Effect of ranitidine on basal and bicarbonate enhanced intragastric PCO₂: a tonometric study

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Abstract
A high intragastric PCO₂ (iPCO₂), determined tonometrically, is the main factor participating in a low gastric intramucosal pH (pHi) and may point to gastric mucosal ischaemia. iPCO₂ might also increase, however, after buffering of gastric acid by bicarbonate; the magnitude of this effect and the efficacy of H₂ blockers to prevent it are unclear. Ten healthy volunteers (20–24 years) were studied at baseline and after oral ingestion of 500 mg sodium bicarbonate. The same test was carried out one hour after intravenous injection of 100 mg ranitidine. A glass pH electrode for continuous gastric juice pH measurements and a Tonomitor catheter were placed 10 cm distally from the gastro-oesophageal junction. iPCO₂ was measured in saline boluses, infused at 30 minute intervals in the balloon at the tip of the Tonomitor. Before ranitidine was given, basal iPCO₂ (mean (SD)) was 8.40 (2.53) kPa, and increased to 19.20 (5.87) kPa after sodium bicarbonate (p<0.001). After ranitidine, the gastric juice pH increased from 1.8 (0.9) to 5.6 (1.3) (p<0.05), while basal iPCO₂ was 5.60 (0.67) kPa (p<0.01) and did not change after sodium bicarbonate (6.27 (2.27 kPa)). iPCO₂ values after acid secretion suppression were similar to those in capillary blood (5.60 (0.40 kPa)). The difference between intragastric and blood PCO₂ during normal acid secretion probably results from buffering of gastric acid by bicarbonate, rather than by duodenogastric reflux or saliva entering the stomach. During acid secretion suppression, intragastric equals blood PCO₂, even after oral ingestion of sodium bicarbonate. Hence, acid secretion inhibition is mandatory for proper assessment of iPCO₂ and pHi as specific measures of the adequacy of gastric mucosal blood flow.

 Patients and methods
We studied 10 healthy volunteers, 20–24 years of age, who were not receiving any treatment. The pH of the gastric fluid was measured continuously, using a combined glass electrode with integral Ag/AgCl reference electrode near the tip (Ingold 440, Ingold Messtechnik, Urdorf, Switzerland). Before introduction, the electrode was calibrated at pH 4.0 and 7.0, and this was repeated after withdrawal. The electrode was connected to a receiver, storing the mean pH for every six second period. These data were stored in a hospital developed microcomputer system for pH analysis. The electrode was introduced through the nose and advanced under direct pH measurement until the tip was 10 cm below the gastro-oesophageal junction, identified by an abrupt pH decrease as the probe entered the stomach.

 A Tonomitor (Tonometrics Inc, Bethesda, Maryland, USA), sigmoid model, consisting of a silastic, CO₂ impermeable nasogastric tube with a silicone CO₂ permeable balloon at the tip, was placed nasogastrically at the same
distance from the nose as the pH electrode. Measurement of iPCO₂ was performed by aspirating 2.5 ml saline, installed in the balloon for exactly 30 minutes, using a standard blood gas analyser (Corning 178, Ciba-Corning, Houten, The Netherlands). The samples were analysed within fifteen minutes after aspiration. Because complete equilibration of CO₂ in the Tonomitor and surrounding fluid takes about one hour, a correction factor has to be applied. Using different fluids and PCO₂ values the correction factor for 30 minutes equilibration was shown to be 1.29.16 In the midgut of dogs this correction factor proved valid.16 Thus, iPCO₂=1.29×measured PCO₂.

A capillary blood sample from a finger was used to determine the actual bicarbonate content and PCO₂, using the blood gas analyser. Gastric intramucosal pH was calculated according to the Henderson-Hasselbalch equation, using iPCO₂ (in mm Hg) and the bicarbonate content of the capillary blood: pH=6.1+log((bicarbonate/(0.04×iPCO₂))).

The validity of this calculation was established in animal models using submucosally tunnelled pH electrodes.17 The coefficient of variation for three successive measurements of intragastric PCO₂ is 1.12 (0.8)%, according to published works.17

Sodium bicarbonate 500 mg was dissolved in 50 ml water. The volunteers drank the solution in 10 minutes while in the left supine position to prevent immediate passage through the pylorus.

PROTOCOL

The protocol was approved by the hospital committee on ethics. After introduction of the pH probe and the Tonomitor (t=0 minutes) we measured iPCO₂ from 0 to 30 minutes (period I), and took a capillary blood sample at t=20 minutes. In some pilot experiments introduction of the pH probe and Tonomitor led to abdominal discomfort and, thus, possibly duodenogastric reflux. Therefore, we chose to measure basal iPCO₂ from 60 to 90 minutes (period II); a capillary blood sample was obtained at t=80 minutes. From 90 to 100 minutes the sodium bicarbonate solution was slowly swallowed. To determine the immediate effects of this buffer we measured iPCO₂ from 90 to 120 minutes (period III), for late effects we measured from 120 to 150 minutes (period IV). Then, at t=150 minutes, 100 mg of ranitidine was given intravenously. This dose sufficiently suppresses acid section within one hour, and this lasts for at least four hours.18 From 210 to 240 minutes (period V) we measured basal iPCO₂ during acid secretion suppression and took a capillary blood sample at t=230 minutes. From 240 to 250 minutes sodium bicarbonate was ingested with measurement of iPCO₂ from 240 to 270 minutes and from 270 to 300 minutes (periods VI and VII).

For calculation of pH i the bicarbonate content in blood taken at t=20 for period I, at t=80 for periods II, III, and IV, and t=230 for periods V, VI, and VII was used. We chose not to draw blood samples for all study periods because it can be calculated that the maximal rise in blood bicarbonate after oral ingestion of 500 mg of sodium bicarbonate, approximately 0.2 mmol/l, would not exceed the error of its measurement.

We calculated mean, maximum, and minimum pH for every 30 minute period, time matched with measurement of iPCO₂. We calculated duration and magnitude of alkaline shifts, defined as a gastric juice pH profile >4.0, during period I and II.19,20 For graphic presentation, we calculated the mean (SD) pH for 90 second periods.

STATISTICAL ANALYSIS

The analysis of variance was used to test for period differences. Thereafter, differences between periods were examined with the paired Student’s t test. To examine relations, linear regression analysis was used. A p<0.05 was considered statistically significant. Data were expressed as mean (SD).

Results

GASTRIC JUICE pH

The gastric juice pH (Fig 1) differed between periods (p<0.001). Between period I and II, however, no difference in mean gastric juice pH (1.8 (0.7), and 1.8 (0.9), respectively, p>0.05), in maximum pH (2.97 (1.0) and 2.79 (1.5), p>0.05), or in time of pH>4.0 (0.3 (0.9) and 1.2 (2.7) minutes, respectively) was found. Ingestion of sodium bicarbonate increased gastric juice pH to 3.5 (2.4) in period III (p<0.05 vs II) with a maximum pH of 5.2 (1.6); the mean duration of gastric juice pH>4 was 12 (10) minutes.

After ranitidine was given, gastric juice pH in period V was 5.6 (1.3) (p<0.001 vs period

Figure 1: Mean (SD) of the mean of 90 second gastric juice pH values of individual volunteers (n=10). Period I, II, and V: basal (fasting) period, period III and VII: during oral ingestion of 500 mg sodium bicarbonate, period IV, and VII: after ingestion of sodium bicarbonate. The gap between period I and II was used to obtain an optimal steady state situation after introduction of the pH electrode and Tonomitor. Immediately after period IV, ranitidine was given, and 60 minutes was taken for effective acid secretion suppression. 'B': sodium bicarbonate, 'R': 100 mg ranitidine given intravenously.
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II); the minimum pH was <4·0 in 4 of 10 volunteers. After ingestion of sodium bicarbonate, the gastric juice pH in period VI increased to 7·1 (0·7) (p<0·005 v period V); in all volunteers the minimum pH was >4·0. In period VII the gastric juice pH was 6·7 (0·7) (p<0·05 compared with period VI, p<0·01 compared with period V); in 2 of 10 volunteers the minimum pH decreased below 4·0.

iPCO₂
iPCO₂ differed (p<0·001) between periods (Fig 2). Before ranitidine, during period II, basal PCO₂ was 8·40 (2·53) and rose to 19·20 (5·87) kPa in period III after oral sodium bicarbonate (p<0·001). This increase in iPCO₂ was shortlived, with an iPCO₂ of 10·00 (1·71) kPa in period IV (p<0·001 compared with period III, p<0·05 compared with period II). After inhibition of acid secretion, basal iPCO₂ in period V was 5·60 (0·67) kPa (p<0·005 compared with II), and 6·00 (2·27) kPa in period VI during ingestion of sodium bicarbonate (p<0·05 v VII). In this period, the two volunteers with the lowest gastric juice pH immediately before sodium bicarbonate was given, 3·6 and 4·6, showed the highest iPCO₂ of 3·87 and 4·53 kPa, respectively. After the sodium bicarbonate, in period VII, iPCO₂ was 6·55 (0·85) kPa (p<0·05 compared with period V).

BLOOD
Blood pH, PCO₂, and bicarbonate content did not change during the study period (Table). Before ranitidine was given, a significant difference between intragastric and blood PCO₂ was found (Fig 3), under basal circumstances (period II) of 2·81 (2·28) kPa (p=0·01), rising to 13·49 (5·75) kPa after sodium bicarbonate ingestion in period III (p<0·001). After ranitidine, the basal iPCO₂ in period V and the PCO₂ during sodium bicarbonate ingestion in period VI were similar to blood PCO₂ (differing by 0·07 (0·81) and 0·45 (2·77) kPa, respectively, p<0·05). In period VII, during which gastric acid secretion recurred in some subjects, a small, but significant difference between intragastric and blood PCO₂ (0·83 (0·95) kPa, p<0·05) was again noticed, however.

iPCO₂ in relation to gastric juice pH
To further delineate the mechanisms underlying the difference in basal iPCO₂ before and after ranitidine we calculated the correlation coefficient between iPCO₂ and mean gastric juice pH, duration, and area under the curve of alkaline shifts, and peak pH in periods I and II. No correlation between iPCO₂ and any of these parameters was found, suggesting that basal iPCO₂ is not affected by bicarbonate from duodenum or oesophagus periodically entering the stomach.

Discussion
Our study in healthy volunteers shows that proper tonometric assessment of iPCO₂, as an index of the adequacy of gastric mucosal blood flow, warrants suppression of acid secretion. After ranitidine, iPCO₂ was similar to blood PCO₂ even during ingestion of 500 mg sodium bicarbonate, mimicking reflux of the bicarbonate produced by the duodenum per hour. Because healthy volunteers have adequate gastric mucosal blood flow, even after acid secretion suppression, the PCO₂ in the gastric mucosa roughly equals blood PCO₂. Thus, for gastric tonometry, an increased iPCO₂, or decreased pHii, would be a valid indicator of mucosal ischaemia, for instance after haemorrhage, sepsis, and arterial occlusion.1–4,22 only if acid secretion is suppressed. The source of intraluminal hypercapnia during hypoperfusion is an increased organ CO₂ content because blood flow is insufficient to remove all produced CO₂.21–25 In addition, in ischaemic cells an excess of hydrogen ions is produced because ATP hydrolysis exceeds ATP synthesis; buffering

Capillary blood gas analysis in 10 healthy volunteers (mean (SD))

<table>
<thead>
<tr>
<th></th>
<th>t=20 (period I)</th>
<th>t=80 (period II)</th>
<th>t=230 (period V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7·40 (0·002)</td>
<td>7·40 (0·01)</td>
<td>7·40 (0·02)</td>
</tr>
<tr>
<td>PCO₂ (kPa)</td>
<td>41·9 (2·4)</td>
<td>42·9 (2·6)</td>
<td>42·9 (3·7)</td>
</tr>
<tr>
<td>PO₂ (kPa)</td>
<td>69·9 (8·0)</td>
<td>65·4 (5·3)</td>
<td>67·7 (8·8)</td>
</tr>
<tr>
<td>HCO₃ (mmol/l)</td>
<td>26·0 (1·7)</td>
<td>25·9 (1·0)</td>
<td>25·6 (1·0)</td>
</tr>
</tbody>
</table>
of these hydrogen ions results in increased production of CO₂. As CO₂ readily diffuses across the gastrointestinal mucosa, \(^{10,27,28}\) the intraluminal PCO₂ will rise during ischaemia.

Our study confirms and extends the findings by Heard et al.,\(^ {14}\) suggesting that suppression of acid secretion decreases basal iPCO₂, but in that study there were no within subject comparisons. As suppression of acid secretion does not affect basal gastric blood flow, the fall in iPCO₂ with H₂ blockade might be explained by less buffering of acid by duodenal or salivary bicarbonate entering the stomach. This is unlikely, however, as analysis of the gastric juice pH data showed no correlation between alkaline shifts and iPCO₂. Therefore, the most probable cause of a higher iPCO₂ during normal \(v\) suppressed acid secretion is either buffering of gastric acid by gastric bicarbonate\(^ {29}\) or buffering of gastric acid by bicarbonate in the first part of the duodenum, followed by reflux of CO₂ through the pylorus, as the iPCO₂ in the duodenal bulb may reach values of 500 mm Hg (or 67 kPa).\(^ {30}\)

Authors using tonometry to assess the adequacy of gastrointestinal blood flow consider the gastric mucosa highly permeable for CO₂. On the other hand, most authors who use luminal PCO₂ to calculate mucosal bicarbonate production\(^ {31-34}\) discard diffusion of PCO₂ from mucosa to lumen, or consider the gastric mucosa hardly permeable for CO₂. Although contradictory at first glance, these views are not incompatible. Under normal circumstances, there is net production of CO₂ in the stomach and duodenum as a consequence of buffering of gastric acid by duodenal bicarbonate.\(^ {30,35}\) This CO₂ diffuses slowly to the surrounding mucosa, with complete equilibration in 240 minutes.\(^ {10,27,29,36}\) When the luminal PCO₂ is lower than mucosal PCO₂, however, as in gastric tonometry with introduction of saline in the intragastric balloon, diffusion of CO₂ from mucosa to lumen is completed within 60 minutes.\(^ {10,27,29,37}\) The cause of this directional difference in diffusion velocity is not clear, but might relate to the high concentration of carbonic anhydrase in the gastric epithelium,\(^ {38}\) facilitating transport of CO₂ from mucosa to lumen.\(^ {39}\) Thus, when performing gastric tonometry, CO₂ diffuses comparatively rapidly from the surrounding mucosa to the saline in the gastric balloon. Conversely, the high intragastric PCO₂ after exogenous sodium bicarbonate, presumably did not lead to severe gastric intramucosal acidosis because the period of increased PCO₂ is too short for complete diffusion of produced CO₂ into the mucosa. Hence, the calculated pH of 6.89 (0.15) overestimates true gastric mucosal acidity. The calculated pH of 7.24 (0.13), however, during steady state CO₂ generation in the presence of acid secretion (period II), compared with the pH after ranitidine (7.41 (0.06) in period V), may signify intramucosal acidosis during acid secretion.

The dosage regimen of ranitidine, needed to ensure adequate suppression of acid secretion for proper tonometric determination of iPCO₂ for long periods, is unclear. In this study, basal iPCO₂ measured one hour after 100 mg ranitidine was given intravenously, roughly equalled blood PCO₂ in all volunteers, even though the gastric juice pH was still <4.0 in 4 of 10. Even during ingestion of 500 mg sodium bicarbonate, the iPCO₂ hardly changed in 8 of 10 volunteers; only in the two volunteers with the lowest gastric juice pH immediately before sodium bicarbonate was given, was an increase in iPCO₂ above blood concentrations seen. Two and a half hours after ranitidine was given intravenously, however, a small, but significant difference between blood and intragastric PCO₂ was noted. Therefore, the usual ranitidine dosage regimen in intensive care patients, 50 mg intravenously at eight hourly intervals, might be insufficient to ensure adequate tonometric measurements.

Figure 3: Difference between iPCO₂ and capillary blood PCO₂ (kPa); values expressed as mean (SD) (n=10). Period I, II, and V: basal (fasting) period, period III and VI: during oral ingestion of 500 mg sodium bicarbonate, period IV and VII: after ingestion of oral sodium bicarbonate. TR: 100 mg ranitidine given intravenously.

Figure 4: Values of the pHs, calculated from iPCO₂ and blood bicarbonate content in individual volunteers (n=10). Period I, II, and V: basal (fasting) period, period III and VI: during oral ingestion of 500 mg sodium bicarbonate, period IV and VII: after ingestion of oral sodium bicarbonate. TR: 100 mg ranitidine given intravenously.
throughout the day. Future studies are needed to establish the adequate acid secretion suppression regimen for proper tonometric measurements of iPCO\textsubscript{2} in critically ill patients.

In conclusion, our results in healthy volunteers show that the proper determination of iPCO\textsubscript{2} as a measure of gastric mucosal P\textsubscript{CO\textsubscript{2}} and thus the adequacy of gastric mucosal blood flow, necessitates suppression of acid secretion. After ranitidine, iPCO\textsubscript{2} equals the P\textsubscript{CO\textsubscript{2}} in capillary blood. The gradient between iPCO\textsubscript{2} and blood P\textsubscript{CO\textsubscript{2}} during acid secretion is probably caused by buffering of gastric acid by gastric mucosal or duodenal bicarbonate.

The support of Giaso (Holland) in supplying Tonometers is kindly acknowledged.

1 Hamilton J, Dawson A, Webb J. Observations upon small gut "mucosal" \textit{pO\textsubscript{2}} and P\textsubscript{CO\textsubscript{2}} in anesthetized dogs. Gastroenterology 1968; 55: 52-60.


