None of the patients received premedication.

Laparoscopy Technique

All patients underwent intravenous cholangiography before the operation. Four ports were used for the procedure (10, 10, 5, 5 mm). Patients were kept at 30° head-down tilt during CO2 insufflation. After insertion of four cannulas,

the position of the patient was changed to 15°–20° head-up tilt. Standard techniques were used to perform laparoscopic cholecystectomy. Intra-abdominal pressure is adjusted between 12-14 mm Hg. Critical views of safety is of utmost importance to prevent bile duct injury. Clipping of the cystic duct and cystic artery is achieved from 10 mm epigastric port. Gallbladder extraction is generally done from either epigastric or umbilical port.

Anesthesia Care

After each patient had been taken to the operating room, D2 lead ECG, oxygen saturation (SpO_2), and noninvasive arterial blood pressure monitoring were implemented. Vascular hydration was initiated using a 20-gauge angiocath cannula. All patients underwent general anesthesia induction with 1 μg/kg fentanyl, 3 mg/kg propofol, and 0.6 mg/kg rocuronium. Intubation was performed with a cuff-straight classical intubation tube. Anesthesia was maintained with 1%–2% sevoflurane and a mixture of 50% oxygen/50% air. An orogastric catheter was inserted after intubation; its location was confirmed by auscultation. A gastric tonometer pH measurement probe (Trip™; Tonometrics, Helsinki, Finland) was sent 50 cm through the orogastric catheter. Two pH measurements were performed simultaneously and recorded as initial pH values, using an automated function of the gastric tonometer to improve measurement reliability. Cardiac apex beat (CAB), mean arterial pressure (MAP), and SpO_2 values were also recorded simultaneously. A urinary catheter was placed and the patient's urine was evacuated. A transducer for indirect IAP measurement (Holtech Medical, Charlottenlund, Denmark) was also inserted. The transducer was fixed in place at the symphysis pubis. After injection of 70 ml of saline into the bladder, the urinary catheter was clipped and IAP measurement was recorded. The operation was then initiated. Gastric pH, CAB, MAP, and SpO_2 measurements were recorded during the period of intraperitoneal gas insufflation. Insufflation pressures (IP) and IAP measurements made indirectly through the bladder were recorded. All measurements were repeated at 15, 30, and 60 minutes after onset of insufflation (AI 15, AI 30, and AI 60, respectively) and at the end of insufflation (EI) (before extubation); all values were recorded.

Anesthesia was stopped when the operation was completed. Patients whose spontaneous respiration and airway reflexes returned to normal were extubated after neuromuscular blockade antagonization with 0.01 mg/kg atropine and 0.03 mg/kg neostigmine. Patients with Aldrete Recovery Score ≥9 were considered to be stable and were transferred to the postoperative care unit after waking. The duration of anesthesia (time from induction to patient recovery), operation time (time from skin incision to last

suture), and time of insufflation (time from the beginning to the end of CO_2 insufflation) were recorded. All complications related to anesthesia or surgery were recorded.

Statistical Analysis

SPSS 15.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Descriptive statistics are shown as the mean, standard deviation, and minimum, maximum for numerical variables. Differences in numerical variables in the dependent group were examined using the Friedman test because a normal distribution was not present. Relationships between numerical variables were examined by Spearman correlation analysis, because no parametric test was suitable for analysis. In all analyses, $p < 0.05$ was considered to indicate statistical significance.

Results

Overall, 75 patients were assessed for eligibility and 50 patients met the inclusion criteria. During the study period, one patient was excluded from the analysis due to pH metre failure. Finally, 49 patients were included in the analysis. Figure 1 shows a flow diagram of the study. The mean patient age was 45.3±12.4 years. Twenty-six of the 49 patients were men; the remaining 23 patients were women. Mean anesthesia time, mean surgical time, and mean insufflation time were 70.5±15.4, 55.8±16.8, and 44.8±15.7 minutes, respectively. None of the patients had complications related to surgery or anesthesia.

The mean IP, IAP, pH_1, pH_2, CAB, and MAP measurements are presented in Table 1. Variations of IP, IAP, pH_1, pH_2, CAB, and MAP are presented in Table 2. The IAP, pH_1, and pH_2 levels decreased as IP increased. The relationships among IP, IAP,
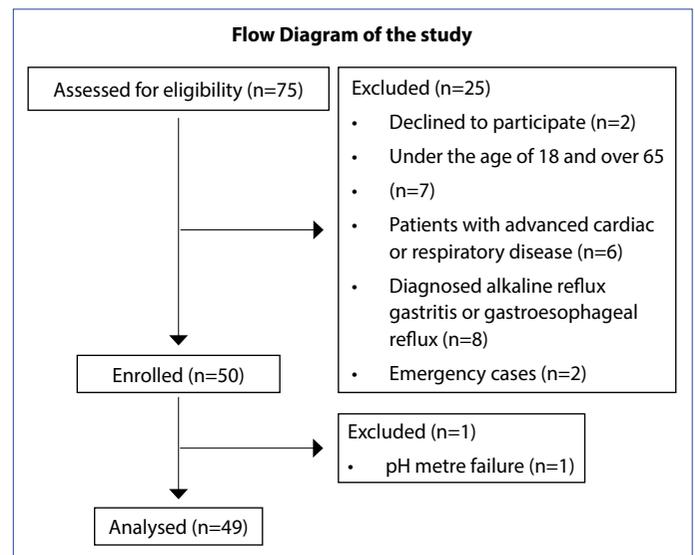
Figure 1. Flow diagram of the study.

pH_1, and pH_2 are presented in figure 2. Elevation of IAP, due to CO_2 insufflation during LS, led to reductions of pH_1 and pH_2. There was an inverse correlation between gastric pH measurement and IAP elevation. IAP was significantly higher than baseline at AI 15, AI 30, AI 60, and EI (all $p < 0.001$). The pH_1 and pH_2 levels were significantly lower at AI 15 and AI 30, compared with baseline (all $p < 0.001$). The pH_2 levels were also significantly lower at EI, compared with AI 60 ($p = 0.005$). Changes in pH1 and pH2 at other time points were not statistically significant (all $p > 0.05$). CAB levels were significantly lower than baseline at AI 15, AI 30, and EI ($p = 0.001$, $p < 0.001$, and $p = 0.006$, respectively). There were no statistically significant differences regarding changes in CAB and MAP at any other time points (all $p > 0.05$).

Table 1. Mean Insufflation pressure (mmHg), mean intraabdominal pressure (mmHg), mean pH_1, mean pH_2 mean measurements of the study group

	IP (mmHg)	IAP (mmHg)	pH_1	pH_2	CAB (per/min)	MAP (mmHg)
Baseline (Mean±SD)	0.0±0.0	4.8±2.2	2.43±1.41	2.45±1.35	83.7±12.3	92.0±15.2
(min-max)	(0-0)	(2.0-10)	(1.3-6.8)	(1.3-7.1)	(60-110)	(64-140)
AI (Mean±SD)	12.3±1.8	12.3±3.7	2.26±1.40	2.32±1.35	77.4±12.6	97.7±15.5
(min-max)	(9-18)	(8-23)	(1.0-6.2)	(1.0-6.2)	(54-110)	(65-134)
AI 15 min (Mean±SD)	12.2±1.9	11.8±3.2	2.18±1.37	2.20±1.26	73.9±12.2	96.8±14.8
(min-max)	(10-16)	(7.0-19)	(1.0-6.2)	(1.2-6.0)	(53-108)	(65-126)
AI 30 min (Mean±SD)	11.9±1.5	11.6±2.8	2.13±1.3	2.12±1.27	72.9±12.0	95.8±13.2
(min-max)	(10-15)	(8.0-18)	(1.0-6.3)	(1.0-5.8)	(50-104)	(70-130)
AI 60 min (Mean±SD)	12.3±1.8	11.6±2.2	1.98±1.19	1.98±1.19	68.4±12.5	96.5±11.9
(min-max)	(10-15)	(8.0-17)	(1.1-6)	(1.0-6.0)	(54-100)	(82-120)
EI (Mean±SD)	0.0±0.0	5.6±1.6	2.51±1.62	2.57±1.55	71.8±13.1	91.0±11.3
(min-max)	(0-0)	(3.0-9.0)	(1.2-7.0)	(1.3-6.8)	(48-98)	(68-120)

AI: After Insufflation; B: Baseline; AI 15 min: 15th minutes of insufflation; AI 30 min: 30th minutes of insufflation; AI 60 min: 60th minutes of insufflation; EI: End insufflation; CAB: Cardiac Apex Beat; MAP: Mean Arterial Pressure; IP: Insufflation pressure; IAP: Intraabdominal pressure.

Table 2. Variations of pH_1, pH_2, Cardiac Apex Beat and Mean Arterial Pressure over time

	pH_1 p	pH_2 p	CAB p	MAP p
AI vs. B	<0.001	0.001	0.001	0.046
AI 15 min vs B	<0.001	<0.001	<0.001	0.079
AI 30 min vs B	<0.001	<0.001	<0.001	0.118
AI 60 min vs B	0.020	0.008	0.006	0.119
EI vs. B	0.906	0.417	<0.001	0.801
AI 15 min vs EI	0.110	0.011	0.042	0.746
AI 30 min vs. AI 15 min	0.719	0.297	0.228	0.446
AI 60 min vs. AI 30 min	0.675	0.755	0.482	0.501
EI vs. AI 60 min	0.075	0.005	0.698	0.047

AI: After Insufflation; B: Baseline; AI 15 min: 15th minutes of insufflation; AI 30 min: 30th minutes of insufflation; AI 60 min: 60th minutes of insufflation; EI: End insufflation; CAB: Cardiac Apex Beat; MAP: Mean Arterial Pressure.
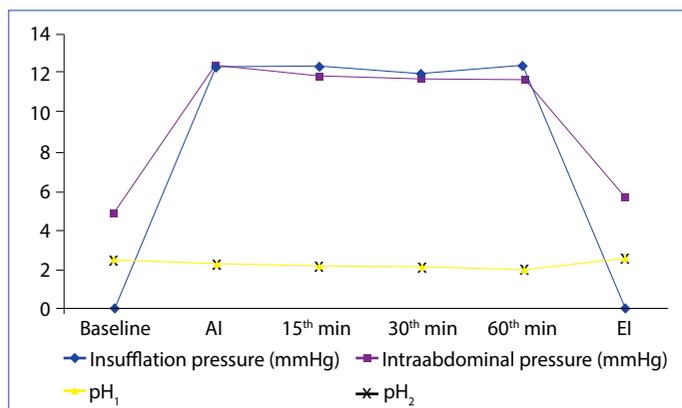
Figure 2. The relationships among IP, IAP, pH_1, and pH_2.

Discussion

We conducted a prospective study in a cohort of 49 patients undergoing laparoscopic cholecystectomy surgery. During the insufflation phase, gastric pH measurements were obtained. Our results demonstrated that elevation of IAP, due to CO_2 insufflation during LS, led to reductions of pH_1 and pH_2. There was an inverse correlation between gastric pH measurement and IAP elevation.

The term splanchnic circulation refers to all blood flow originating from the celiac, superior mesenteric, and inferior mesenteric arteries, which is widely distributed to all abdominal viscera and important organs (e.g., spleen, liver, intestine, omentum, and pancreas). Thus, the splanchnic circulation can act as a site of cardiac output regulation, as well as a blood reservoir. Therefore, evaluation of splanchnic circulation is very important. Notably, small bowel perforations due to ischemia after laparoscopic cholecystectomy have been reported in the literature. Therefore, studies in this field are always important.[4]

Mucosal pH measurement is an indicator of direct splanchnic blood flow and oxygen consumption. Reductions of pH measured using a gastric tonometer are correlated with reductions of blood flow and oxygen consumption; they may constitute a sensitive and specific indicator of mucosal ischemia.[5-7]

In a meta-analysis involving measurement of gastric mucosal pH in critically ill patients, Zhang et al.[8] showed that gastric pH had important prognostic value in early diagnosis and in reducing mortality. In a review regarding gastric tonometry, Taylor et al.[9] emphasized that measurement of gastric pH is helpful in early diagnosis of tissue oxygenation and end-organ damage in patients in the intensive care unit. They suggested that splanchnic ischemia may be the first indicator of shock. Recent findings indicated that intramucosal pH measurement is a simple, noninvasive monitoring technique, which is useful for guiding treatment and improving survival in critically ill patients.[9]

These data suggest that information regarding splanchnic circulation can be obtained using the same technique in LS procedures, where assessment of organ perfusion is important. Although blood pressure, heart rate, and urine output may be normal in LS, splanchnic blood circulation may be affected by various factors (e.g., anesthesia, hypoxia, and hypercapnia). The relationships between intestinal lesions and clinical parameters in IAP, as well as their safety thresholds, remain unknown.[10]

One of these factors comprises the elevation of IAP caused by CO_2 insufflation during LS. Elevated CO_2 insufflation pressure results in reduction of splanchnic blood flow. Especially at insufflation pressures >20 mmHg, venous return is disrupted, cardiac output decreases, and vascular resistance increases.[1, 11, 12] Vasoconstriction occurs in the splanchnic area prior to hemodynamic changes; splanchnic ischemia may be the first precursor of reductions in microcirculation. Knolmayer et al. performed gastric pH measurement in an intraperitoneal pig model between 8–18 mmHg; they compared the results with cardiac output, wedge pressure measurement, mixed venous blood gas, and lactate levels from the pulmonary artery catheter.[13] The results showed that gastric pH change is an early indicator of ischemia. In a comparison of laparoscopic cholecystectomy with open surgical technique, Eleftheriadis et al.[14] used transcutaneous laser-Doppler flowmetry to evaluate liver microcirculation; they also performed simultaneous gastric pH measurement. Notably, Eleftheriadis et al. found deterioration of liver microcirculation in LS and reductions of concurrent gastric pH measurements. In the present study, CAB measurements showed reductions at all time points after onset of insufflation compared to baseline; no differences were

found in mean arterial pressures. Reductions of CAB may be correlated with anesthesia; this change is statistically, but not clinically, significant. Therefore, we cannot state that hemodynamic changes were not present in pneumoperitoneum. However, gastric pH values decreased with the onset of insufflation, compared to baseline measurements; this suggested that gastric pH measurement may provide early signs of splanchnic ischemia. Correa-Martin et al. increased IAP at 20 and 30 mmHg by CO_2 insufflation in pigs for 5 hours;[15] they observed a reduction of gastric pH at 30 mmHg at 90 minutes, whereas they observed an elevation of lactate level only at 180 minutes. Therefore, they considered gastric pH measurement to be a more sensitive means of evaluating splanchnic hypoperfusion. Caldwell et al. showed that intramucosal pH decreased to 7.14 at IAP >20 mmHg; moreover, intramucosal pH decreased to 6.98 at IAP >40 mmHg.[11] However, the values in those studies were much higher than the pressures currently used in LS.

Çelik et al. examined the effects of five insufflation pressures (8, 10, 12, 14, and 16 mmHg) on gastric pH in a study of patients undergoing laparoscopic cholecystectomy; they found no differences between groups.[16] Moreover, they found that insufflation pressures of 8–16 mmHg used during LS were safe values at which splanchnic circulation was not impaired. Thaler et al.[17] reported no changes in intramucosal pH when IAP was maintained below 15 mmHg. Our findings differed from those of Çelik et al. and Thaler et al., because we found a reduction of gastric pH after insufflation, even at pressures as low as 12 mmHg.[16, 17] The differences among studies may be related to the techniques used; notably, Çelik et al.[16] and Thaler et al.[17] used gastric tonometers, whereas we used pH meters for measurement. The gastric tonometer measures the CO_2 levels and calculates the pH with the Henderson–Hasselbalch equation; therefore, it is an indirect means of measuring intragastric pH.[17] However, we measured the pH directly using a pH meter, which is more sensitive than a tonometer for detection of pH changes.

In the present study, the lowest and highest insufflation pressures were 8 mmHg and 18 mmHg; the average pressure was 12 mmHg. IAPs measured after insufflation ranged from 7 to 23 mmHg, with a mean of 11.6 mmHg. Although LS was performed at low pressures, significant pH changes were detected at all time points after onset of insufflation, compared to baseline. There was a correlation between IAP elevation and pH change.

Luo et al.[18] evaluated the effects of prolonged pneumoperitoneum on oxidative stress and bowel ischemia in robotic-assisted laparoscopic radical prostatectomy for up to 4 hours; they found an elevation of malondialdehyde level

and a reduction of gastric pH level from the onset of insufflation. In that study, an insufflation pressure of 15 mmHg was used; ischemic changes continued until 2 hours after the end of insufflation. In the present study, we used an average of 44 minutes of insufflation and found no correlation between the duration of insufflation and pH change. We found that the pH values returned to their initial values at 15 minutes after the end of insufflation.

Some studies have examined the effects of open surgery and LS on splanchnic circulation based on oxidative stress response and gastric pH changes; they found no significant differences between the two techniques.[17, 19, 20] Our study had some limitations in that there was no comparison group, the number of patients was low, short-term LS was performed, and gastric tonometry was not used for measurement.

Conclusion

Elevation of IAP, due to CO_2 insufflation during LS, led to reductions of pH_1 and pH_2. There was a correlation between gastric pH measurement and IAP elevation. Gastric pH measurement may be useful during LS to evaluate blood circulation in the splanchnic area.

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