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ORIGINAL ARTICLE

A comparison of the end-tidal CO_2 measured by portable capnometer and the arterial PCO_2 in spontaneously breathing patients

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Abstract An end-tidal CO_2 ($ETCO_2$) monitor (capnometer) is used most often as a noninvasive substitute for $PaCO_2$ in anesthesia, anesthetic recovery and intensive care. However, the utility and accuracy of the portable capnometer in spontaneously breathing patients with or without chronic pulmonary diseases has received little recognition. To determine the utility of the portable capnometer in general wards and in in-home care, we examined the correlation between $ETCO_2$ measured by a portable capnometer and simultaneous $PaCO_2$ measured in 41 spontaneously breathing patients. TV-$ETCO_2$ ($ETCO_2$ measured by tidal volume maneuver) was lower than $PaCO_2$ by an average of 9.0 mmHg and VC-$ETCO_2$ ($ETCO_2$ measured by vital capacity maneuver) was lower than $PaCO_2$ by an average of 0.5 mmHg. The mean difference between $PaCO_2$ and VC-$ETCO_2$ was not statistically significant. Regression analysis showed a close correlation between VC-$ETCO_2$ and $PaCO_2$ ($r = 0.91$, $P < 0.0001$). Thus, VC-$ETCO_2$ was highly correlated with $PaCO_2$. Furthermore, a close correlation between VC-$ETCO_2$ and $PaCO_2$ was also observed in patients with compromised pulmonary function ($r = 0.88$, $P < 0.0001$ in patients with below 70% of $FEV_{1.0}$%; $r = 0.89$, $P < 0.0001$ in patients with below 80% of %VC). Our studies show that VC-$ETCO_2$ measured by the portable capnometer gives a reliable point estimate of $PaCO_2$, and can be useful to evaluate the respiratory condition of spontaneously breathing patients in general wards and in in-home care.

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Keywords capnometer; TV-$ETCO_2$; VC-$ETCO_2$; $PaCO_2$.

INTRODUCTION

In today's changing health-care environment, noninvasive cardiopulmonary monitors are tools that can be used to a greater extent to affect quality of care. Pulse oximetry is widely used to evaluate respiratory condition (especially oxygenation) in medical facilities, such as intensive care units, general wards, nursing homes and in-home care. Because the monitor shows oxygen saturation, we can easily estimate arterial O_2 pressure (PaO_2). However, we cannot use the device to estimate arterial CO_2 pressure ($PaCO_2$), another important index for evaluating respiratory condition (especially ventilation). Therefore, monitoring $PaCO_2$ along with pulse oximetry are very useful tools for evaluation of respiratory status.

Capnometry is a noninvasive tool that can measure end-tidal CO_2 ($ETCO_2$). The difference between $PaCO_2$ and $ETCO_2$ has been shown to be only 1–2 mmHg in healthy subjects with normal lungs and uncompromised pulmonary function (1,2). Recently, an inexpensive, portable, colorimetric device has been developed permitting semiquantitative assessment of $ETCO_2$. The device is now used mainly in intensive care, post-anesthetic recovery and emergency care (3–6). However, the utility and

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accuracy of portable capnometry in nonintubated patients has not been fully examined (7).

This study, undertaken with a group of nonintubated patients, had the following goals: (1) to examine the correlation between $PaCO_2$ and $ETCO_2$ in spontaneously breathing patients with or without chronic pulmonary diseases, (2) to determine whether $ETCO_2$ measured by tidal volume (TV-$ETCO_2$) or vital capacity (VC-$ETCO_2$) shows a more significant correlation with $PaCO_2$, and (3) to describe the relationship between VC-$ETCO_2$ and $PaCO_2$ in patients with compromised pulmonary function.

METHODS

Study population

Forty-one patients admitted to medical wards of Kumamoto Rosai Hospital participated in the study. There were 30 men and 11 women, and their ages were 69 ± 14 years. All patients were informed of the purpose of the study and gave written consent. All could breathe spontaneously, and their consciousness was clear with a Glasgow Coma Scale ≥ 13. Cardiac shock and pulmonary thromboembolism were not observed in our cases. Underlying diseases of the patients were as follows: chronic obstructive pulmonary disease, nine cases; pneumoconiosis, five cases; pneumonia, five cases; lung cancer, four cases; other lung diseases, four cases; diseases other than lung diseases, seven cases; and preoperative state, seven cases.

$ETCO_2$ measurements

The $ETCO_2$ in the exhaled air was measured using microstream nondispersive infrared spectroscopy (NPB-75 handheld capnograph/pulse oximeter, Nellcor Puritan Bennett Inc., Pleasanton, CA, U.S.A). The response time of the device was 240 ms, and the results were displayed digitally as the breath-to-breath peak CO_2 concentration. Subjects were asked to perform a tidal volume (TV) maneuver and a vital capacity (VC) maneuver into the mouthpiece by constant flow. The $ETCO_2$ measured by a TV maneuver was defined as TV-$ETCO_2$, and the $ETCO_2$ measured by a VC maneuver was defined as VC-$ETCO_2$. Exhaled air was gathered by connecting a side stream sampling device at a constant sampling rate of 50 ml/min, and the value of stable plateau $ETCO_2$ was recorded. Two successive and stable recordings were undertaken, and the mean of the two values was used for statistical analysis.

Data collection

First, blood gas analysis was performed for each patient. Next, $ETCO_2$ was measured and recorded for each patient. Pulmonary function tests were measured by a dry rollingseal spirometer (Fudac-70, Fukuda Denshi Co., Tokyo, Japan). In addition, vital signs of each patient were also examined and recorded.

Statistical analysis

Data are shown as means $\pm$ SD. The significance of the difference between simultaneously obtained $PaCO_2$ and TV-$ETCO_2$ or VC-$ETCO_2$ was evaluated using the paired Student's t-test. Linear regression was used to calculate the correlation between (1) $PaCO_2$ and VC-$ETCO_2$, and (2) $PaCO_2$ and VC-$ETCO_2$ in patients with below 70% of $FEV_{1.0}$% (ratio of forced expiratory volume in 1 s to forced vital capacity) or in patients with below 80% of %VC (ratio of vital capacity to predicted vital capacity).

RESULTS

Physical examinations of the patients were as follows: body temperature was 36.5 ± 0.5°C, systolic blood pressure was 128 ± 23 mmHg, diastolic blood pressure was 72 ± 12 mmHg, $PaCO_2$ was 44.0 ± 15.7 mmHg, PaO_2 was 83.8 ± 17.8 mmHg, %VC was 80.7 ± 25.7%, $FEV_{1.0}$% was 67.4 ± 17.8%, and the ratio of peak expiratory flow to predicted peak expiratory flow (%PEF) was 67.4 ± 36.2%. Individual values of $PaCO_2$, TV-$ETCO_2$ and VC-$ETCO_2$ are listed in Table 1.

The relationship between $PaCO_2$ and the error of the TV-$ETCO_2$ measurement ($PaCO_2$ minus TV-$ETCO_2$, mmHg) is graphed in Fig. 1. Differences between $PaCO_2$ and TV-$ETCO_2$ varied from -8.2 to 52.5 mmHg. Overall bias was 9.0 mmHg, with a precision of 12.9. This observation indicates that, on average, TV-$ETCO_2$ was 9.0 mmHg lower than simultaneously measured $PaCO_2$. The mean difference between $PaCO_2$ and TV-$ETCO_2$ was statistically significant ($P < 0.0001$).

The relationship between $PaCO_2$ and the error of the VC-$ETCO_2$ measurement ($PaCO_2$ minus VC-$ETCO_2$, mmHg) is graphed in Fig. 2. Differences between $PaCO_2$ and VC-$ETCO_2$ varied from -12.3 to 20.5 mmHg. Overall bias was 0.5 mmHg, with a precision of 6.5, indicating that VC-$ETCO_2$ was 0.5 mmHg lower than simultaneously measured $PaCO_2$. The mean difference between $PaCO_2$ and VC-$ETCO_2$ was not statistically significant ($P = 0.61$). Simultaneous $PaCO_2$ and VC-$ETCO_2$ values are graphed in Fig. 3. A correlation between the two was observed ($r = 0.91$, $P < 0.0001$). Thus, VC-$ETCO_2$ showed a significant correlation with $PaCO_2$.

We further examined whether VC-$ETCO_2$ was correlated with $PaCO_2$ in patients with compromised pulmon-

TABLE I. Respiratory variables

Patient	$PaCO_2$ (mmHg)	TV-$ETCO_2$ (mmHg)	VC-$ETCO_2$ (mmHg)
1	57.0	22.0	61.0
2	55.0	49.0	60.0
3	33.5	33.0	41.0
4	35.1	27.0	25.0
5	59.6	20.0	56.0
6	66.1	50.0	66.0
7	36.9	30.0	38.0
8	33.0	32.0	45.0
9	52.2	35.0	53.0
10	38.9	39.0	37.0
11	35.3	28.0	27.0
12	49.6	38.0	54.0
13	61.9	44.0	58.0
14	24.8	33.0	37.0
15	54.7	31.0	61.0
16	35.8	33.0	38.0
17	44.8	35.0	47.0
18	67.2	28.0	53.0
19	38.9	38.0	34.0
20	58.6	56.0	64.0
21	35.9	24.0	32.0
22	39.1	38.0	38.0
23	46.8	38.0	46.5
24	44.8	38.0	44.0
25	32.7	28.0	34.0
26	35.5	28.0	29.0
27	37.5	29.0	31.0
28	37.7	33.0	32.0
29	39.5	35.0	37.0
30	31.5	36.0	32.0
31	33.0	39.0	35.0
32	117.5	65.0	97.0
33	34.8	26.0	35.0
34	43.5	37.0	43.0
35	39.8	35.0	37.0
36	31.7	34.0	35.0
37	33.7	38.0	46.0
38	38.4	29.0	35.0
39	35.7	26.0	33.0
40	33.0	39.0	36.0
41	43.5	39.0	41.0
mean	44.0	35.0	43.5
SD	15.7	8.7	13.8

TV-$ETCO_2$: end-tidal CO_2 measured by tidal volume maneuver.
VC-$ETCO_2$: end-tidal CO_2 measured by vital capacity maneuver.

ary function. Fig. 4A illustrates the correlation between VC-$ETCO_2$ and $PaCO_2$ in patients with below 70% of $FEV_{1.0}$% (n = 15). A significant correlation between VC-$ETCO_2$ and $PaCO_2$ was observed ($r = 0.88$, $P < 0.0001$). Figure 4B illustrates the correlation between VC-$ETCO_2$ and $PaCO_2$ in patients with below 80% of %VC (n = 13). A significant correlation between VC-$ETCO_2$ and $PaCO_2$ was observed ($r = 0.89$, $P < 0.0001$).

DISCUSSION

Pulse oximetry and capnometry have been widely accepted as sensitive and accurate instruments that produce clinically useful data. They are used mainly in anesthetic practice and intensive care (8). The pulse oximeter gives a noninvasive continuous readout of the oxygen saturation of hemoglobin in arterial blood allowing

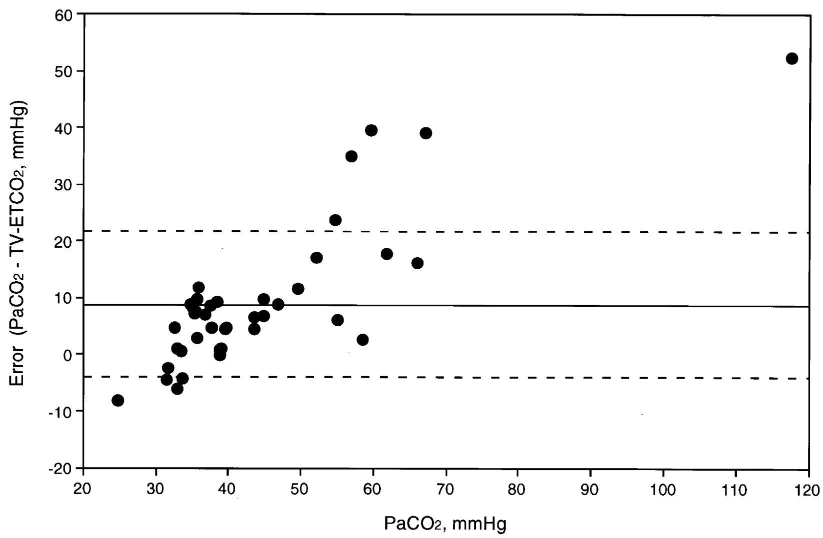

FIG. 1. Relationship between $PaCO_2$ and the error of the TV-$ETCO_2$ measurement ($PaCO_2$ minus TV-$ETCO_2$, mmHg) in 41 spontaneously breathing patients. Solid line and dashed lines define mean and standard deviation, respectively. The mean difference between $PaCO_2$ and TV-$ETCO_2$ was statistically significant ($P < 0.0001$).

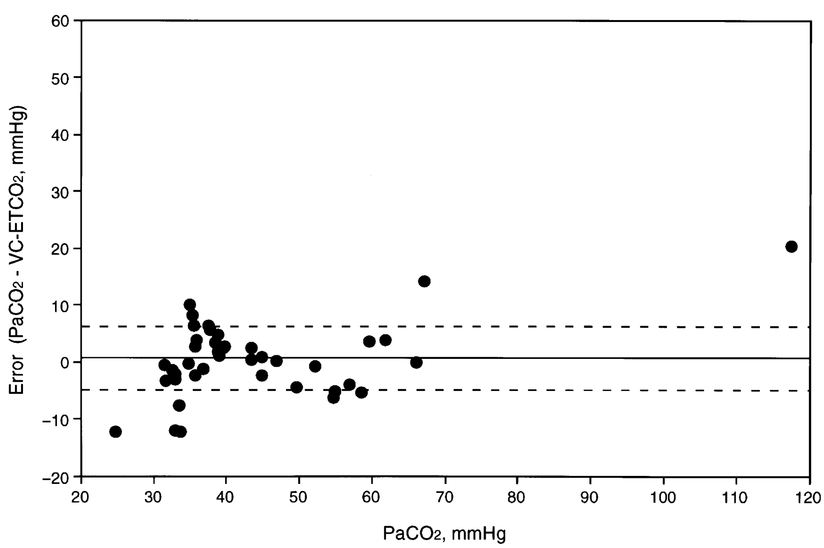

FIG. 2. Relationship between $PaCO_2$ and the error of the VC-$ETCO_2$ measurement ($PaCO_2$ minus VC-$ETCO_2$, mmHg) in 41 spontaneously breathing patients. Solid line and dashed lines define mean and standard deviation, respectively. The mean difference between $PaCO_2$ and VC-$ETCO_2$ was not statistically significant ($P = 0.61$).

assessment of adequacy of lung perfusion and oxygen delivery to tissues. On the other hand, $PaCO_2$, which is an index of respiratory ventilation, is a valuable indicator of the clinical status of metabolic, cardiovascular, and respiratory systems. Although arterial blood gas (ABG) analysis provides a $PaCO_2$ value, we cannot always measure ABG, especially in nursing homes and in in-home care. Thus, we examined whether the portable capnometer can estimate actual $PaCO_2$ in patients breathing spontaneously.

In the present study, we demonstrated that VC-$ETCO_2$ measured by portable capnometer showed a significant correlation with $PaCO_2$. We also demonstrated that VC-$ETCO_2$ was highly correlated with $PaCO_2$ in patients with compromised pulmonary function. These results show that the measurement of VC-$ETCO_2$ by portable capnometer can be helpful in estimating $PaCO_2$ and detecting hyper- or hypoventilation in patients breathing spontaneously.

The measurement of $ETCO_2$ is easily undertaken and has been found useful for continuous monitoring, particularly in mechanically ventilated patients (9). In addition, studies of the relationship between $PaCO_2$ and $ETCO_2$ have traditionally examined intubated and mechanically

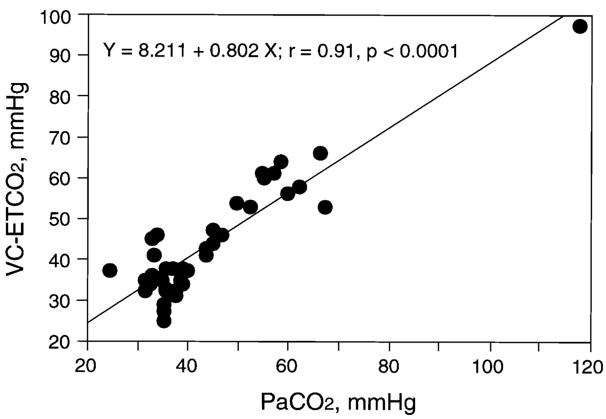

Fig. 3. Comparison of simultaneously determined $PaCO_2$ and VC-$ETCO_2$ in 41 spontaneously breathing patients. The two were highly correlated ($r = 0.91$, $P < 0.0001$).

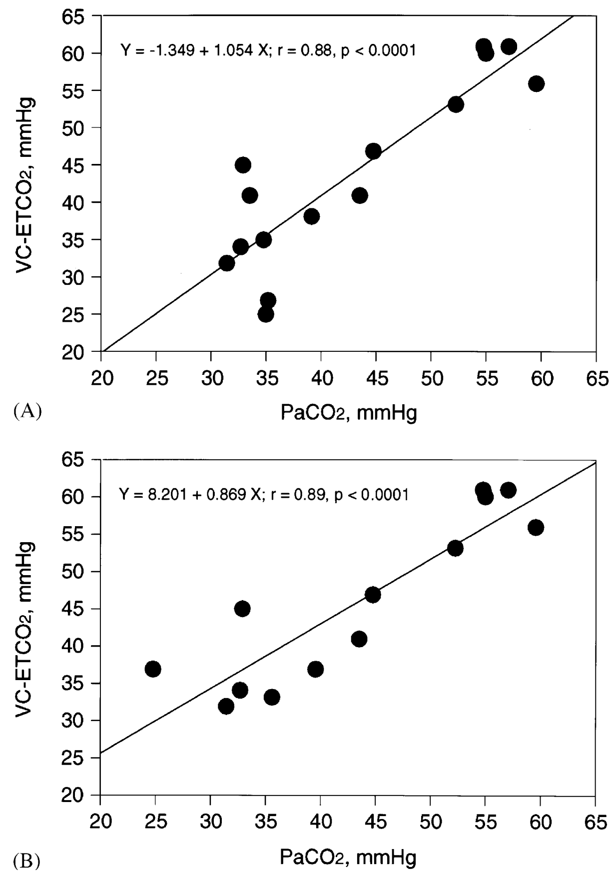

Fig. 4. (A) Comparison of simultaneously determined $PaCO_2$ and VC-$ETCO_2$ in 15 patients with below 70% of $FEV_{1.0}$%. The two were highly correlated ($r = 0.88$, $P < 0.0001$). (B) Comparison of simultaneously determined $PaCO_2$ and VC-$ETCO_2$ in 13 patients with below 80% of %VC. The two were highly correlated ($r = 0.89$, $P < 0.0001$).

ventilated patients with chronic or acute on chronic respiratory failure (10). However, studies of the relationship between $PaCO_2$ and $ETCO_2$ in the patients breathing spontaneously have not been fully examined (7). The levels of $ETCO_2$ and $PaCO_2$ depend on ventilation, cardiac output, CO_2 output, and pulmonary function; a change in any of these will cause a change in $ETCO_2$ (11). In our study, reliable $ETCO_2$ was obtained when a VC maneuver was performed on each patient, indicating that full expiration to the maximal expiratory position is necessary for precise estimation of $PaCO_2$. These results indicate that $PaCO_2$ estimation by VC-$ETCO_2$ using portable capnometer is unsuitable for the patients with dementia, unclear consciousness, or unstable respiratory failure, and for sleep studies.

Our studies also showed that the [Pa-(VC-ET)]CO_2 gradient was on average 0.5 mmHg. Hatle and Rokseth measured P(a-et)CO_2 in several groups of individuals (12). The $PaCO_2$ of normal subjects during normal respiration was within 3.5 mmHg of $ETCO_2$, and they considered ± 5 mmHg to represent the normal range for P(a-et)CO_2. Although patients with various lung diseases were included in our study, our results corroborated their results, suggesting that the difference between $PaCO_2$ and $ETCO_2$ is small in both healthy subjects and patients with compromised pulmonary function. Thus, $ETCO_2$ is also reliable in patients with impaired pulmonary function.

In summary, the current study demonstrates that in patients breathing spontaneously, VC-$ETCO_2$ measured by portable capnometer provides a more accurate estimate of $PaCO_2$ than TV-$ETCO_2$. Thus, we have found the portable capnometer not only accurate but simple to use and therefore appropriate for homecare monitoring of respiratory patients.

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