Accuracy of respiratory rate monitoring using a non-invasive acoustic method after general anaesthesia

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Background. Respiratory rate should be monitored continuously in the post-anaesthesia care unit (PACU) to avoid any delay in the detection of respiratory depression. Capnometry is the standard of care but in extubated patients requires a nasal cannula or a face mask that may be poorly tolerated or can be dislodged, leading to errors in data acquisition and false alarms. The value of a new non-invasive acoustic monitor in this setting has not been fully investigated.

Methods. Adult patients admitted to the PACU after general anaesthesia were included. After tracheal extubation, an adhesive sensor with an integrated acoustic transducer (RRaTM) was placed on the patient’s throat and connected to its monitor while the patient breathed through a face mask with a carbon dioxide sampling port (CapnomaskTM) connected to a capnometer. Both the acoustic monitor and the capnometer were connected to a computer to record one pair of data per second for up to 60 min.

Results. Fifty-two patients, mean (range) age 54 (22–84) yr and BMI 26 (19–39) kg m⁻², were studied. Compared with capnometry, the bias and limits of agreement of the acoustic method were 0 (−1.4–1.4) bpm. The acoustic sensor was well tolerated while the face mask was removed by eight patients, leading to study discontinuation in two patients.

Conclusions. In extubated patients, continuous assessment of respiration rate with an acoustic monitor correlated well with capnometry.

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

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Approximately 234 million major surgical procedures are performed worldwide each year. Respiratory depression is common during the early postoperative period, especially after extubation and when narcotic analgesics are required for pain management.¹ Delayed detection of respiratory depression increases the risk of death and major neurological sequelae. Therefore, continuous monitoring of arterial oxygen saturation (SpO₂) and respiration rate is recommended for all patients in the immediate period after general anaesthesia.²

Capnometry is the standard of care for continuously monitoring respiration rate in intubated patients. In extubated patients, end-tidal carbon dioxide concentration assessment requires a nasal cannula or a face mask that may be poorly tolerated or can move, inducing errors in data acquisition and false alarms.³ ⁴ A non-invasive respiratory monitoring device, using an adhesive sensor with an integrated acoustic transducer positioned on the patient’s throat (Rad-87 Pulse CO-Oximeter with acoustic monitoring technology RRaTM, Masimo Corp., Irvine, CA, USA), has been recently introduced. This device analyses respiratory vibrations to detect inspiratory and expiratory flow. The acoustic signal is then converted to continuous, numeric values of respiration rate.

The purpose of this study was to determine the accuracy of respiratory rate assessment by an acoustic method using RRaTM in extubated adult patients after scheduled surgery. Capnometry using a face mask (CapnomaskTM, GHW group, Meylan, France) was used as the reference method for measuring respiration rate because this method is as accurate as clinical measurement.⁵

Methods

This prospective study was conducted at the University Hospital of Poitiers, a 1000 acute care teaching hospital located in France. The study is registered at Eudract database.
The local ethics committee approved the design of the study and informed consent was obtained from all patients. After general anaesthesia, adult patients admitted to the post-anaesthesia care unit (PACU) were included after extubation. Exclusion criteria were failure to tolerate an acoustic sensor or a face mask due to the presence of surgical sutures at points of contact with the device, requirement of non-invasive mechanical ventilation, pregnancy, and patients deprived of their liberty by court or administrative decision.

Patients were continuously monitored with electrocardiography, non-invasive blood pressure, and pulse oximetry per standard of care. An adhesive sensor with an integrated acoustic transducer (RRaTM rev C, Masimo Corp.) was applied to the patient’s throat and connected to a specific monitor (Rad-87 Pulse CO-Oximeter, software version 7713, Masimo Corp.). According to the manufacturer’s directions for use, the sensor was placed on either side of the larynx, above the thyroid cartilage and below the jaw line. Patients breathed via a size 3 or 4 CapnomaskTM connected to a capnometer (Capnostream 20TM, Oridion, Jerusalem, Israel) with a fixed oxygen flow rate of 6 litre min$^{-1}$. The CapnomaskTM is a newly developed oxygen face mask with a $P_{\text{ETCO}}$ sampling line intended for use in spontaneously breathing patients. The CapnomaskTM samples expired CO$_2$ from both the nose and the mouth, reducing the risk of false alarms. Both the acoustic monitor and the capnometer were connected to a computer for recording one pair of data per second for a maximum of 60 min, for subsequent analysis. The acoustic sensor or the face mask was repositioned when the signal was lost. For the acoustic monitor, the loss of signal is indicated by displaying double dashes instead of a number.

Episodes of apnoea, defined as an absence of chest wall movements lasting more than 10 s and determined by clinical observation, were recorded. Events that could interfere with measures (speaking, coughing, snoring, moving, sighing, vomiting, moaning, and repeated swallowing) were recorded and considered as impacting measurement accuracy of either device if a sudden change of at least 4 bpm for 10 s or more followed the occurrence of the event, without a concomitant change in the readings of the other device. Actual respiration rate was assessed clinically when the two monitors gave a difference of more than 4 bpm for at least 20 s.

### Statistical analysis

Capnometry was regarded as the reference method of respiration rate assessment and the acoustic device as the method of comparison. Agreement between the reference method and the test method was assessed as described by Bland and Altman.$^6$ As unequal numbers of measurements per patient were collected, mean bias and limits of agreement were then adjusted and estimated by a component of variance technique.$^6$ Statistical analyses were performed with R software version 2.13.1 (R Development Core Team, Vienna, Austria).$^7$

### Results

A total of 52 patients were studied (Table 1). Patients were monitored for their respiration from 16 to 60 min providing a total of 99 002 pairs of respiratory rate measurements. Respiratory rates were easily assessed with both instrumental methods and ranged from 6 to 24 bpm. The acoustic sensor was well tolerated but required repositioning 13 times for loss of signal. The face mask was removed by eight patients, leading to study discontinuation for repeated removal in two of them.

The Bland–Altman plots for assessing respiration rate by the acoustic method are depicted in Figure 1. Compared with capnometry, the bias and limits of agreement were 0
Nasal cannulas are more comfortable than face masks for spectrographic measurements within the capnometric range and may be a good alternative to time-consuming clinical assessment. The device appears to be well-tolerated and may be a good alternative to time-consuming clinical assessment. The device appears to be well-tolerated and may be a good alternative to time-consuming clinical assessment.

### Discussion

We report the first published study comparing acoustic respiration rate (RRa™) monitoring with capnometry using a face mask for respiratory rate assessment in extubated patients admitted to the PACU after scheduled surgery. Compared with capnometry, the acoustic device was accurate and well tolerated.

In extubated patients, capnometry requires the use of nasal cannulae or face masks to continuously draw a gas sample for spectrographic measurements within the capnometer. Nasal cannulae are more comfortable than face masks and allow for very low-flow oxygen delivery rates. However, they can be easily dislodged from their proper position or can become occluded against the nasal mucosa, leading to inaccurate readings. Moreover, when patients convert to mouth breathing, nasal devices simply do not work. In contrast, face masks such as the Capnomask sample expired carbon dioxide from both the nose and the mouth and are at lower risk of being displaced from their proper position, reducing the risk of false alarms. In a previous study, the bias and limits of agreement of capnometry using the Capnomask™ to assess respiration rate were 0 (--1.0–1.0) bpm, compared with visual inspection of chest breathing motions, justifying its choice as the reference method in the present study. However, face masks are less comfortable than nasal cannulae and are sometimes removed from the face by patients. In the present study, the face mask was intentionally removed by eight patients, leading to study discontinuation in two of them. Finally, the occurrence of specific events can lead to measurement errors with capnometry. In the present study, speaking, moving, and coughing were the three main causes of inaccurate capnometry readings. Although the causes of the aberrant measurements could have been detected by nurses and therefore ignored, false alarms waste the time of the medical staff and desensitize them to true alarms.

Compared with capnometry, the accuracy of the acoustic device to measure respiration rate in our PACU patients was excellent, but was subject to error during repeated swallowing. A larger study or use of acoustic monitoring in other care areas may identify other common patient activities that interfere with the accuracy or data acquisition of the acoustic monitor that we did not observe in our study. The bioacoustic sensor was well tolerated, with no patient deliberately removing it, but on 13 occasions, the sensor had to be repositioned due to signal loss. Appropriate sensor placement, therefore, may be critical to obtaining accurate and reliable monitoring by this method. Other potential limitations to the acoustic monitor could be its use on perspiring patients (if moisture affects the adhesive) and in small children (due to the sensor size).

Our study has some limitations. Only one patient developed apnoea and no episodes of oxygen desaturation occurred, so it is not known whether the acoustic device might detect these potentially fatal events earlier than capnometry. No patient had obstructive sleep apnoea: whether airway obstruction would be detected by this device is not known. No patient in our study had a respiration rate above 24 bpm, so accuracy above this rate cannot be assumed. We did not record the ambient sound level during the study and so cannot comment on whether the device is affected by noisy environments.

In conclusion, monitoring postoperative respiration rate in extubated patients with an acoustic monitoring device is as accurate as capnometry through an adapted oxygen mask and may be a good alternative to time-consuming clinical assessment. The device appears to be well-tolerated and no more subject to error than capnometry.

### Declaration of interest

O.M., A.G., and D.F. received lecture fees and travel expenses from Masimo Corp.

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**Table 2** Events affecting the accuracy of respiratory rate measurement of the two devices. The occurrence of an event was considered as affecting measurement accuracy of either device if a sudden change of at least 4 bpm for 10 s or more followed the occurrence of the event, without a concomitant change in the readings of the other device.

<table>
<thead>
<tr>
<th>Event</th>
<th>Capnometer</th>
<th>Acoustic device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speaking (n=15)</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Moving (n=7)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Coughing (n=5)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Repeated swallowing (n=2)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Mask removal or sensor repositioning (n=21)</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

(–1.4–1.4) bpm. Differences in respiration rate of >4 bpm for 20 s or more between the two devices led to 28 clinical assessments of respiration rate. Errors were attributed to the capnometer in 13 cases, the acoustic device in 10 cases, and both methods in five cases. Eighty events that could interfere with respiratory measurements occurred during the study period, including 30 episodes of speaking, 23 of moving, 14 of coughing, six of snoring, three of repeated swallowing, one of sighing, one of vomiting, one of moaning, and one of apnoea. Fifteen episodes of speaking, seven episodes of moving, five episodes of coughing, and two episodes of repeated swallowing led to inaccurate readings (a change of at least 4 bpm for 10 s or more reported by one device but not the other) during the study period (Table 2). Most often, an erroneous increase in respiratory rate was displayed. Only one episode of apnoea, lasting for 30 s, was observed clinically during the study period. Apnoea was detected immediately by the acoustic device, whereas capnometry displayed a slow decrease in respiration rate.
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References
9 Paul J, Ling E, Hajjgato J, McDonald L. Both the OxyArm and Capnopygen mask provide clinically useful capnographic monitoring capability in volunteers. Can J Anaesth 2003; 50: 137–42
12 Yanagidate F, Dohi S. Modified nasal cannula for simultaneous oxygen delivery and end-tidal CO₂ monitoring during spontaneous breathing. Eur J Anaesthesiol 2006; 23: 257–60