Is Measurement of End-tidal CO_2 Through a Nasal Cannula Reliable?

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When using a nasal cannula to sample gases expired by a patient, air from the room may dilute the sample. For this reason, the accuracy of the partial pressure of end-tidal carbon dioxide (E_TCO_2) measurements is questionable. We experimentally examined the reliability of E_TCO_2 measurements through a nasal cannula and found that they depended on both biological factors (tidal volume and respiratory rates) and mechanical factors (the diameter and the length of the cannula and the diameter of the prongs). These results suggest that the correct use of an appropriate sampling cannula will provide reliable E_TCO_2 measurements without clinical problems.

Key Words: End-tidal CO_2; Nasal cannula; Capnography.

Capnography is useful for respiratory monitoring during intravenous sedation.[1–6] However, because the air in a room may dilute the gases expired by a patient during sampling through a nasal cannula, a question arises regarding the accuracy of measurements of the partial pressure of end-tidal carbon dioxide (E_TCO_2). It is necessary to have accurate values of E_TCO_2 during intravenous sedation to detect respiratory depression, including apnea. In this study we experimentally examined this issue, including the reliability of various nasal cannulas for measuring E_TCO_2.

METHODS

Experimental Model

Figure 1 shows the experimental model. We used a volume-limited ventilator (ARF-850E; Acoma Medical Industry, Tokyo, Japan) as a model lung. By connecting a CO_2 cylinder to the ventilator, the rate of delivery of CO_2 was constant. The experimental model also allowed us to preset the partial pressure of the CO_2 eliminated at 40 mmHg. A face model, with a dead air space of 150 ml, was connected to the ventilator. Two types of nasal cannulas were examined (Figure 2). The type one cannula was handmade and used for carbon dioxide sampling and oxygen delivery. The cannula was 300 cm long and composed of two portions. The distal 80-cm portion, including the prongs, was 2.0 mm in diameter. The proximal 220-cm portion was only 1.7 mm in diameter. The distal portion had a removable part, which was 53 cm long that permitted us to change the length of the cannula (from 300 to 247 cm), the diameter of the cannula (from 2.0 to 1.5 mm), and the diameter of the prongs (from 2.0 to 1.0 mm). The type two cannula is commercially available (Model 4000; Salterlabs). This cannula was 240 cm long and 1.5 mm in diameter, but the prongs were only 1.0 mm in diameter.

Experimental Protocol

The E_TCO_2 of the expired gas from the experimental model was sampled with an anesthetic gas monitor (Capnomac; Datex, Helsinki, Finland) using both types of nasal cannulas. The sampling rate was calibrated to 200 ml/min. The E_TCO_2 was measured under the following seven different conditions: tidal volumes (V_T) of 250, 380, and 500 ml with respiratory rates (RR) of 10 and 14/min, and a V_T of 250 ml with a RR of 20/min. With the type one cannula, the E_TCO_2 was measured under three additional conditions: changing the diameter of the prongs from 2.0 to 1.0 mm, changing the diameter of the distal portion of the cannula from 2.0 to 1.5 mm, and changing the length of the cannula from 300 to 247 cm. With the type two cannula, the V_T was

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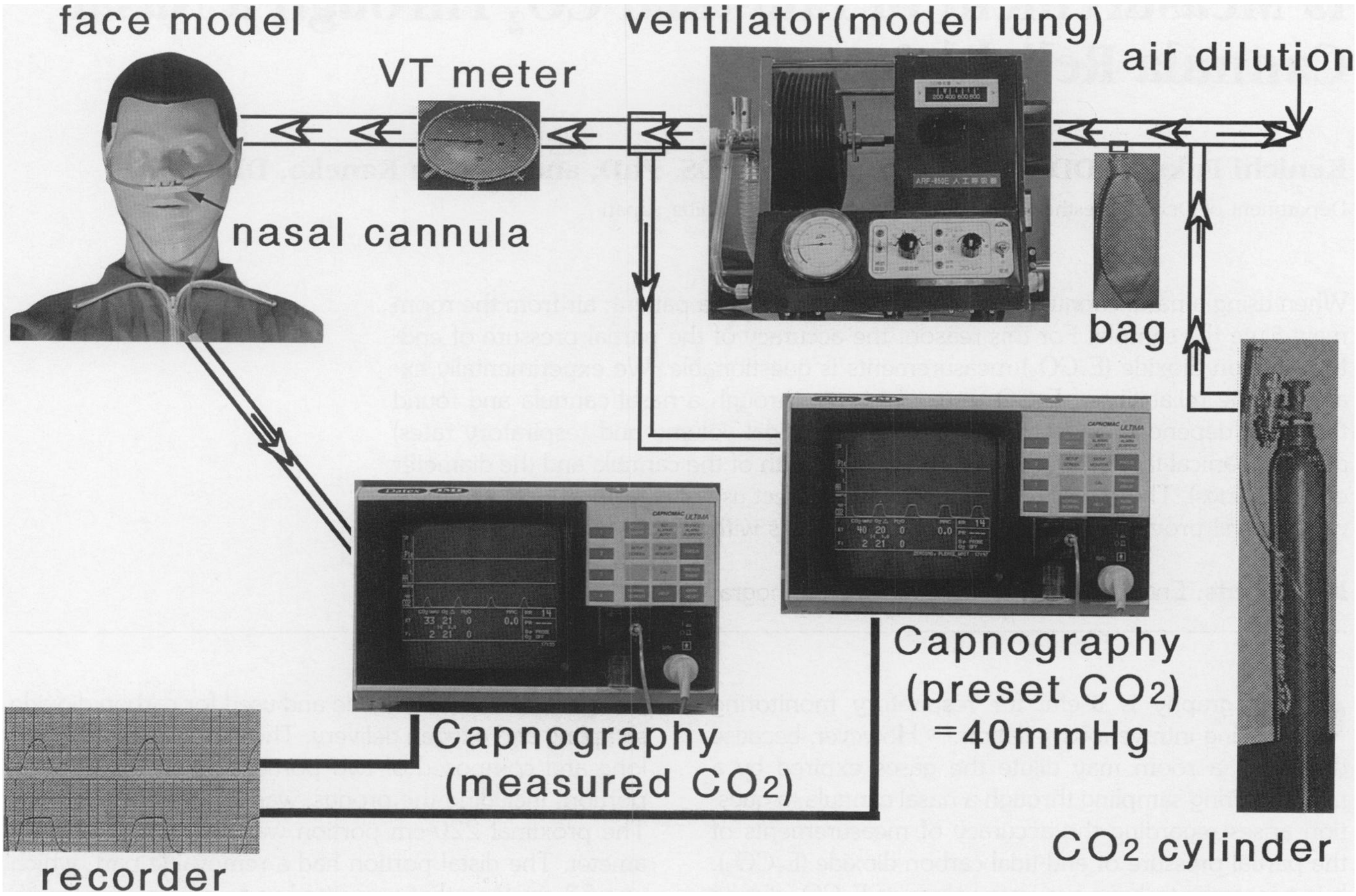

Figure 1. Experimental model: the CO_2 was delivered at a constant flow rate from the cylinder. The partial pressure of the CO_2 eliminated from the nares of the face model was preset to a constant 40 mmHg.

gradually increased from 380 to 500 ml at a constant RR of 14/min. This protocol was used to detect the V_T level at which the E_TCO_2 approximated 40 mmHg, the preset partial pressure of the CO_2 eliminated.

RESULTS

The measurements were repeated many times in this study and equivalent values were obtained for each experiment. Larger V_T resulted in more reliable E_TCO_2 measurements (Figure 3) than did smaller V_T. The type two cannula for a V_T of 500 ml produced an accurate E_TCO_2, measurement; however, the type one cannula for a V_T of 250 ml showed far less E_TCO_2 than the preset partial pressure of the CO_2 eliminated. Lower RR

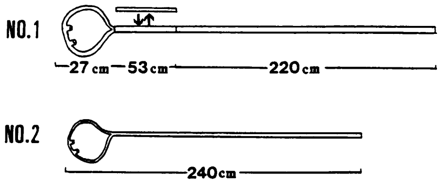

Figure 2. Type one nasal cannula (handmade) showing the anterior portion (diameter 2.0 mm, length 80 cm), posterior portion (diameter 1.7 mm, length 220 cm), removable anterior portion (diameter 1.5 mm, length 53 cm), and the prongs (diameter 2.0 mm). Type two nasal cannula (Salterlabs model 4000) showing the prongs (diameter 1.0 mm) and the tube (diameter 1.5 mm, length 240 cm).

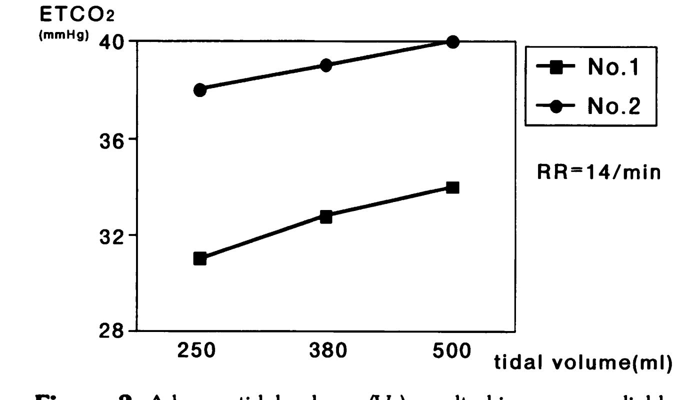

Figure 3. A larger tidal volume (V_T) resulted in a more reliable measurement of the partial pressure of the end-tidal carbon dioxide (E_TCO_2)

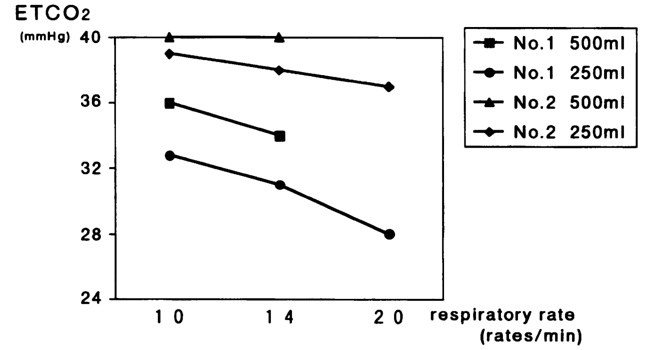

Figure 4. A lower respiratory rate (RR) resulted in a more reliable measurement of the partial pressure of the end-tidal carbon dioxide (E_TCO_2).

gave more reliable E_TCO_2 measurements (Figure 4) than higher RR did. The type two cannula for RR of 10 and 14/min and a V_T of 500 ml gave accurate E_TCO_2 values, but the type one cannula for the same conditions showed less E_TCO_2 than the preset partial pressure of the CO_2 eliminated. For the lowest V_T and the highest RR, the E_TCO_2 measured using the type two cannula was 37 mmHg, and it was 28 mmHg when the type one cannula was used. The latter value is far less than the preset partial pressure of the CO_2 eliminated (Figure 5a). This value was slightly improved by using the smaller diameter prongs (Figure 5b), by using the smaller diameter cannula (Figure 5c), or by using the shorter cannula (Figure 5d). When the V_T was gradually increased with a constant RR of 14/min using the type two cannula, the value for E_TCO_2 approximated 40 mmHg at 410 ml V_T.

DISCUSSION

The accuracy of the E_TCO_2 measurements depends on several factors, including the V_T and the RR (biological factors) and the diameter and length of the cannula (mechanical factors). The capnogram shows a plateau when the alveolar gas is expired because, at that time, the gas in the dead air space no longer influences the capnogram. The maximum value at the end of the plateau is equal to the alveolar CO_2 concentration. For the E_TCO_2 to approximate the alveolar CO_2 concentration, there must be sufficient V_T to completely flush the dead air space. Badgwell et al reported that low V_T values resulted in low E_TCO_2 values.[7] Kugimiya pointed out that in cases of anesthetized small children with low V_T, even 20 ml of dead air space results in low E_TCO_2 values.[8] In spontaneously breathing patients, the dead air space is about twice as large as the dead air space in intubated patients. Therefore the patient's dead air space, especially during low V_T, may readily influence the values of E_TCO_2 monitored using a nasal cannula. An increase in the RR causes parabolic distortion of the capnogram that is followed by a decrease in the value of E_TCO_2 because the time is too short to eliminate the gases in the dead air space.[9,10] These results suggest that inaccurately low E_TCO_2 levels may be detected during low

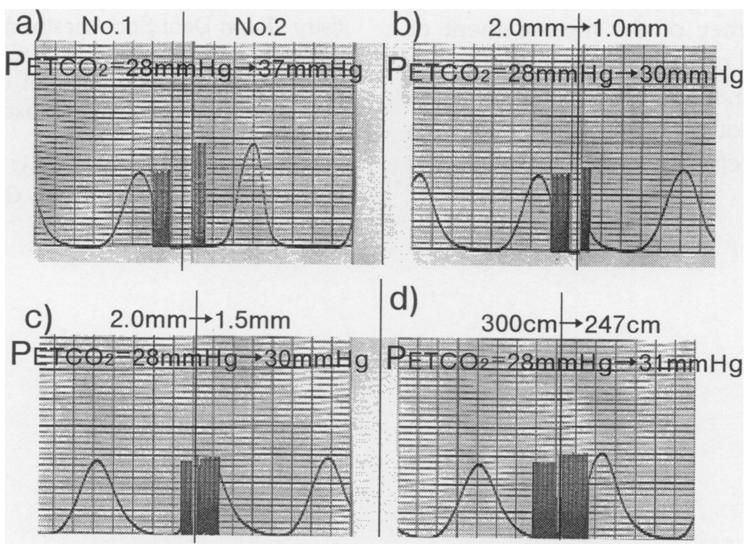

Figure 5. Capnographs when the tidal volume was 250 ml and the ventilation rate was 20/min. (a) The difference in values of the partial pressure of the end-tidal carbon dioxide (E_TCO_2) between type one and type two nasal cannulas. (b) The effect of reducing the diameter of the prongs of the type one nasal cannula from 2.0 to 1.0 mm. (c) The effect of reducing the diameter of the distal portion of the type one nasal cannula from 2.0 to 1.5 mm. (d) The effect of reducing the length of the type one nasal cannula from 300 to 247 cm.

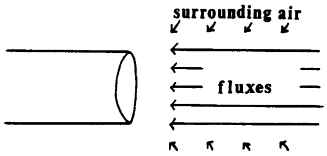

Figure 6. The smaller the cross-sectional area of the prongs of nasal cannula, the less likely the values of the partial pressure of the end-tidal carbon dioxide will be reduced by the surrounding air.

V_T and high RR, such as sedation with intravenous midazolam.[11,12]

The smaller diameter prongs, the shorter cannula, and the smaller diameter cannula resulted in improved measurement of E_TCO_2. The turbulence generated by the expired gases may essentially close the prongs of the cannula (Figure 6) and thus prevent the aspiration of surrounding air into the cannula. We therefore speculated that even longer prongs into the nose might improve reliability of the measurements as long as it did not cause the patient discomfort. Moreover, the capnometer with side-stream sampling, a low sampling rate, and a large diameter cannula result in a lower E_TCO_2 value, because expired gases are diluted with inspired gases in the cannula.[13] It is clear that the E_TCO_2 value was influenced by the volume of the cannula. When the type two cannula, which has a smaller volume than the type one cannula, was used in the present study, the E_TCO_2 value was 37 mmHg. This value is clinically acceptable, even at a V_T of 250 ml and a RR of 20/min. However, thoughtless extension of the cannula should be avoided.

In conclusion, the accuracy of the measurement of the E_TCO_2 through a nasal cannula depends on the patient's V_T and RR. However, if an appropriate nasal cannula is used then there should be no clinical problems and end-tidal CO_2 measurements should be reliable in these situations.

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