RESPIRATION AND THE AIRWAY

Accuracy of respiratory rate monitoring by capnometry using the Capnomask® in extubated patients receiving supplemental oxygen after surgery

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Editor’s key points

- This study compared clinical monitoring of respiratory rate with thoracic bioimpedance and a new oxygen mask incorporating capnometry.
- The Capnomask® was similar to clinical observation and more accurate than bioimpedance even at high oxygen flow rates.
- If confirmed, these data suggest that the Capnomask® might be useful in postoperative patients breathing spontaneously.

Background. Respiratory monitoring is standard after anaesthesia and surgery. Abnormal respiratory rate is a sensitive indicator of respiratory problems, even in patients receiving supplemental oxygen, but the best method for its continuous measurement in spontaneously breathing patients is unclear. This study compared respiratory rate assessment by capnometry using a new oxygen mask with a carbon dioxide sampling port (Capnomask®) and thoracic impedance pneumography with clinical measurement (used as a reference method) in extubated patients receiving supplemental oxygen.

Methods. Adult males admitted to the post-anaesthesia care unit after general anaesthesia were studied. Immediately after extubation, a Capnomask® connected to a capnometer was positioned appropriately. Respiratory rate was measured by visual inspection of chest movement for 1 min, by capnometry, and thoracic impedance pneumography. One set of measurements was obtained for every patient receiving supplemental oxygen at different flow rates.

Results. Twenty men, mean (inter-quartile range) age 54 (23–66) yr and BMI 25 (21–31) kg m⁻², were studied. Compared with visual inspection, the bias and limits of agreement were 0.0 (1.0 to −1.0) bpm for the Capnomask® and −2.2 (2.0 to −6.5) bpm for the impedance pneumography. The accuracy of respiratory rate assessment using Capnomask® was not influenced by the supplemental oxygen flow rate.

Conclusions. In extubated patients, continuous assessment of respiratory rate with the Capnomask® is more accurate than by thoracic impedance pneumography even when supplemental oxygen is delivered at a high flow rate.

Keywords: capnography; physiological monitoring; postoperative care; postoperative complications; recovery room; respiratory depression

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Respiratory problems are common during the postoperative period, especially in extubated patients requiring opioid analgesics for pain management. The incidence of acute respiratory failure was reported as 3.4% after major non-cardiac surgery, whereas the incidence of myocardial infarction was only 0.7%. The late detection of respiratory failure increases the risk of death and major neurological sequelae, so the continuous monitoring of oxygen saturation (SpO₂) and respiratory rate for all patients after general anaesthesia is routine. However, normal SpO₂ values have been observed in patients with respiratory distress, particularly if they are receiving supplemental oxygen.

Despite its clinical importance, respiratory rate remains the last vital sign without a reliable continuous monitoring method that is easily tolerated. Respiratory rate is usually assessed clinically, by counting chest wall movements. This is time consuming, may be difficult to perform in busy post-anaesthesia care units, and is limited by its intermittent nature. Respiratory rate can be monitored continuously in two ways. Thoracic impedance pneumography estimates respiratory rate by measuring changes in electrical impedance associated with chest movement during respiration. However, many factors including inaccurate ECG electrode placement, motion artifact, and physiological events.
unrelated to respiration that cause chest wall movement, such as coughing and crying, may generate a high number of false alarms due to inaccurate readings.\textsuperscript{5, 6} Insensitivity to obstructive apnoea, that is, the presence of chest wall movement without any actual gas exchange, is another significant limitation of impedance pneumography. Continuous end-tidal carbon dioxide concentration (\(P_{\text{ET}}\text{CO}_2\)) monitoring with capnometry is used for the early detection of respiratory or haemodynamic changes during the anaesthesia. This method is capable of detecting central, obstructive, and mixed apnoea. In non-intubated patients, \(P_{\text{ET}}\text{CO}_2\) assessment requires a device that draws a continuous gas sample for spectrographic measurements within the capnometer.\textsuperscript{7–11} The Capnomask\textsuperscript{R} (GHW group, Meylan, France) is a newly developed oxygen face mask with a \(P_{\text{ET}}\text{CO}_2\) sampling line intended for use in spontaneously breathing patients. A previous study used this device to monitor respiratory rate in spontaneously breathing patients undergoing monitored anaesthesia care.\textsuperscript{12}

The purpose of this study was to compare respiratory rate assessment by capnometry using the Capnomask\textsuperscript{R} and by thoracic impedance pneumography with clinical measurement (used as a reference method) in extubated adults after elective surgery. Because patients routinely require different oxygen flow rates during recovery from anaesthesia, a secondary goal was to determine whether oxygen flow rate affected the ability of the capnometry to adequately assess respiratory rate.

**Methods**

This prospective study was conducted at the Hospital of Poitiers, a 1000 acute care teaching hospital located in France. The scientific and ethics committee of Service d’Anesthésie-Réanimation du Centre Hospitalier Universitaire de Poitiers approved the design of the study. The study was registered with EudraCT (ref: 2011-001806-83) and informed consent obtained from all patients. After general anaesthesia, adult male patients without beards or moustaches, admitted to the post-anaesthesia care unit, were included after tracheal extubation. Exclusion criteria were: age below 18 yr, inability to maintain \(\text{SpO}_2\) >92\% breathing room air, failure to support the Capnomask\textsuperscript{R} (e.g. due to the presence of surgical sutures at points of contact with the mask), requirement for non-invasive mechanical ventilation, the presence of a cardiac pacemaker, and inability for any reason to properly place the ECG electrodes.

All patients were monitored continuously with pulse oximetry and three-lead electrocardiography, set in an automatic mode, through a multiparameter monitor (M1166A, Hewlett Packard, Boeblingen, Germany). A size 4 Capnomask\textsuperscript{R} designed to administer nasal oxygen and sample both nasal and oral carbon dioxide was appropriately positioned to measure \(P_{\text{ET}}\text{CO}_2\) with a side-stream infrared capnometer (MedizinSysteme, Boeblingen, Germany; aspiration flow rate of 100 ml min\(^{-1}\)). The capnometer was calibrated before each series of measurements. Respiratory rate was also estimated by thoracic impedance pneumography using three electrodes positioned as recommended by the manufacturer under the middle of the right clavicle, under the middle of the left clavicle, and between the fifth and sixth left intercostal space at the median clavicle line.

Measurements were recorded 3 min after a constant and normally shaped capnography waveform was obtained. Respiratory rate was measured by counting chest wall movements for 1 min, and at the end of the procedure, the values displayed by the capnometer and the multiparameter monitor using impedancemetry were simultaneously recorded. Patients coughing or moving during the measurements were not excluded. One set of measurements was obtained for every patient receiving supplemental oxygen at nine different flow rates: 0, 1, 3, 5, 7.5, 10, 12.5, 15, and 20 litre min\(^{-1}\). For each supplemental oxygen flow rate, the rate was maintained for 3 min before respiratory rate determinations were recorded. Episodes of apnoea, defined as an absence of chest wall movements lasting more than 10 s, and arterial desaturation, defined as a \(\text{SpO}_2\) value <95\%, were recorded and their causes elucidated. The study period was for 30 min for every patient.

**Statistics**

Quantitative variables are expressed as median and interquartile range (IQR). Clinical assessment of respiratory rate was regarded as the reference method, and thoracic impedance pneumography and capnometry as methods of comparison. Agreement between the reference method and each test method was assessed as described by Bland and Altman. Owing to multiple measurements per patient, the mean bias and limits of agreement were then estimated by a component of variance technique.\textsuperscript{13} A random-effect model was used to estimate the within-subject variation (random error). Using the random-effects model allows to calculate the within-subject variance after the between-subject variation (agreement between methods) has been taken into account. In this analysis, the sequence of oxygen flow rate was taken as the random effect. Assuming that the variance of the repeated measurements for each subject by each method was independent of the mean of the repeated measures [check by plotting the within-subject standard deviation (SD) against the mean of each subject by each method], the model was adjusted for the mean value for the individual for each oxygen flow rate and the mean measurement between the two methods. The SD of the difference between the means of the repeated measurements was calculated based on the within-subject SD estimates. The 95\% confidence intervals for the combinations of component of variance were calculated as described by Burdick and Graybill.\textsuperscript{14} For each oxygen flow rate, distributions of \(P_{\text{ET}}\text{CO}_2\) measured by capnometry were graphically represented. For respiratory rate by capnometry only, the effect of supplemental oxygen on accuracy was assessed by comparing in analysis of variance each bias and limits of agreement calculated for each oxygen flow rate. For two-tailed tests, a
Results

Twenty men, median (IQR) age 54 (23–66) yr, weight 73 (60–95) kg, and body mass index 25 (21–31) kg m$^{-2}$, were studied. Four patients were ASA physical status I, 12 were ASA II, three were ASA III, and one was ASA IV. Patients were undergoing urological surgery ($n=7$), orthopaedic surgery ($n=6$), abdominal surgery ($n=4$), ear–nose–throat surgery ($n=2$), and vascular surgery ($n=1$). The Capnomask® was well tolerated by all patients. Respiratory rates were easily assessed with both instrumental methods even in patients receiving the highest oxygen flow rate. No episodes of apnoea or arterial desaturation occurred during the study period.

The Bland–Altman plots for each test method compared with the clinical reference method in assessing respiratory rate are depicted in Figure 1A and B. Compared with the clinical reference method, the bias and limits of agreement were 0.0 (1.0 to –1.0) bpm for the Capnomask® and –2.2 (2.0 to –6.5) bpm for the thoracic impedance pneumography. The accuracy of Capnomask® in assessing respiratory rate was not influenced by the supplemental oxygen flow rate (Fig. 2). In contrast, the average $P_{\text{E}}\text{'CO}_2$ decreases gradually with increasing oxygen flow (Fig. 3).

Discussion

In extubated patients after general anaesthesia, continuous assessment of respiration rate by capnometry with a facial mask (Capnomask®) was more accurate than by thoracic impedance pneumography. Delivery of supplemental oxygen even at a high flow rate did not affect respiratory rate measurement, but altered $P_{\text{E}}\text{'CO}_2$ assessment.

Continuous capnometric monitoring previously required that a patient be intubated, and therefore, its use was limited mostly to patients in critical care areas. Recently, nasal cannulae and face masks have been developed to monitor respiratory rate and to detect apnoea episodes in spontaneously breathing patients requiring supplemental oxygen.7–12 These studies reported that when compared with visual inspection or auscultation with a pretracheal
stethoscope, capnometry gave an accurate measurement of respiratory rate. Capnometry has also the advantages of providing a continuous measurement of respiratory rate, which cannot be the case for the reference method, and detecting apnoeic episodes earlier than pulse oximetry or visual assessment. However, the cost of capnometry may limit its widespread use in wards. Each type of capnometer has its advantages and limitations. Devices with nasal cannulae are more comfortable and allow very low-flow oxygen delivery rates. However, they can be easily dislodged from their proper position or can become occluded against the nasal mucosa, both situations leading to inaccurate readings. Moreover, when patients convert to mouth breathing, nasal devices simply do not work. In contrast, facial masks such as the Capnomask® sample expired CO₂ from both the nose and the mouth, reducing the risk of false alarms. Other potential advantages of facial masks are the ability to deliver high oxygen flow rates to hypoxaemic patients and the lower risk of displacement from their proper position. However, the impact of higher oxygen flow rates on respiratory rate measurement by the device has not been previously explored.

In the present study, increasing oxygen flow rates up to 20 litre min⁻¹ decreased the amplitude of measured CO₂ probably via dilution. Therefore, assessing adequacy of ventilation by using CO₂ measurement was less reliable. However, agreement between clinical and capnometric measurement of respiratory rate remained excellent, implying that the Capnomask® can be used for oxygen therapy while simultaneously monitoring respiratory rate. Since the risk of rebreathing CO₂ during delivery of oxygen at a low rate has not been evaluated, it seems advisable to reserve this device for patients requiring a supplemental oxygen flow rate conventionally used for oxygen face masks (higher than 5 litre min⁻¹).

This study also found a significant departure between thoracic impedance pneumography measures of respiratory rate and an observer counting respiratory rate. The data may have been skewed by outlying values (Fig. 1a), most of which were from patients with coughing or moving. Although these departures could have been detected by nurses and therefore ignored, false alarms waste staff time and may desensitize them from true alarms.¹⁶

Our study has some limitations. First, only adult males without beards or moustaches were included, to limit the risk of leakage around the device since only one mask size was available at the start of the study. However, multiple sizes are now available, extending the potential use of Capnomask® to children and women. Secondly, only 20 patients participated in the study. However, nine sets of measurements were performed per patient, resulting in 180 triplets of data available to provide a means of detecting within-subject variations. Thirdly, data collection was not blinded. However, clinical measurement was performed first, followed by the recording of the displayed values, so the impact of the lack of blinding on the results, if any, was perhaps limited. Finally, the validity of the measured PₐCO₂ values was not tested because the main purpose of assessing PₑCO₂ in extubated patients breathing spontaneously is to monitor for respiratory depression and apnoea.

Future studies might assess the Capnomask® patients with obstructive sleep apnoea.

In conclusion, we found that monitoring postoperative respiratory rate by capnometry through an adapted oxygen mask (Capnomask®) in extubated patients was more accurate than by thoracic bioimpedance and may be a good alternative to clinical assessment.

**Authors’ contribution**


**Declaration of interest**

None declared.

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