CAPNOMETRY FOR CONTINUOUS POSTOPERATIVE MONITORING OF NONINTUBATED, SPONTANEOUSLY BREATHING PATIENTS

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ABSTRACT. We continuously monitored spontaneous respiration after extubation by end-tidal CO_2 tension ($P_{ET}CO_2$) in 19 patients aged 20 to 72 years who had undergone major operations. The respiratory gas was sampled from the nasopharynx via a special nasal catheter and analyzed by a sidestream analyzer. In each case, optimal placement of the nasal catheter was determined by CO_2 waveform and the capnograms were recorded for waveform analysis and trend monitoring. $P_{ET}CO_2$ was compared with arterial CO_2 tension ($PaCO_2$) two to four times during the 2- to 19-hour observation periods by simultaneous measurements. For 65 simultaneous measurements, mean $P_{ET}CO_2$ was 38.9 ± 5.7 mm Hg (range, 26.3 to 48.3 mm Hg) and mean $PaCO_2$ was 38.9 ± 5.7 mm Hg (range, 26.8 to 46.0 mm Hg; $r = 0.82$; $p < 0.01$). While the mean values for $P_{ET}CO_2$ and $PaCO_2$ were similar, several patients had large differences for $PaCO_2$ to $P_{ET}CO_2$. The differences of the individual patients did not differ significantly between the various times of measurement. We conclude that this form of capnometry is well suited for continuous, noninvasive monitoring of respiration in nonintubated, spontaneously breathing patients.

KEY WORDS. Measurement techniques: capnography. Monitoring: carbon dioxide tension; end-tidal. Ventilation: spontaneous.

Since respiratory problems are a major cause of postoperative morbidity and mortality, monitoring respiration after extubation is important. Respiration can be monitored by several means: detection of respiratory flow at mouth and nose (temperature probe), measurement of changes in abdominal and thoracic volume (bellows pneumograph, abdominal and thoracic magnetometers, respiratory jacket plethysmograph, impedance pneumography, electrical inductance transducer, inductance plethysmography), and direct measurement of gas flow (canopy ventilation monitor) [1–4].

However, the noninvasive respiratory monitors currently available for continuous quantitative measurement of respiratory parameters in nonintubated patients are too cumbersome or inappropriate for postoperative monitoring. Although continuous determination of end-tidal CO_2 is a recognized and established method for monitoring the adequacy of alveolar ventilation [5–9], little information is available on the postoperative application of capnometry in nonintubated patients [10]. Our study investigated the clinical applicability of capnometry for monitoring spontaneous respiration in nonintubated patients after major operations. The arterial catheter, inserted preoperatively, permitted repeated blood gas analyses, and a recently developed nasopharyngeal tube was used for gas sampling.

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METHODS

End-tidal CO_2 ($P_{ET}CO_2$) measurement by capnometry was used postoperatively to monitor spontaneous respiration after extubation in 19 patients (ASA status II or III; ages, 19 to 72 years; mean age, 52 years) who gave informed consent to participate in the study prior to operation. Seventeen patients had open heart surgery for coronary artery or valvular heart disease, 1 patient underwent gastrectomy, and 1 underwent esophagectomy.

A calibrated capnometer with monitor display of CO_2 (HP 78345 A, Hewlett Packard) was used to determine partial CO_2 pressure in respiratory gas. Trend was monitored by simultaneous tracing of the capnogram by an analog recorder (HP 7754 A; Hewlett Packard, Böblingen, Germany) with a writing speed of 0.25 mm/s. Respiratory gas was sampled continuously by a prototype polyvinylchloride catheter with guide (3 mm ID; 4 mm OD) (Rüsch, Waiblingen, Germany; distributed by Hewlett Packard) (Fig 1).

The catheter was introduced approximately 8 to 10 cm through the nose and advanced into the nasopharynx. As the guide was withdrawn, the tip of the tube opened to form a basket (Fig 1b), thus preventing the catheter opening from touching the pharyngeal wall and preventing aspiration of secretions. The catheter was optimally positioned with the probe in the nasopharynx and the CO_2 waveform showing a distinct end-expiratory plateau. Because the Hewlett Packard capnometer is a mainstream analyzer, gas flow through the gauge head is maintained by a pump (suction speed, 150 mL/min) with an attached water trap.

Arterial blood gas was analyzed two to four times during the 2- to 19-hour monitoring phase (ABL 30; Radiometer, Copenhagen, Denmark). At the same time, $P_{ET}CO_2$ was recorded and, for exact waveform evaluation, the capnogram was traced for 30 seconds at a writing speed of 25 mm/s.

Spearman rank correlation was performed to determine the correlation between arterial CO_2 tension ($PaCO_2$) and $P_{ET}CO_2$. Wilcoxon signed rank test was performed to compare $PaCO_2$–$P_{ET}CO_2$ differences for the 4 sets of measurements. Data are expressed as mean ± SD. Statistical significance was set at $p < 0.05$.

RESULTS

The CO_2 curves obtained during placement of the nasal tube indicated that acceptable capnograms were produced even in somnolent or uncooperative patients, some of whom breathed through their mouths. Patients tolerated the tubes well; only one tube had to be reinserted during the 16-hour monitoring period because it had been withdrawn by a restless patient. When the catheter was inserted 8 to 10 cm into the nose, the capnograms showed almost horizontal plateaus, rapid CO_2 increase during expiration, and rapid CO_2 decrease during inspiration (Fig 2). Deeper tube placement may evoke coughing or retching.

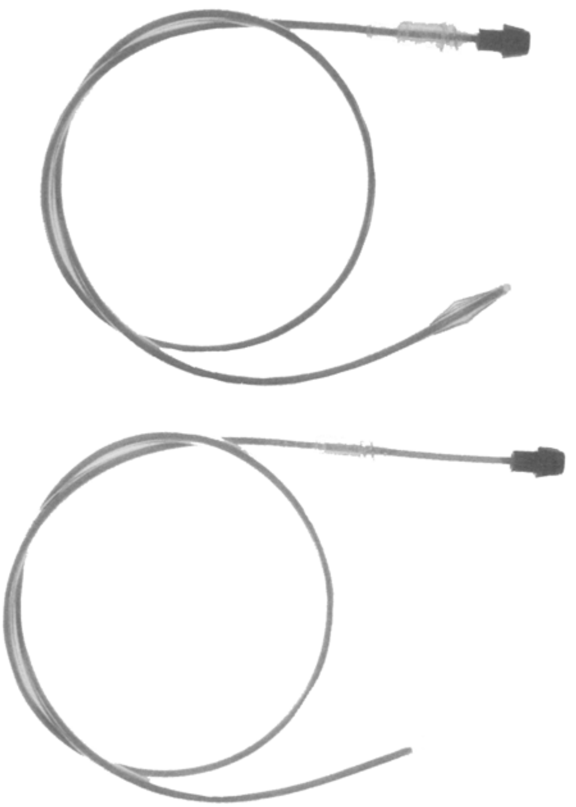

Fig 1. Rüsch nasal catheter. (Top) *The guide inside creates a stretched tip.* (Bottom) *With the guide withdrawn, a basket tip is exposed.*

For 65 simultaneous measurements, mean $P_{ET}CO_2$ was 38.9 ± 5.7 mm Hg (range, 26.3 to 48.3 mm Hg) and mean $PaCO_2$ was 38.9 ± 5.7 mm Hg (range, 26.8 to 46.0 mm Hg) (Fig 3). There was a close correlation between $P_{ET}CO_2$ and $PaCO_2$ ($r = 0.82$, $p < 0.01$). The mean $PaCO_2$–$P_{ET}CO_2$ difference was 0.2 ± 3.4 mm Hg. The $PaCO_2$–$P_{ET}CO_2$ differences of the individual patients did not differ significantly between the various times of measurement (Fig 4).

DISCUSSION

Continuous noninvasive capnometric monitoring of alveolar ventilation in mechanically ventilated patients is a widely accepted clinical practice [11] and has also been described for monitoring of spontaneous respiration in intubated intensive care patients [10]. However, few data are available on capnometric monitoring in nonintubated, spontaneously breathing patients, although

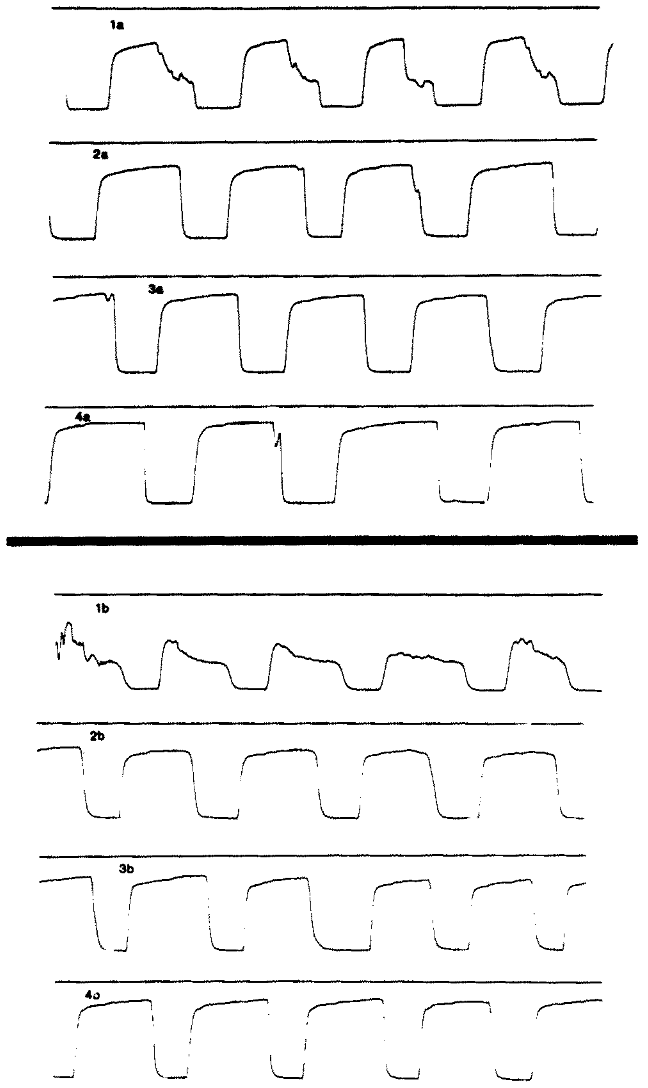

Fig 2. Capnograms at various depths of insertion. (Top) *Nasal breathing with catheter inserted 4 (1a), 6 (2a), 8 (3a), and 10 (4a) cm into the nose.* (Bottom) *Mouth breathing with catheter inserted 4 (1b), 6 (2b), 8 (3b), and 10 (4b) cm into the nose.*

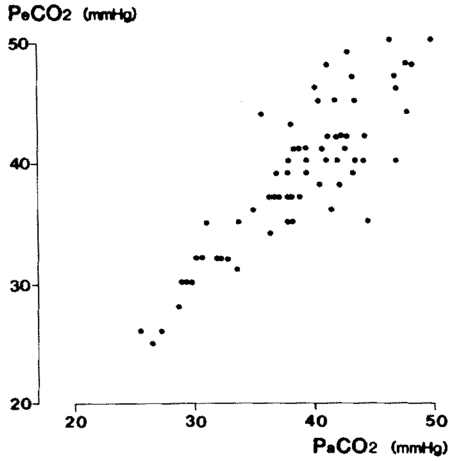

Fig 3. An x-y plot of $PETCO_2$ ($PeCO_2$) *versus $PaCO_2$. The coefficient of correlation was r = 0.82; the data fit the equation $PaCO_2 = 3.67 + 0.91\ PETCO_2$.*

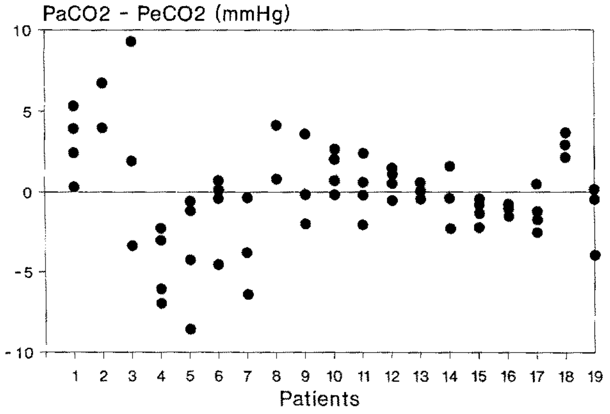

Fig 4. Plot of $PaCO_2$–$PETCO_2$ ($PeCO_2$) *differences at two to four times of measurement in 19 patients.*

several methods of expiratory CO_2 measurement have been described [12–17].

Our findings in postoperative patients indicate that, for clinical purposes, the correlation between noninvasively determined $PETCO_2$ and invasively determined $PaCO_2$ is good. While the mean values for $PETCO_2$ and $PaCO_2$ were similar, several patients had large $PaCO_2$–$PETCO_2$ differences. Comparison of $PaCO_2$–$PETCO_2$ differences, however, showed no significant differences between the first set of measurements and the subsequent sets of measurements. This finding is of interest with respect to the practice of "calibrating" the $PaCO_2$ estimate by an initial measurement of $PaCO_2$ [7,18,19].

The low mean $PaCO_2$–$PETCO_2$ difference observed (0.2 ± 3.4 mm Hg) is in contrast to reported $PaCO_2$–$PETCO_2$ differences under anesthesia [9,18,19]. Low $PaCO_2$–$PETCO_2$ differences, however, were observed during cesarean section and postdelivery tubal ligation [20].

Whereas the markedly elevated (positive) $PaCO_2$–$PETCO_2$ differences in some of our patients may be attributed to disturbances of ventilation to perfusion ratio or, even more likely, incomplete expiration and contamination of the expiratory gas fraction by ambient air [9,11,19], zero and negative $PaCO_2$–$PETCO_2$ differences, observed in 9 of 19 patients (47%), are difficult to explain. Negative $PaCO_2$–$PETCO_2$ differences have also been reported during cesarean section (in 50% and 78% of the study's patients), during postdelivery tubal ligation (in 31%), and in nonpregnant patients under anesthesia (in 12%) [20]. Several explanations for zero and negative $PaCO_2$–$PETCO_2$ differences have been reported, including (1) rebreathing of CO_2 from relatively underventilated compartments; (2) equilibration of

PaCO$_2$ with mixed venous PCO$_2$ in patients with a low ventilation to perfusion ratio; and (3) the Haldane effect associated with release of CO$_2$ as hemoglobin becomes saturated with O$_2$ [20–22]. End-tidal PCO$_2$ may exceed spatial and temporal mean PaCO$_2$, especially if functional residual capacity is reduced, as in pregnant or obese patients [20,22]. This may be true for postoperative patients with reduced functional residual capacity.

Since our method is continuous and noninvasive, it is especially well suited for monitoring spontaneously breathing, nonintubated patients. The patient is not overly stressed and, apparently, not subject to any risk. When capnometry is performed correctly, the rate and depth of respiration in terms of alveolar ventilation (PCO$_2$) can be estimated. Upper and lower alarm limits for both parameters can be set so that the capnometer warns of impending hypopnea and apnea. Continuous capnography at a slow writing speed allows for uninterrupted documentation and trend monitoring, while the capnogram and the end-expiratory plateau can be analyzed with capnography at a fast writing speed [8]. Analysis of CO$_2$ waveform is well suited to detect pathologic changes in the air passages and alveoli [8,11]. Whereas Riker and Haberman [10] reported that the nasopharyngeal catheter they used for gas sampling was often plugged with secretory fluid, no such plugging of our catheter was observed.

In conclusion, continuous PETCO$_2$ monitoring permits early detection of alveolar hypoventilation and/or airway obstruction without the necessity of frequent blood gas analyses. Based on the good correlation, PaCO$_2$ can be estimated from PETCO$_2$ measurements once the difference is established by an arterial blood gas analysis. In our patients, this method was reliable for clinical purposes, even in the presence of deviations, because the PaCO$_2$–PETCO$_2$ difference remained essentially stable. In addition to postoperative monitoring, the method may also be suitable for surveillance of patients at risk during regional anesthesia and parenteral or epidural application of opiates, as well as for monitoring subjects participating in sleep research projects.

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