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

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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 $P_{a\text{-}CO_2}$ 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 $P_{a\text{-}CO_2}$ (mean difference 5.6 ± 3.4 mm Hg). The Microcap Plus significantly underestimates $P_{a\text{-}CO_2}$ (mean 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 $P_{a\text{-}CO_2}$. 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.

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-
pared sampling exhaled gas via the Smart CapnoLine O₂ 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 CO₂ 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_CO₂ measurement was randomized for each of the 30 patients between conventional face mask (Octurno, Poland) and the Microstream oral/nasal cannula (Smart CapnoLine O₂, 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 CO₂ readings (P_tCO₂) and the end-tidal CO₂ readings (P(etCO₂)) 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_aCO₂) 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_aCO₂, 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_aCO₂, 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_aCO₂ 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
using a heated sensor over a long period. This is why other sensors with higher temperatures require more frequent changes of location. The Tosca sensor, however, is heated at 42°C, and no change in placement is needed before an application time of 12 h. 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. 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. 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.

Errors that influence end-tidal capnometry have been described. The Microstream technology is supposed to minimize most of those errors. 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

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**Table 2. Mean P\textsubscript{aCO\textsubscript{2}} Values* From Arterial-Blood Analysis, the Tosca Capnograph, and the Microcap Plus Capnograph**

<table>
<thead>
<tr>
<th></th>
<th>PaCO\textsubscript{2} (mm Hg)</th>
<th>PtCO\textsubscript{2} (mm Hg)</th>
<th>PetCO\textsubscript{2} (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD values</td>
<td>41.88 ± 4.21</td>
<td>47.50 ± 5.79</td>
<td>27.8 ± 7.0</td>
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</tbody>
</table>

*Mean ± SD values from the 30 subjects

PaCO\textsubscript{2} = measured from arterial blood samples
PtCO\textsubscript{2} = readings from the Tosca transcutaneous capnometer
PetCO\textsubscript{2} = readings from the Microcap Plus end-tidal capnometer

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

references

12. Tosca manual. Linde Medical AG, Basel, Switzerland.