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Intraabdominal Pressure and Gastric Intramucosal pH: Is There an Association?

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Abstract. This study evaluated the potential association between increased intraabdominal pressure (IAP) and abnormally low gastric intramucosal pH (pHi) ($\leq$ 7.32) in postoperative patients and assessed its effect on patient outcome. Altogether 73 patients undergoing major abdominal surgery over a 9-month period were studied prospectively. All underwent gastric tonometry and intravesical IAP measurements three time daily. An IAP of $\geq$ 20 mmHg and a pHi of $\leq$ 7.32 were considered abnormal. The development of the following complications were also documented: hypotension [mean aortic pressure (MAP) < 80 mmHg], abdominal sepsis, renal impairment, and death. The median APACHE II score was 16 (range 5–34). Twenty-two patients had upper gastrointestinal (GI) surgery, 27 lower GI surgery, and 24 aortic surgery; 44 of these patients underwent emergency surgery. Abnormal pHi ($\leq$ 7.32) occurred in 36 patients while on the intensive care unit. Compared to patients with normal pHi, abnormal pHi patients were 11.3 times (3.2–43.5) [odds ratio ± 95% CI] more likely to have an increased IAP. Abnormal pHi was significantly associated with hypotension ($\chi^2 = 6.8$; $p = 0.009$), sepsis ($\chi^2 = 3.7$; $p = 0.06$), renal impairment ($\chi^2 = 28.3$; $p = 0.0000001$), relaparotomy ($\chi^2 = 4.1$; $p = 0.04$), and death ($\chi^2 = 9.7$; $p = 0.002$). This study demonstrated a significant clinical association between increased IAP and abnormal pHi. An abnormally low pHi was associated with poor outcome.

Since the popularization of gastric tonometry by Fiddian-Green and colleagues it has become an important indicator of visceral perfusion [1–5]. Intraabdominal pressure (IAP) exerts an important influence on visceral and renal perfusion [6–8]. It is uncertain as to whether there is a clinical association between IAP and gastric intramucosal pH (pHi). Animal work has shown that an increase in abdominal pressure decreases splanchnic perfusion [8]. Pusajo and colleagues, in a study of 10 patients with increased IAP ($\geq$ 10 mmHg) were probably the first to suggest that a correlation between IAP and pHi exists [9]. The present study evaluated the association between pHi and IAP in a sample of surgical intensive care patients.

Methods

A prospective study of consecutive patients undergoing major abdominal surgery and admission to the intensive care unit (ICU) of the Liverpool Hospital (a 400 bed university hospital) was undertaken. Patients who had transferred to the ICU from general surgical wards or other hospitals who had undergone abdominal surgery within the preceding 2 weeks were also included. The study was approved by the South Western Sydney Area Health Service Ethics Committee. Among 100 consecutive patients eligible for the study, 27 were excluded from the study. They included patients who did not require urinary catheters (n = 3), who failed to have a gastric tonometer placed (n = 14), who had a gastric tonometer but no reading (n = 7), who had an esophagogastric anastomosis (n = 2), or who had esophageal varices (n = 1). All patients were followed until hospital discharge or death. Daily APACHE II scores were calculated [10]. Renal impairment was defined as a postoperative serum creatinine concentration of > 130 μmol/L, or an increase in serum creatinine of > 100 μmol/L within 72 hours of surgery [11]. Oliguria was defined as < 600 ml of urine over a 24-hour period [12].

For the purposes of the study, increased IAP was defined as a pressure of $\geq$ 20 mmHg [13]. The technique used for IAP measurement was a modification of the Kron technique [14, 15]. A T-piece (Surgicare Proprietary, Rockdale, 2216 NSW, Australia) bladder pressure device was attached to the indwelling catheter, and a pressure transducer was connected to the system. The IAP was recorded every 8 hours.

The gastric tonometer was inserted in the operating theater or immediately after admission to the ICU. The position of the tube was checked radiologically, and the tonometer balloon was primed with 2.5 ml of normal saline and allowed to equilibrate for 30 minutes. Once equilibrated, the tonometer balloon was aspirated (the first 1 ml being discarded), and the partial pressure of carbon dioxide (PCO_2) in normal saline was determined using a blood gas analyzer (Corning 278; Corning, Medfield, MA, USA). Simultaneously an arterial blood specimen was obtained and the arterial bicarbonate concentration measured. The gastric mucosal pHi was then calculated by substituting the tonometrically measured PCO_2 and the arterial bicarbonate concentration into the Henderson-Hasselbalch equation. Measurements were continued for as long as there was a clinical indication for the nasogastric tube to remain in situ. A pHi of $\leq$ 7.32 was considered to be abnormal [16, 17]. The ICU does not routinely administer H_2 antagonists to its patients [18].

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Table 1. Comparison of patients with normal and abnormal pHi.

No.	pHi	Age (years)	Sex		Type of surgery		APACHE II score on admission
			Male	Female	Emergency	Elective	
36	≤ 7.32	61	25	11	24	12	19
37	> 7.32	63	22	15	20	17	11

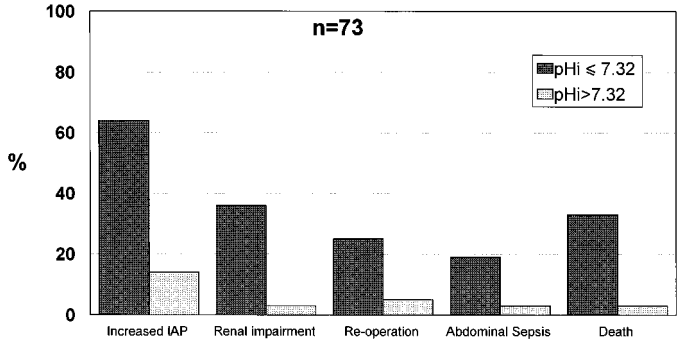

Fig. 1. Complications in patients with normal and abnormal pHi.

Statistical analysis was carried out using EPIINFO Version 6 (USD, Stone Mountain, GA, USA). Significant differences between groups were assessed by the Student *t*-test, chi-square (Yates corrected) test, and Fisher exact tests where appropriate. Odds ratios with 95% confidence intervals were used for risk estimation. The association between pHi and IAP adjusted for the patient's underlying disease on admission to the ICU was calculated using the Mantel-Haenszel weighted odds ratio. Patients were stratified into two groups according to their APACHE II score (≤ 20 and > 20) on admission. Statistical significance was set at the $p < 0.05$ level. Values for continuous variables are reported as means and standard deviations.

Results

There were 73 patients, mean age 62 years (range 18–83 years) studied; 47 of the 73 (64%) were male. Of these patients, 24 had undergone aortic surgery, 22 lower GI surgery, 17 upper GI surgery, and 10 exploratory surgery; 44 of the 73 (60%) had undergone emergency surgery. The mean ± SD APACHE II admission score was 16 ± 9 (range 3–40). A pHi ≤ 7.32 occurred in 36 patients. In 29 of 36 (80.5%) of these patients the first abnormal pHi occurred on the first reading in the ICU. In three patients the first abnormal reading was on day 2, in two on day 3, and in two after day 8. An IAP reading of ≥ 20 mmHg occurred in 28 patients, 22 (79%) of whom had abnormal pHi readings. An elevated IAP was present on the first ICU admission reading in 21 of 28 patients: in two patients on days 2 and 3 and in four patients after day 8. The predominant reason for increased IAP was tissue edema or ileus in 24, ascitic fluid in 2, and hemorrhage in 2. Taking 15 mmHg as a cutoff point, 31 patients had an IAP of ≥ 15 mmHg.

Compared to patients with normal pHi, abnormal pHi patients were 11.3 times (95% CI 3.2–43.5) more likely to have increased IAP. The adjusted odds ratio for the association between pHi and IAP was 1.4 (95% CI 0.4–5.1). This result shows that the patient's underlying disease is an important confounder and must be taken into consideration when examining the relation between pHi and IAP. Taking a lower level as a cutoff for increased IAP (≥ 15 mmHg), the odds ratio of having an abnormal pHi was 14.7 (4.0–57.7). Abnormal pHi was significantly associated with hypotension ($\chi^2 = 6.8$; $p = 0.009$), sepsis ($\chi^2 = 3.7$; $p = 0.06$), renal impairment ($\chi^2 = 28.3$; $p < 0.001$), relaparotomy ($\chi^2 = 4.1$; $p = 0.04$), and death ($\chi^2 = 9.7$; $p = 0.002$). Patients with a normal or abnormal pHi are compared in Table 1, and the frequency of complications are shown in Figure 1. A detailed breakdown of the odds ratio for the development of increased IAP and complications in the presence of pHi ≤ 7.32 are shown in Table 2. Nine patients required relaparotomy, eight for proved intraabdominal sepsis. Eight of the nine patients had an abnormal pHi. Renal impairment was significantly greater in patients with abnormal pHi. There were 13 deaths, and 12 of these patients had an abnormal pHi.

Table 2. Odds ratios for the occurrence of increased IAP and complications in patients with pHi ≤ 7.32.

Condition	Odds ratio	95% CI	χ^2 df = 1	*p*
IAP ≥ 20 mmHg	11.3	3.2–43.5	17.5	< 0.01
MAP < 80 mmHg	6.4	1.5–32.2	6.8	< 0.01
Sepsis	8.7	0.97–198.9	3.7	0.06
Renal impairment	63.7	7.6–1396.9	28.3	< 0.01
Relaparotomy	5.8	1.0–42.9	4.1	0.04
Death	18.0	2.2–394.9	9.7	< 0.01

Discussion

This study has identified that there is a strong association between abnormally low pHi readings and increased IAP. Pusajo et al. were probably the first to describe this association in a small number of patients [9], but they used 10 mmHg as indicative of increased IAP, a figure that has not been supported elsewhere. The present study enrolled a larger number of patients, and IAP readings of 15 and 20 mmHg showed a similar association with an abnormal pHi of ≤ 7.32. The underlying disease in patients was found to be an important confounder in this association. In the present study the stratified analysis used only the ICU admission APACHE II and IAP values and thus did not take into account seven (26%) of the patients who developed an increased IAP later in their ICU stay.

The current study identified that the prevalence of abnormal pHi readings present on ICU admission was 80.5%. Mythen and Webb found that 63% of patients undergoing major elective surgery had an abnormally low pHi at the end of surgery [18]. In our series 60% of patients underwent emergency surgery, which may explain the greater prevalence of abnormal pHi readings than was found in the Mythen and Webb study. IAP was ≥ 20 mmHg

in 28 of 73 (38%) patients on admission to the ICU after major abdominal surgery. If one were to take an IAP of ≥ 15 mmHg as the cutoff point, a similar percentage (70.9%) would have been abnormal on the first ICU reading. These results suggest that there is a need for more meticulous management of patients before they arrive in the ICU.

Global indices of adequacy of tissue perfusion such as blood pressure, pulse rate, urine output, arterial pH, and lactate may not reflect aberrations of regional perfusion [19]. Visceral perfusion may be of the utmost importance as the role of increased intestinal permeability and bacterial translocation in the pathogenesis of multiple organ failure is further clarified [20]. Increases in IAP have been shown to reduce visceral and renal perfusion [7, 8], which may exacerbate an already compromised GI tract. This study has shown a significant statistical association between abnormal pHi and increased IAP, but it was beyond our scope to identify which is the antecedent causal factor. In this series 10% of patients developed an abnormally low pHi prior to an increase in IAP. Physiologically, it would make sense if the tissue edema was the result of visceral hypoperfusion.

This study showed that abnormal pHi is an indicator of increased risk of death and a predictor of major complications. The study identified a strong association between IAP and pHi. Further clinical studies are needed.

Résumé

Dans cette étude on a évalué les effets sur l'évolution de l'association néfaste d'une pression intrapéritonéale (PIP) augmentée et un pHi abaissé (≤ 7.32) chez l'opéré. Pour cela nous avons étudié prospectivement 73 patients ayant eu une chirurgie abdominale majeure pendant une période de 9 mois. La PIP a été mesurée trois fois par jour grâce à une sonde manométrique intragastrique et intravésicale. On a considéré comme anormaux une PIP ≥ 20 mm Hg et un pHi ≤ 7.32. On a enregistré les complications suivantes: hypotension (pression artérielle systolique < 80 mm Hg), sepsis abdominal, insuffisance rénale et décès. La médiane du score APACHE II était de 16 (extrêmes 5-34). Vingt-deux patients ont eu une chirurgie du tube digestif supérieur, 27 une chirurgie du tube digestif inférieur, 24 une chirurgie aortique, et parmi ceux-ci, 44 ont eu une chirurgie d'urgence. Un pHi anormal (≤ 7.32) a été retrouvé chez 36 patients en soins intensifs. Comparés aux patients avec un pHi normal, les patients ayant un pHi anormal avaient 11.3 fois plus de chances (3.2–43.5) [odds ratio ± 95% CI] d'avoir une PIP augmentée. Une PIP anormale était associée à une hypotension ($Chi^2 = 6.8$, $p = 0.009$), à un sepsis ($Chi^2 = 3.7$, $p = 0.06$), à une insuffisance rénale ($Chi^2 = 28.3$, $p = 0.0000001$), à une ré - intervention ($Chi^2 = 4.1$, $p = 0.04$) et au décès ($Chi^2 = 9.7$, $p = 0.002$). Cette étude démontre qu'il existe une association significative entre une PIP augmentée et un pHi anormal et ce pHi anormalement bas est associé à une évolution défavorable.

Resumen

El presente estudio evaluó la asociación entre la presión intraabdominal (PIA) y un pHi bajo (< 7.32) en pacientes postoperados y determinó su efecto sobre la evolución final del paciente. Setenta y tres pacientes sometidos a cirugía abdominal en un período de 9 meses, fueron estudiados postoperatoriamente. Se practicaron mediciones de tonometría gástrica y PIA intravesical tres veces diarias. Una PIA de > 20 mmHg un pHi de <7.32 fueron considerados anormales. El desarrollo de las siguientes complicaciones también fue documentado: hipotensión (PAM < 80 mmHg), sepsis abdominal, alteración renal y muerte. El índice APACHE II medio fue 16 (rango 5–34). Veintidós pacientes fueron sometidos a cirugía gastrointestinal superior, 27 a cirugía gastrointestinal inferior, 24 a cirugía aórtica y de éstos 44 tuvieron operación de urgencia. Se registró pHi anormal (< 7.32) en 36 pacientes mientras permanecieron en la UCI. En comparación con los pacientes con pHi normal, aquellos con pHi anormal demostraron ser 11.3 veces (3.2–43.5) [relación odds ñ9.5% CI] más susceptibles a tener PIA aumentada. El pHi anormal probó estar significativamente asociado con hipotensión (x23D6.8 p3D0.009), sepsis (x23D3.7 p3D0.06), disfunción renal (x23D28.3 p3D0.0000001), relaparotomía (x23D4.1 p3D0.04) y muerte (x23D9.7 p3D0.002). Este estudio demostró una significativa asociación clínica entre una PIA aumentada y un pHi anormal; el pHi anormalmente bajo se asoció con mala evolución clínica.

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Invited Commentary

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This study provides further evidence that acutely increased intra-abdominal pressure (IAP) is potentially devastating and that its severity can be estimated by measuring gastric mucosal pH (pHi). In addition to intestinal ischemia (and necrosis), these patients can develop renal failure, are difficult to ventilate with high peak inspiratory pressures [1, 2], and may have increased intracranial pressure as well [3–5], all of which improve with abdominal decompression. As the authors point out, increased urinary bladder pressure is the most sensitive and simplest technique for detecting this problem. However, they did not mention whether they used it as an indication for relaparotomy and abdominal decompression.

Evidence suggests that there may also be a chronic abdominal compartment syndrome, as morbidly obese patients have been found to have significantly increased IAP that may be associated with chronic venous stasis disease, gastroesophageal reflux, urinary stress incontinence, increased risk of incisional hernia, idiopathic intracranial hypertension (pseudotumor cerebri), and possibly systemic hypertension [6–8]. In this situation, gastric pHi may be a more accurate reflection of a pathologically increased IAP. Finally, cardiac filling pressures may be misleading in patients with either an acutely or chronically increased IAP, as it increases the pleural pressure, necessitating increased central venous, pulmonary artery, and wedge pressures. These individuals may require high filling pressures to maintain an adequate cardiac output [9], which if impaired can be another cause for intestinal ischemia and a low gastric pHi as noted in the study by Sugrue and colleagues.

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