In vitro validation of gastric air tonometry using perfluorocarbon FC 43 and 0.9% sodium chloride

J. Graf, B. Königs, K. Mottaghy and U. Janssens

1 Medical Clinic I and 2 Institute of Physiology, University Hospital of RWTH Aachen, Pauwelsstrasse 30, D-52057 Aachen, Germany
*Corresponding author: Klinikum der RWTH Aachen, Medizinische Klinik I, Pauwelsstrasse 30, D-52057 Aachen, Germany

Monitoring splanchnic perfusion by means of gastric intramucosal tonometry is carried out using saline, or more recently, air tonometry using the Tonocap. The objective of this study was the validation of the Tonocap in saline and perfluorocarbon FC 43. The two methods underestimated the predefined \( \text{P}_{\text{CO}_2} \) value by an average of 10%, with clinically acceptable precision. Accuracy of the Tonocap improved at high \( \text{P}_{\text{CO}_2} \) values (9.33 and 9.94 kPa), whereas saline tonometry was superior at low \( \text{P}_{\text{CO}_2} \) values (3.99 and 3.75 kPa). The Tonocap provides a fast and reliable estimation of the \( \text{P}_{\text{CO}_2} \), and with the revised software requiring only 10 min of equilibration, will increase the comparability of future studies.


Keywords: equipment; gastrointestinal tract; measurement techniques, tonometry; monitoring

Accepted for publication: October 22, 1999

Two methods of monitoring splanchnic perfusion and oxygenation by means of gastric tonometry are available at present: conventional saline tonometry and, more recently, the Tonocap. In contrast to saline tonometry, the Tonocap automatically inflates a balloon with air and the catheter is constantly connected to the monitor, resulting in a closed system. This new device is expected to solve at least some of the practical and methodological problems inherent in saline tonometry. Since the software for the Tonocap has been revised recently and now allows an equilibration time of only 10 min, a new in vitro validation study was essential. This in vitro study was designed to validate the accuracy of the Tonocap using two liquids: sodium chloride 0.9% and perfluorocarbon FC 43 (PFC 43).

Methods and results

Four tonometry catheters (TRIP Tonometry Catheter, 16 F; Tonometrics Instrumentarium Corporation, Datex Ohmeda Division, Helsinki, Finland) were placed in a sealed container serving as an equilibration chamber. Two tonometers were connected to the Tonocap monitors (Tonocap TC 200, version 2.1, 1998; Tonometrics Instrumentarium Corporation). Conventional saline tonometry was carried out with the two remaining catheters. Details of the two methods have been published elsewhere. The container was partly filled with PFC 43 (3M Specialty Chemical Division, Neuss, Germany), which is known for its exceptionally high carbon dioxide solubility, or sodium chloride 0.9%. Steady-state \( \text{P}_{\text{CO}_2} \) was reached by constantly bubbling carbon dioxide test gases (4 and 9.97% carbon dioxide in nitrogen, relative accuracy ±1%; Linde, Cologne, Germany), and the temperature was maintained at 37°C. The \( \text{P}_{\text{CO}_2} \) (kPa) used as the reference for tonometry was calculated from the carbon dioxide content of the calibration gas, the vapour pressures of saline 0.9% (6.27 kPa) and PFC 43 (0.24 kPa) at 37°C and the barometric pressure (\( P_{\text{bar}} \); median 99.98 kPa, range 99.80–100.20 kPa) according to Dalton’s law:

\[
\text{P}_{\text{CO}_2} = \%\text{CO}_2 \times (P_{\text{bar}} - \text{vapour pressure}) \times 100.
\]

Throughout all experiments the chamber \( \text{P}_{\text{CO}_2} \) was checked simultaneously with the Tonocap measurements every 10 min, by (1) sampling 0.5 ml PFC 43 or sodium chloride 0.9% for \( \text{P}_{\text{CO}_2} \) analysis using a conventional blood-gas analyser (ABL 505; Radiometer Copenhagen, Denmark) and (2) recording the real-time readings of an intravascular carbon dioxide sensor (Paratrend 7; Diametrics Medical, High Wycombe, Buckinghamshire, UK). All samples were obtained by the same investigator, and no factor was applied to correct for incomplete equilibration. In both PFC 43 and sodium chloride 0.9%, two series of experiments were carried out, one series at a high \( \text{P}_{\text{CO}_2} \) level and one at a low level.

The statistical analysis was executed using SPSS 7.5 (SPSS, Chicago, IL, USA) and MedCalc 4.16a (F. Schoonjans, Ghent, Belgium). All data are expressed as mean (SD). The paired \( t \) test was used to compare the different methods at corresponding experimental time-
points. Pearson’s correlation coefficient was calculated for all data sets. Bias and precision were analysed according to the method of Bland and Altman.³

No significant within-method difference was observed among the means obtained by the two Tonocap monitors and among the two conventional tonometry catheters. Consequently, the results obtained with each method were pooled for further analyses.

Tonocap and saline tonometry underestimated the calculated $P_{CO_2}$ in both sodium chloride 0.9% and PFC 43. At the high $P_{CO_2}$ levels, the bias of the Tonocap was smaller compared with the low $P_{CO_2}$ levels and saline tonometry in both solutions, whereas the accuracy of saline tonometry was higher at the low $P_{CO_2}$ levels and decreased with increasing $P_{CO_2}$. The overall precision of the two methods was similar (Table 1).

Direct comparison of the Tonocap with saline tonometry yielded an overall bias of 2% in PFC 43 and −0.3% in saline (precision 6.7 and 8%, respectively).

**Comment**

The main finding of this study is that the Tonocap and conventional saline tonometry underestimated the calculated chamber $P_{CO_2}$ by an average of 10%. The precision of both methods was within acceptable clinical limits.

The bias of the Tonocap increased with decreasing $P_{CO_2}$ level. This might be attributed in part to the Tonocap’s display, which allows only one decimal place; values between 3.5 and 3.6 kPa, for example, are rounded. This may lead to an absolute difference between the measured and the displayed value of 0.04 kPa, corresponding to approximately 1% bias at low $P_{CO_2}$ levels but only 0.5% bias at high $P_{CO_2}$ levels in this study. However, this does not explain the observed difference of more than 4%.

The deviation of saline tonometry from the calculated $P_{CO_2}$ at high chamber $P_{CO_2}$ levels was probably caused by constructional features of the blood-gas analyser itself and the low stability of carbon dioxide in saline. This results in loss of carbon dioxide before the sample reaches the measuring electrode. Because the $P_{CO_2}$ gradient is the determinant of carbon dioxide diffusion, this environmental loss of carbon dioxide is pronounced at high $P_{CO_2}$ values.⁴

Creteur and colleagues used a conventional blood-gas analyser to assess the $P_{CO_2}$ of an equilibration chamber. At a given $P_{CO_2}$ level of 10.66 kPa, they found a smaller bias (−2.1%) and better precision (2.4%) compared with our results (mean of six measurements, 10 min dwell time, values from the original publication converted into kPa and percentages).⁵

The majority of studies validating the Tonocap calculated the chamber $P_{CO_2}$ according to Dalton’s law. Kolkman and colleagues calculated the mean of 20 repeated measurements with an equilibration time of 5 min at four $P_{CO_2}$ levels, and reported a bias of −2% and a precision of 2% with a response time of 19 (2) min (i.e. time to detect 95% of an instantaneous change in bath $P_{CO_2}$).⁶ The 5-min cycle time used in this study was carried out with a prototype Tonocap system that was not available commercially. Temmesfeld-Wollbrück and colleagues repeated their measurements three times and found no bias at a chamber $P_{CO_2}$ of 5.33 kPa and a bias of 3.58%, with a precision of 1.54% at 7.60 kPa (data from the original publication converted into kPa).⁷

Using the capnograph facility of the Tonocap as a reference, Barry and colleagues reported a bias of −2.5% and a precision of 2.1%.⁸ This procedure potentially avoids possible sources of error, such as the analysis of $P_{CO_2}$ with a conventional blood-gas analyser. However, dependent variables must not be correlated with each other, and validation of the sensor without an independent reference method might introduce systematic errors.

A major drawback is that different reference methods and study procedures (with regard to dwell time, $P_{CO_2}$ level and the number of repeated measurements) limit the comparability of studies. Furthermore, the revised software of the Tonocap used in this study did not allow us to adjust the cycle time to confirm previous results.

In conclusion, the Tonocap is an easy, fast and precise device for estimating intramucosal $P_{CO_2}$ within clinically acceptable limits. Moreover, the new software provides the first standardized method for the bedside assessment of perfusion and oxygenation in the critically ill patient.
References