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Effect of temperature on gastric intramucosal P_{CO_2} measurement by saline and air tonometry

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Intramucosal pH (pHi) and the P_{CO_2} gap (Pi_{CO_2}-Pa_{CO_2}) (Pi_{CO_2}: intramucosal P_{CO_2}) are often used to assess the state of splanchnic oxygen metabolism. However, the tonometric measurements of Pi_{CO_2} needed to calculate these parameters may be influenced by various factors, including temperature [1,2].

The present in vitro study aimed to evaluate the influence of temperature changes on the accuracy of tonometric measurements by comparing data obtained using the two most commonly employed methods: the saline method and the air-gas method, the latter with a Tonocap monitor (Datex Instrumentarium, Helsinki, Finland).

Three tonometry catheters (TRIP Sigmoid Catheter, Tonometrics, Hopkinton, MA) were employed: two for the saline method and one for the air-gas method. the dwell time for the saline method was set at 60 min, and 10 min, as instructed by the manufacturer, was used with the Tonocap. The three catheters were inserted into the same air-tight cylindrical chamber (diameter, 11.0 cm; height, 11.8 cm; volume 1.71 l) that was set in a bath filled with water. A one-way valve fitted to the top prevented gas pressure from increasing within the chamber while at the same time avoiding gas mixing from the atmosphere. Throughout the measurement period, the bath was kept close to one of three temperatures (34.0, 37.0, or 40.0°C) by a heater (TR-1; Icuchi Inst., Tokyo). A Tonocap monitor can be used with an infrared sensor to measure a patient's end-tidal P_{CO_2}. In our set-up, an additional tube was inserted into the chamber and connected to the inlet of the Tonocap normally used for measuring end-tidal P_{CO_2}. The test chamber was flushed with a mixture of oxygen and carbon dioxide gas at a flow rate of between $8 l \cdot m^{-1}$ to $11 l \cdot m^{-1}$. The P_{CO_2} in the chamber was set to 40 mm Hg by adjusting the flows of the two gases while viewing the screen of the Tonocap. The Tonocap monitor was calibrated using a standard gas (Quick CAL; Datex Engstrom, Helsinki, Finland).

The two catheters for the saline method were prepared as recommended by the manufacturer. Saline was injected into the balloon and, after the dwell time (60 min) had elapsed, the first 1.0 ml was discarded. Then, the P_{CO_2} of 1.5 ml of the saline from the balloon (Ps_{CO_2}) was measured with an automated blood-gas analyzer (ABL 300; Radiometer, Copenhagen, Denmark). All Ps_{CO_2} values were corrected with respect to a temperature of 37°C when measured in the analyzer. P_{CO_2} within the chamber (Pb_{CO_2}) was recorded every 10 min during the dwell time. A correction factor for the saline method (CF-S) was then calculated for each temperature by dividing the average of the six Pb_{CO_2} values by the single Ps_{CO_2} value.

The Tonocap measures the P_{CO_2} of the tonometer gas (Pg_{CO_2}) automatically every 10 min (pre set by the manufacturer), so we obtained six values by the air-gas method while waiting for the dwell time for the saline method to be completed. Because the Tonocap displayed the P_{CO_2} of the surrounding gas every 10 min, six Pb_{CO_2} values were obtained in 60 min. Thus, values were obtained for both parameters (Pb_{CO_2} and Pg_{CO_2}) at the same six time points (once every 10 min, for an effective dwell time of 10 min). A correction factor for the air-gas method (CF-G) was calculated for each temperature by dividing each Pb_{CO_2} value by the Pg_{CO_2} value obtained at

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Table 1. Results of the Bland-Altman analysis of the $P_{s_{CO_2}}$ (saline method) and $P_{g_{CO_2}}$ (air-gas method) data

Temperature (°C)	Bias (mm Hg)	Precision (mm Hg)	Standard deviation of the mean (mm Hg)
34	−3.2	−5.8 to −0.6	1.3
37	−4.5	−7.7 to −1.3	1.6
40	−6.2	−8.6 to −3.8	1.2

the same time point, and then taking the average of the resulting six values.

Data are expressed either as mean +/− SD or median with the 75-25 interquartile range. To analyze differences among the study groups with respect to sequential data over time, we used repeated-measures analysis of variance (ANOVA), followed by a Bonferroni/Dunn test for multiple analysis and a Bland-Altman analysis. To evaluate differences among correction factors, Mann-Whitney's U test was used. $P < 0.05$ was considered significant, except in the multiple analysis, in which significance was set at $P < 0.015$.

The Bland-Altman analysis of P_{CO_2} data measured by the two methods (Ps_{CO_2} and Pg_{CO_2}) demonstrated that bias increased with temperature and that the two methods gave widely different tonometer Pb_{CO_2} values at the same chamber P_{CO_2} (i.e., precision was poor) (Table 1).

CF-S values for Pb_{CO_2} in the saline method were 1.07 (0.036), 1.13 (0.048), and 1.19 (0.045) at 34°, 37°, and 40°C, respectively. The multiple analysis revealed significant differences among the three values (Fig. 1).

CF-G values in the air-gas method were 0.99 (0.014), 1.00 (0.06), and 1.00 (0.09) at 34°, 37°, and 40°C, respectively (Fig. 1). The multiple analysis revealed a significant difference only between 34° and 40°C; however, the difference was very small (1%).

In the present study, temperature had a significant influence on the tonometer readings obtained using the saline method, but less influence in the semiautomated air-gas method. In the case of the saline method, the difference between the CF-S values obtained for two temperatures 3°C apart was about 5%, which means that at a Pb_{CO_2} of 40 mm Hg, the error may be about 2 mm Hg per 3°C or about 0.7 mm Hg per °C. The P_{CO_2} gap has been recommended as an index of oxygen metabolism [3,4], but no standard cut-off value has been established (although one report used 7 mm Hg [5]. At a temperature of 40°C, the sensitivity to temperature change shown by the saline method could lead to an error of some 29% if this method is used with 7 mm Hg as the cut-off value (since 2 mm Hg divided by 7 mm Hg is about 0.29). In fact, the actual values obtained by the saline method varied over a wide range. Our results imply that the saline method may not give an accurate Pi_{CO_2} value when the body temperature changes.

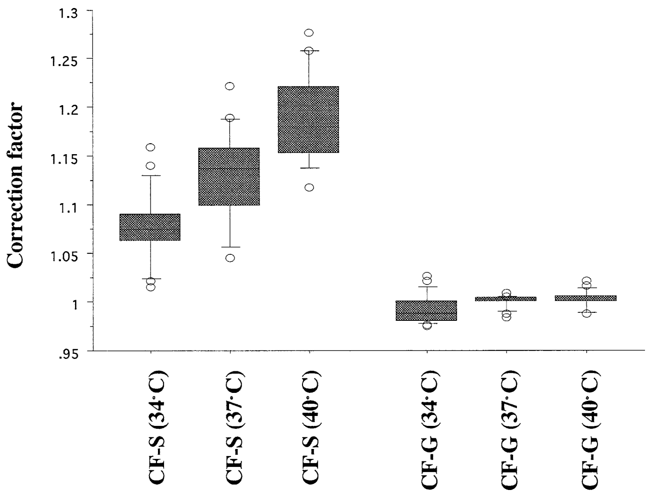

Fig. 1. Temperature-induced changes in the correction factor. The correction factor obtained with the saline method increased as temperature increased, but with the air-gas method, only a small difference was observed among the three groups. The *boxes* represent the interquartile ranges with the *central horizontal line* showing the median. The *whiskers* represent the 5% and 95% confidence limits

The accuracy of tonometer measurements varied with the Pi_{CO_2} level itself [6]. The limitation of the present study was that we examined only one level of Pb_{CO_2} (40 mm Hg). However, at this one level we observed a clear difference between the two methods in terms of the influence of temperature correction factors.

In conclusion, the results of the present study suggest that the air-gas method is likely to be more reliable than the saline method over the range of temperatures likely to be encountered in clinical practice.

References

1. Takala J, Parviainen I, Siloaho M (1994) Saline is an important source of error in the assessment of gastric intramucosal pH. Crit Care Med 22:1877–1879
2. Barry B, Mallick A, Hartley G, Bodenham A, Vucevic M (1998) Comparison of air tonometry with gastric tonometry using saline and other equilibrating fluids: an in vivo and in vitro study. Intensive Care Med 24:777–784
3. Miller PR, Kincaid EH, Meredith JW, Chang MC (1998) Threshold values of intramucosal pH and mucosal-arterial CO_2 gap during shock resuscitation. J Trauma 38:868–872

4. Schlichtig R, Mehta N, Gayowski TJ (1996) Tissue-arterial P_{CO_2} difference is a better marker of ischemia than intramural pH (pHi) or arterial pH-pHi difference. J Crit Care 11:51–56
5. Uusaro A, Lahtinen P, Parviainen I, Takala J (2000) Gastric mucosal end-tidal P_{CO_2} difference as a continuous indicator of splanchnic perfusion. Br J Anaesth 85:563–569
6. Venkatesh B, Morgan J, Jones RD, Clauge A (1998) Validation of air as an equilibration medium in gastric tonometry: an in vitro evaluation of two techniques for measuring air P_{CO_2}. Anaesth Intensive Care 26:46–50