An Evaluation of a Transcutaneous and an End-Tidal Capnometer for Noninvasive Monitoring of Spontaneously Breathing Patients

Norman Stein MD, Holger Matz PhD, Andreas Schneeweiß MD, Christian Eckmann MD, Angela Roth-Isigkeit MD, Michael Hüppe PhD, and Hartmut Gehring MD

BACKGROUND: Since there is a growing use of analgesia and sedation in spontaneously breathing patients undergoing diagnostic or therapeutic interventions, recommendations by national societies of anesthesiologists call for the application of capnometry during all anesthetic procedures. METHODS: We compared readings from a transcutaneous capnometer (Tosca) and an end-tidal capnometer (Microcap Plus) to P_{aCO_2} measurements made via arterial-blood-gas analysis. We studied 30 spontaneously breathing patients who were recovering from general anesthesia, and we used Bland Altman analysis to compare the capnometry readings to the arterial-blood-gas values. Expiratory gas samples for end-tidal capnometry were taken either from a conventional face mask or an oral/nasal cannula. RESULTS: The Tosca significantly overestimates P_{aCO_2} (mean ± SD difference 5.6 ± 3.4 mm Hg). The Microcap Plus significantly underestimates P_{aCO_2} (mean ± SD difference −14.1 ± 7.4 mm Hg). There was no significant difference between the face mask and oral/nasal cannula with regard to collecting end-tidal samples. CONCLUSION: Both the Tosca and Microcap Plus provide just an approximate estimation of P_{aCO_2}. Clinical use of these monitors can not be proposed under actual conditions but will be advantageous after correction of the limiting errors. *Key words: capnometry, anesthetic, arterial blood gas analysis.* [Respir Care 2006;51(10):1162–1166. © 2006 Daedalus Enterprises]

Introduction

The early detection of ventilatory malfunction leads to the prevention of hypoxemia, which is predicted by pulse oximetry with a certain delay.[1,2] This is why the advantage of capnometry as an early warning system for circulatory and respiratory failure is more important than pulse oximetry. In consequence, the application of capnometry has been proposed for intubated, mechanically ventilated patients and spontaneously breathing patients.[3] This might be convenient for patients undergoing diagnostic or therapeutic interventions, because their respiratory function is influenced by anesthetic and sedative agents.[4–6] Recommendations of national societies of anesthesiologists have therefore been expanded to establish the same level of respiratory observation for anesthetized, spontaneously breathing patients as for intubated, mechanically ventilated patients.[7]

The combination of capnometry and pulse oximetry in one device provides the advantage of noninvasive, continuous monitoring of both those gas-exchange variables.[8,9] Capnometry monitors alveolar ventilation, whereas pulse oximetry measures the transport of oxygen from inspiratory gas to the peripheral arterial blood.[1,4]

The aim of the present study was to evaluate the bias and precision of 2 capnometers, the Tosca (Linde Medical Sensors, Basel, Switzerland) and the Microcap Plus (Oridion, Luebeck, Germany), by comparing their readings to blood-gas measurements on arterial blood, with spontaneously breathing patients. Additionally, we com-

Norman Stein MD, Andreas Schneeweiß MD, Angela Roth-Isigkeit MD, Michael Hüppe PhD, and Hartmut Gehring MD are affiliated with the Department of Anesthesiology; Christian Eckmann MD is affiliated with the Department of Surgery, University Clinic of Schleswig-Holstein, Campus Luebeck, Luebeck, Germany. Holger Matz PhD is affiliated with the Institute of Biomedical Engineering, University of Luebeck, Luebeck, Germany.

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Correspondence: Hartmut Gehring MD, Department of Anesthesiology, University Clinic of Schleswig-Holstein, Campus Luebeck, Ratzeburger Allee 160, D-23538 Luebeck, Germany. E-mail: gehring@uni-luebeck.de.

Table 1. Patient Demographic Data

Sex	13 female	
	17 male	
Age (y; mean ± SD)	64 ± 9.6	
Type of Surgery	*n*	%
Vascular	18	60
Abdominal	9	30
Thoracic	3	10

pared sampling exhaled gas via the Smart CapnoLine O_2 oral/nasal cannula to sampling via conventional face mask.

Methods

Patients

With the approval of the ethics committee of the University of Luebeck, and after obtaining written informed consent, we included 30 patients who met American Society of Anesthesiologists status II or III and were recovering from general anesthesia after surgery and who had arterial access lines for invasive arterial blood-pressure monitoring (Table 1, Fig. 1).

Monitors

The Tosca employs an earlobe sensor for transcutaneous CO_2 measurement and a reflection sensor for pulse oximetry. The sensor is heated to 42°C to improve measurement conditions, by capillary arterialization. The Stow-Severinghaus technique is used for capnometry, and the reflection technique for pulse oximetry.[10–12] In its automatic mode, the Tosca monitor has an integrated temperature-correction factor, in combination with a metabolic constant, designed by Severinghaus, to compensate for sensor heating.[12,13]

The Microcap Plus uses the Microstream analyzer. The system integrates a pulse oximetry module that uses a finger sensor (N-200, Nellcor, Pleasanton, California) in the transmission mode. The Microcap Plus exhaled-gas sampling probe's low flow rate (50 mL/min) and the probe line's narrow diameter (1 mm) are supposed to allow measurements with nonintubated, spontaneously breathing patients.[14] The end-tidal method of P_{CO_2} measurement was randomized for each of the 30 patients between conventional face mask (Octurno, Poland) and the Microstream oral/nasal cannula (Smart CapnoLine O_2, Oridion, Germany).

Study Protocol

At the end of general anesthesia, the patients were extubated and monitored in the recovery room or the intermediate care station. Oxygen application was set to 4 L/min.

On the patient's arrival, the study operator received the randomized allocation for either the face mask or oral/nasal cannula. Both the Microcap Plus and Tosca were prepared to measure according to the manufacturer's recommendations.[12,14] With the Tosca this includes an automatically started calibration modus before it is attached to the earlobe. Data registration was started according to the time interval of 5 min for optimal capillary arterialization,[12] and was completed after a period of 1.5 h. Arterial blood samples were taken at 5 time points: 15, 30, 60, 75, and 90 min after the start of data recording. In the recovery room, the arterial blood samples were analyzed with an ABL625 (Radiometer, Copenhagen, Denmark). In the intermediate-care room the arterial blood samples were analyzed with a Rapidlab 865 (Bayer Healthcare, Fernwald, Germany). The transcutaneous CO_2 readings (P_{tCO_2}) and the end-tidal CO_2 readings (P_{etCO_2}) were recorded during a time interval of 1 min before each arterial-blood sample.

Statistical Analysis

To compare the Tosca and Microcap Plus readings with the arterial-blood measurements (P_{aCO_2}) as the reference system, we used Bland Altman analysis.[15] Comparison of the end-tidal sampling systems (face mask and oral/nasal cannula) was achieved with the *t* test for unpaired variables. Differences were considered statistically significant when $p < 0.05$.

Results

The Tosca significantly overestimates P_{aCO_2}, with a bias of 5.6 mm Hg and a standard deviation of 3.4 mm Hg (Table 2, Fig. 2).

The Microcap Plus significantly underestimates P_{aCO_2}, with a bias of −14,1 mm Hg and a standard deviation of 7.4 mm Hg (see Table 2, Fig. 3).

There was no significant difference between sampling exhaled gas via face mask versus via oral/nasal cannula.

Discussion

The measured data of both examined methods reveal clear differences between the P_{aCO_2} measurements and the Tosca and Microcap Plus readings. The difference between the transcutaneous and arterial data were nearly always higher than 0 mm Hg, whereas the difference between the end-tidal and arterial data were always lower than 0 mm Hg.

Transcutaneous capnometry has already been established in clinical application, and its limiting errors are well known.[10,16] Skin burns are one potential consequence when

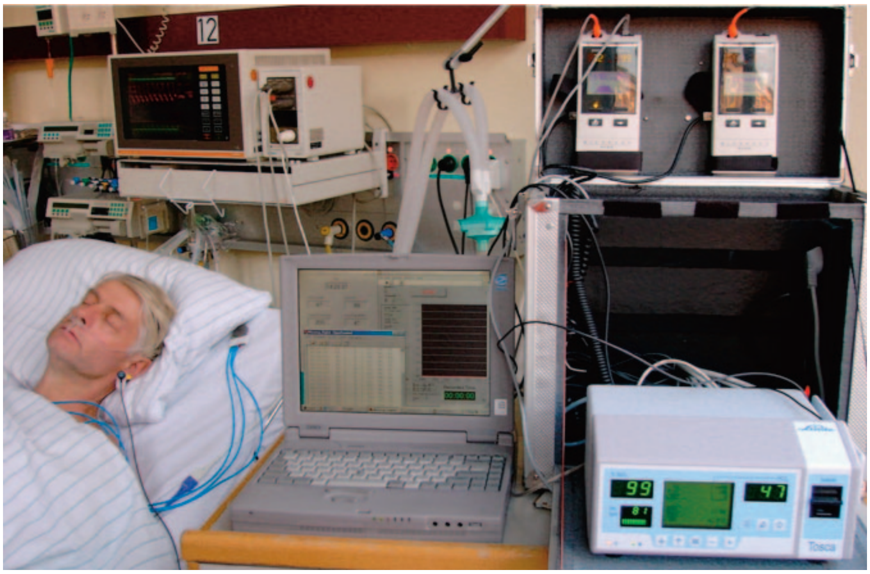

Fig. 1. Data-recording system, with a spontaneously breathing patient connected to the ear sensor of the Tosca system (lower right), the Smart CapnoLine O_2 oral/nasal cannula (in the patient's mouth and nose), and the Microcap Plus system (upper right).

Table 2. Mean P_{CO_2} Values* From Arterial-Blood Analysis, the Tosca Capnograph, and the Microcap Plus Capnograph

P_{aCO_2} (mm Hg)	P_{tCO_2} (mm Hg)	P_{etCO_2} (mm Hg)
41.88 ± 4.21	47.50 ± 5.79	27.8 ± 7.0

*Mean ± SD values from the 30 subjects
P_{aCO_2} = measured from arterial blood samples
P_{tCO_2} = readings from the Tosca transcutaneous capnometer
P_{etCO_2} = readings from the Microcap Plus end-tidal capnometer

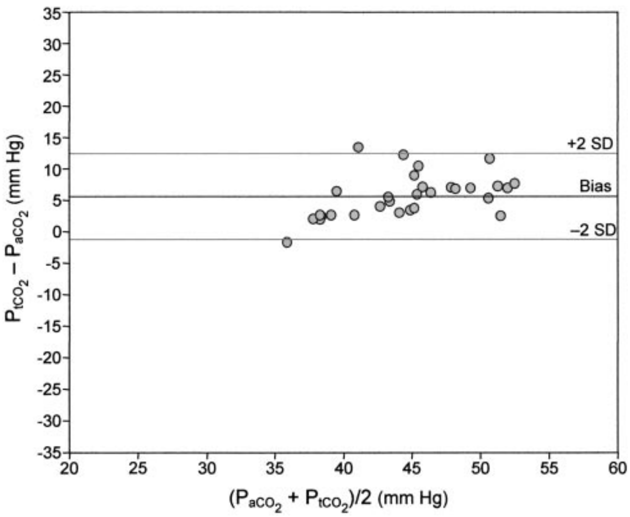

Fig. 2. Bias and limits of agreement between P_{aCO_2} values from arterial blood samples and readings from the Tosca transcutaneous capnometer (P_{tCO_2}). The ordinate scale represents the difference between P_{tCO_2} and P_{aCO_2} (ie, P_{tCO_2} minus P_{aCO_2}). The abscissa scale represents the average of P_{tCO_2} and P_{aCO_2} (ie, P_{tCO_2} plus P_{aCO_2} divided by 2).

using a heated sensor over a long period.[17] This is why other sensors with higher temperatures require more frequent changes of location.[17] The Tosca sensor, however, is heated at 42°C, and no change in placement is needed before an application time of 12 h.[12,18] Wounding related to sensor heating or placement on the earlobe were not observed in the present study. The sensor temperature to improve local perfusion (capillary arterialization) also increases local production of carbon dioxide in the tissue, which leads to falsely high measurements.[17] For this reason, Severinghaus's temperature-correction factor, in combination with a metabolic constant, is established in the Tosca as an automatic mode, the use of which is proposed in the Tosca manual.[12] Since this formula was estimated under the conditions of a sensor working at approximately 44° C and being placed at the forearm, the effectiveness should be re-estimated under the conditions of 42° C and at the earlobe with a clamp, which produces substantial pressure on the skin.[13]

Errors that influence end-tidal capnometry have been described.[2,3] The Microstream technology is supposed to minimize most of those errors.[19] However, some limitations still remain for the application of end-tidal monitoring with spontaneously breathing patients, regarding both measurement and sampling error.

The Microstream technology's low sampling flow rate (50 mL/min) should reduce the risk of sampling room air instead of only the expired gas. In addition, the resulting long response time of the system has been improved by the small cross-section (1 mm) of the sample line and the

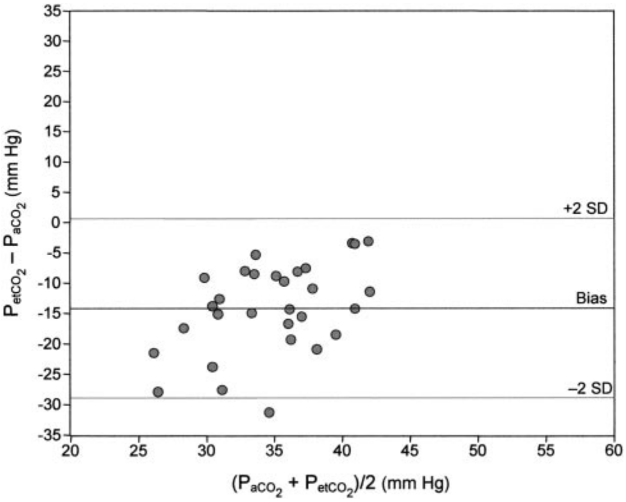

Fig. 3. Bias and limits of agreement between P_{aCO_2} values from arterial blood samples and readings from the Microcap Plus end-tidal capnometer (P_{etCO_2}). The ordinate scale represents the difference between P_{etCO_2} and P_{aCO_2} (ie, P_{etCO_2} minus P_{aCO_2}). The abscissa scale represents the average of P_{etCO_2} and P_{aCO_2} (ie, P_{etCO_2} plus P_{aCO_2} divided by 2).

decreased volume of the measurement chamber (15 μL). This also allows CO_2 measurements during a higher respiration rate and small tidal volume, as with pediatric patients.[20]

Increased oxygen concentration in the sampled gas interferes with the infrared spectrophotometry normally used to measure carbon dioxide, resulting in falsely low values.[3,21] The Microcap Plus incorporates laser-based molecular-correlation spectroscopy, which generates a specific wavelength for CO_2 molecules (4.26 μm), which minimizes the interference with nitrogen dioxide and oxygen.[19]

Simultaneous oxygen delivery to the patient can dilute the carbon dioxide in the expired air and aggravate the measuring conditions.[21–23] When using the oral/nasal cannula, sampling errors corresponding to mouth-breathing seem to be more pronounced.[22,23] We regard this aspect as the essential factor in the P_{aCO_2} underestimation of the end-tidal method in the present study, although the chosen setting of 4 L/min is not supposed to have any influence on the measurement, according to the manufacturer's guideline.[14]

The intention of establishing end-tidal capnometry for spontaneously breathing patients has led some to construct their own connections to face masks or to improvise nasal cannulae.[21,24] Our randomized study protocol to test face mask or oral/nasal cannula focused on the hypothesis that the Smart CapnoLine O_2 can improve end-tidal capnography in spontaneously breathing patients, but the expected effect was not confirmed after a statistical analysis of our results.

Conclusions

The Tosca system overestimates P_{aCO_2}. We propose adjusting the temperature-correction factor and the metabolic constant to achieve closer agreement with P_{aCO_2}. In general, the Tosca system could be used as a trend monitor in ventilatory observation.

The Microcap Plus monitor, in combination with face mask or nasal cannula, provides a poor assessment of P_{aCO_2}. The simultaneous registration of the patient's respiratory rate and the graphic display of the capnography curve support the observation of acute respiratory tachypnea and apnea.

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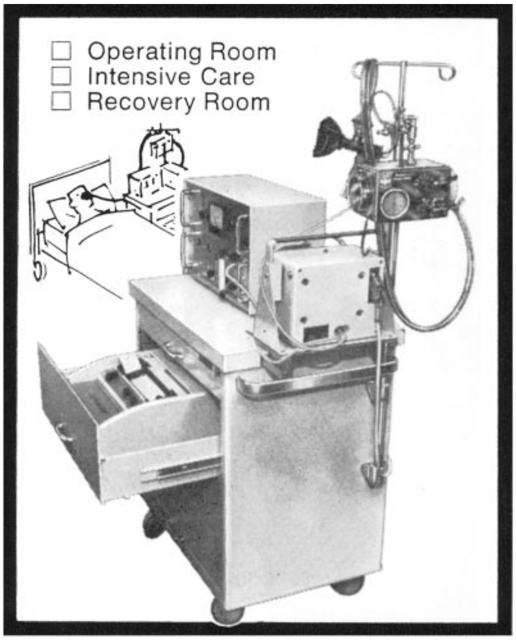

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