

Evaluation of Transcutaneous and End-Tidal Carbon Dioxide During Intravenous Sedation in Volunteers

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Abstract

Objective: During intravenous sedation, end-tidal carbon dioxide (ETCO₂) is usually measured with a nasal cannula or mouth-nose cannula. We compared the measurement accuracy of ETCO₂ between these two devices and TC-CO₂ and assessed which device is more useful during intravenous sedation in volunteers.

Methods: Eight male volunteers aged 25 to 35 years were evaluated in this single-institution blinded observational trial. After they lay quietly for 5 min without supplemental oxygen, the volunteers received supplemental oxygen by means of each device at a flow rate of 3 L/min for 15 min. Next, midazolam (0.05 mg/kg) was intravenously injected, flumazenil (20 mg) was injected 30 min later, and the ETCO₂ and TC-CO₂ waveform were recorded.

Results: The differences between ETCO₂ and TC-CO₂ significantly increased after midazolam injection and decreased after flumazenil injection. The difference between ETCO₂ and TC-CO₂ using the nasal cannula was greater than that using the mouth-nose cannula. The mean difference between TC-CO₂ and ETCO₂ ranged from 3 to 9 mmHg after midazolam injection using a nasal mask, and the mean difference ranged from 3 to 6 mmHg after midazolam injection using a mouth-nose cannula.

Conclusions: The difference between ETCO₂ and TC-CO₂ against TC-CO₂ was within the clinically acceptable range. Both the nasal and mouth-nose cannula were useful for ETCO₂ measurement with supplemental oxygen by means of each device at flow rate of 3 L/min during intravenous sedation in volunteers.

Keywords: End-tidal CO₂; Intravenous sedation; Transcutaneous CO₂; Nasal cannula, Mouth-nose cannula

Introduction

Current clinical guidelines recommend capnography as one of the best noninvasive methods with which to assess the adequacy of ventilation in nonintubated patients. The need for capnographic monitoring has dramatically increased with the large number of procedures performed on sedated patients outside the operating room [1].

End-tidal carbon dioxide (ETCO₂) waveforms on a capnograph can provide vital information about CO₂ retention and respiratory depression [2]. The absence of ETCO₂ waveforms indicates a possible state of apnea [3]. ETCO₂ measurement is important for identification of intraoperative ventilatory problems in patients undergoing general anesthesia with tracheal intubation [4]. ETCO₂ monitoring in nonintubated patients under sedation is frequently necessary in both the intraoperative and postoperative periods. Sedation for medical and dental procedures is a common practice, but it is associated with the risk of excessive respiratory depression [3].

In general, the judgment of whether excessive respiratory depression or apnea has occurred during sedation should involve observation of the presence of breathing, mouth or nose breathing, cyanosis, facial color, movement of the chest wall, and changes in pulse oximetry values. Nevertheless, dental anesthetists performing oral-maxillofacial surgery cannot always immediately judge whether excessive respiratory depression or apnea has occurred because a surgical drape is usually placed over the patient's face and chest wall during sedation. Pulse oximetry measures the results of inadequate respiration, not inadequate respiration itself, and is therefore not an early indicator of problems [5]. Moreover, supplementary oxygen can delay the detection of respiratory depression by pulse oximetry [6]. The

clinical value of ETCO₂ monitoring in intravenously sedated patients undergoing dental treatment has not been established.

The two most commonly used standard oxygen delivery devices available for dental treatment are the nasal cannula and mouth-nose cannula. This study was designed to compare the ETCO₂ sampling characteristics of these two devices in volunteers with an oxygen (O₂) supply. These cannulas deliver O₂ through and sample CO₂ from both nostrils simultaneously. Whether the delivered O₂ significantly dilutes the exhaled gases, thereby providing a falsely low ETCO₂ measurement, remains unknown. Arterial blood gas analysis with measurement of the partial pressure of CO₂ in arterial blood (PaCO₂) is an invasive procedure involving either arterial puncture or placement of an arterial cannula. Arterial blood gas analysis provides only a single measurement. However, a transcutaneous device is used for continuous noninvasive monitoring of PaCO₂ [6]. Previous studies have demonstrated a linear correlation between PaCO₂ and transcutaneous CO₂ (TC-CO₂) [7-9]. The results of TC-CO₂ monitoring are independent of air leakage [10]. Additionally, this technique has long been validated, is a reproducible measure of the partial pressure of O₂ in arterial blood in neonates [11], and is used in adults primarily in the intensive care unit setting [12,13].

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Drysdale [14] reported that TC-CO₂ monitoring can be used to detect changes in CO₂ and is not affected by supplemental O₂.

In the present study, the accuracy of ETCO₂ measurement using the nasal cannula and mouth-nose cannula were compared with the accuracy of TC-CO₂ measurement in volunteer subjects. The aim was to determine which device is more useful during intravenous sedation.

Material and Methods

Ethics approval

This observational study was approved by the Committee on Clinical Investigation for Human Research (IRB) at Iwate Medical University. Written informed consent was obtained from all volunteers.

Data collection and protocol

Cannula: The nasal cannula used was an Adult CO₂ Nasal Sampling Cannula with O₂ Administration Cannula (Novamatrix Medical Systems, Inc.; Wallingford, CT). This four-prong nasal cannula delivers O₂ via a prong in each nostril and samples exhaled gases via another set of prongs in each nostril.

The mouth-nose cannula used was a Nasal Adapter (Nihon Kohden; Tokyo, Japan). This cannula is a flow-through capnometer. With this flow-through technology, exhaled CO₂ can be monitored by drawing and analyzing an air sample at its source. This cannula has two prongs dedicated to sampling exhaled gases via both nostrils. A two-pronged O₂ cannula attached to the nasal adaptor in the area between the CO₂ prongs and mouth guide delivers O₂ to both nostrils.

Capnometry: The CO₂ sampling line of the nasal cannula was connected to a sidestream capnometer (Capnomac Ultima; Datex-Engstrom, Helsinki, Finland). The CO₂ sampling line of the mouth-nose cannula was connected to a flowthrough capnometer (Life Scope BSM-5132; Nihon Kohden).

TC-CO₂ monitor: TC-CO₂ was measured with a surface monitor (9900MK-II; Kohken Medical Co., Ltd., Tokyo, Japan). TC-CO₂ measurement is based on the principle that a heating element in the electrode elevates the temperature of the underlying tissues. This increases the capillary blood flow and partial pressure of CO₂, making the skin permeable to gas diffusion.

Protocol

All volunteers were residents or postgraduate students, and they were not paid to participate in the study. No volunteers had a history of illicit drug use, and all were free from medical conditions such as asthma, respiratory disease, or nasal obstruction. The volunteers comprised eight men ranging in age from 25 to 35 years, with a height of 168.3 ± 2.0 cm and weight of 65.8 ± 8.0 kg. All volunteers were observed with both devices. The observations with the nasal cannula and mouth-nose cannula were performed on different days. The two cannulas were not used at the same time. An electrode was placed on the palmar surface of the forearm of each volunteer and set to a temperature of 43°C. The sidestream capnometer measured the ETCO₂ in the gas expired from the nasal cavity or mouth by means of one of the two devices attached to the nostril or nose. Volunteers received supplemental O₂ by means of each device at a flow rate of 3 L/min for 15 min after they lay quietly for 5 min without supplemental O₂. This was performed because we usually supply O₂ at a flow rate of 2 or 3 L/min when we use these two devices for dental treatment. Midazolam (0.05 mg/kg) was then intravenously injected, and flumazenil (20

mg) was injected 30 min later. The ETCO₂ and TC-CO₂ waveforms were simultaneously recorded for 30 min using a PowerLab 16/30T data acquisition system (ADInstruments, Bella Vista, Australia). The measurements were repeated for each device with either nasal or oral breathing. The accuracy of TC-CO₂ was compared with that of ETCO₂ every minute.

Statistical analysis

Values are presented as mean ± standard error. Statistical analysis was performed using SPSS, version 11.0 (IBM, Chicago, IL, USA). Comparisons between different time points within each group were made using one-way repeated-measures analysis of variance and Dunnett's multiple-comparison test. The value obtained immediately before supplying the O₂ served as the control within each group. Two-way repeated-measures analysis of variance was used to examine between-group differences. Differences were considered statistically significant at a P value of <0.05.

Results

Figure 1 shows the changes in ETCO₂ and TC-CO₂ on the capnometer waveforms with 3 L/min of O₂ supplied using a nasal or mouth-nose cannula during intravenous sedation. The capnometer using the nasal cannula showed a lower peak ETCO₂ concentration immediately after midazolam injection than that before injection. The capnometer using the mouth-nose cannula sometimes showed a lower peak ETCO₂ concentration immediately after midazolam injection than that before injection. Figure 2 shows the changes in TC-CO₂ and ETCO₂ using the nasal and mouth-nose cannulas. The TC-CO₂ increased after midazolam injection and tended to decrease after flumazenil injection, and there were significant differences between the values 5 to 16 min after injection and the value before injection (P<0.05). Finally, the ETCO₂ using the nasal cannula tended to decrease after injection, and that uses the mouth-nose cannula intended to increase immediately after injection. Figure 3 shows the accuracy of TC-CO₂ and ETCO₂ measurement using the nasal and mouth-nose cannula. The accuracy significantly increased after midazolam injection and decreased after flumazenil injection. The mean accuracy of TC-CO₂

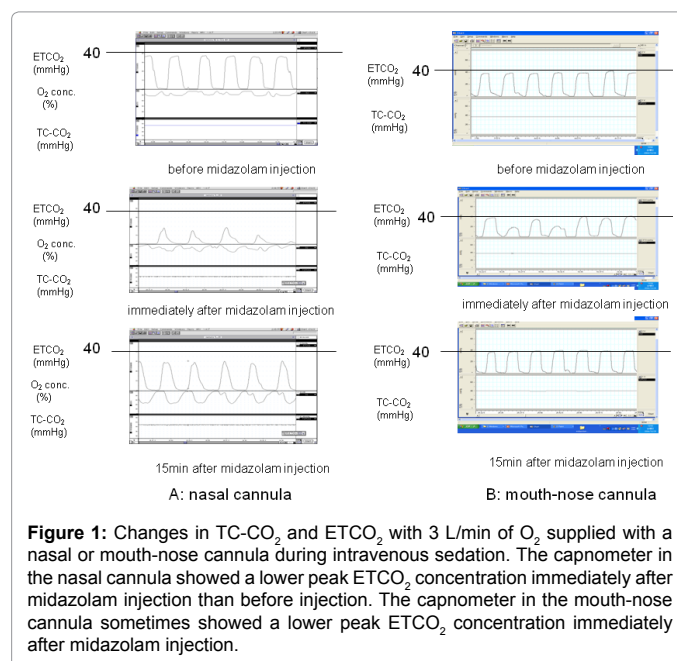


Figure 1: Changes in TC-CO₂ and ETCO₂ with 3 L/min of O₂ supplied with a nasal or mouth-nose cannula during intravenous sedation. The capnometer in the nasal cannula showed a lower peak ETCO₂ concentration immediately after midazolam injection than before injection. The capnometer in the mouth-nose cannula sometimes showed a lower peak ETCO₂ concentration immediately after midazolam injection.

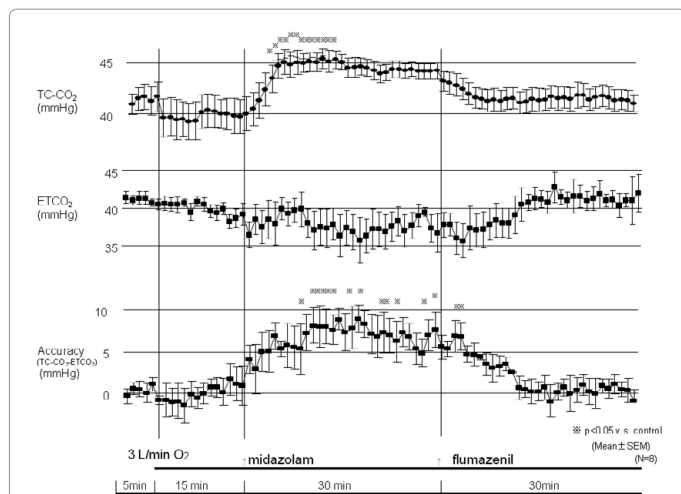


Figure 2: Changes in TC-CO₂ and ET-CO₂ using a nasal cannula during intravenous sedation.

The TC-CO₂ increased after midazolam injection and tended to decrease after flumazenil injection, and there were significant differences between the values 5 to 16 min after injection and that before injection. The ET-CO₂ using the nasal cannula tended to decrease after injection, and that using the mouth-nose cannula tended to increase immediately after injection. The accuracy increased after midazolam injection and decreased after flumazenil injection. The mean accuracy between TC-CO₂ and ET-CO₂ ranged from 3 to 9 mmHg during sedation using the nasal cannula (n=8).

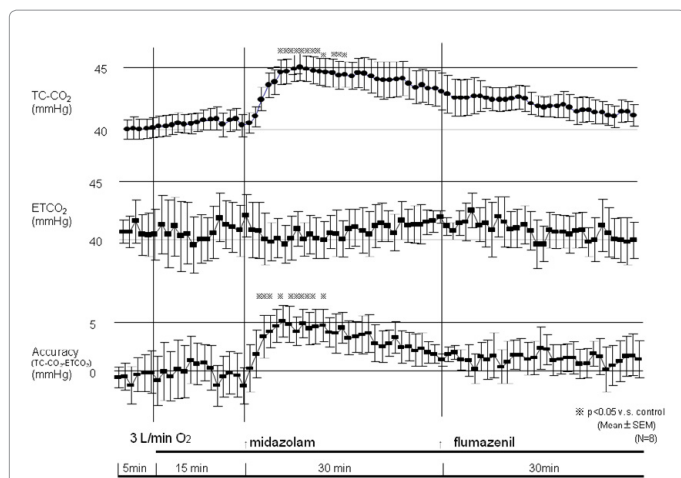


Figure 3: Changes in TC-CO₂ and ET-CO₂ using a mouth-nose cannula during intravenous sedation

The TC-CO₂ increased after midazolam injection and tended to decrease after flumazenil injection. The ET-CO₂ using the nasal cannula tended to decrease after injection, and that uses the mouth-nose cannula intended to increase immediately after injection. The accuracy increased after midazolam injection and decreased after flumazenil injection. The mean accuracy ranged from 3 to 6 mmHg during sedation using the mouth-nose cannula (n=8).

and ET-CO₂ measurement ranged from 3 to 9 mmHg after midazolam injection using a nasal mask, and the mean accuracy ranged from 3 to 6 mmHg after midazolam injection using the mouth-nose cannula.

Discussion

In this study, the accuracy of TC-CO₂ and ET-CO₂ measurement using a nasal or mouth-nose cannula was evaluated during intravenous sedation of volunteers. ET-CO₂ measurement is useful because of its

noninvasiveness, continuity, and response time when sudden changes in ventilation occur during intravenous sedation. In the present study, the TC-CO₂ continuously increased within 30 min after midazolam injection and decreased after flumazenil injection. Previous studies have reported a linear correlation between PaCO₂ and TC-CO₂ [6-8]. Bendjelid [9] reported that evaluation of PaCO₂ data on the basis of TC-CO₂ values was clinically acceptable, although the relationship between TC-CO₂ and PaCO₂ varies in patients breathing spontaneously in the intensive care unit. Therefore, when the TC-CO₂ increased, the increase in PaCO₂ may have occurred after intravenous injection of the sedative drugs. One possible cause of the increased TC-CO₂ is that respiratory depression was induced by the intravenous sedative drugs. We are aware of continuous respiratory depression induced by midazolam during intravenous sedation, but have not observed significant increases in TC-CO₂.

Clinical guidelines recommend the use of capnography as one of the best noninvasive methods with which to assess the adequacy of ventilation in nonintubated patients [1]. Capnography should be used to monitor ventilation in sedated patients outside the operating room. We generally use pulse oximetry to detect hypoventilation. However, pulse oximetry measures the result of inadequate respiration, not inadequate respiration itself, and is therefore not an indicator of early problems [5]. Supplemental O₂ can delay the detection of respiratory depression by pulse oximetry [6]. Additionally, pulse oximeters cannot detect changes in CO₂ that may result from reductions in ventilator drive [14]. We mainly use benzodiazepines or propofol for dental anesthesia because intravenous sedation and benzodiazepines inhibit the pathways to the central nervous system by stimulating gamma-aminobutyric acid, consequently inhibiting the reduction in the respiratory drive [14]. Capnography enables the measurement of ET-CO₂ and the early detection of apnea, allowing for immediate intervention to restore ventilation. Moreover, capnographic monitoring with a simple and inexpensive device reportedly reduced the incidence of hypoxemia in patients undergoing colonoscopy during propofol-based sedation [15]. Deitch et al. [16] reported that in adults who underwent propofol sedation on an emergency basis, the addition of capnography to standard monitoring reduced hypoxemia and provided an advance warning for all hypoxemic events. Thus, the need for capnographic monitoring is increasing.

In the present study, the accuracy of ET-CO₂ and TC-CO₂ measurement using a nasal cannula was greater than that using a mouth-nose cannula; however, the data varied depending on whether the subjects breathed spontaneously. The mean accuracy of TC-CO₂ and ET-CO₂ measurement ranged from 3 to 9 mmHg after midazolam injection using a nasal mask, and the mean accuracy ranged from 3 to 6 mmHg during sedation after midazolam injection using a mouth-nose cannula. The mean accuracy of the mouth-nose cannula was lower than that of the nasal cannula because the mouth-nose cannula was designed to measure ET-CO₂ in expired air during breathing through either the nose or mouth. Nevertheless, the accuracy of the two variables against that of TC-CO₂ was within the clinically acceptable range, and the results of this analysis indicate satisfactory agreement of the data between the two devices. The ET-CO₂ waveform, not the correct ET-CO₂ value, is required to be able to judge whether excessive respiratory depression has occurred. In this study, both nasal and mouth-nose cannulas were useful for measurement of ET-CO₂ with the administration of supplemental O₂ by means of each device at a flow rate of 3 L/min during intravenous sedation in volunteers.

In conclusion, the accuracy of TC-CO₂ and ET-CO₂ measurement

was compared between the nasal and mouth-nose cannula. The accuracy of ETCO_2 and TC-CO_2 measurement using the nasal cannula was greater than that using the mouth-nose cannula. Nevertheless, the accuracy of the two variables against the TC-CO_2 and ETCO_2 waveform obtained by means of these two devices was within the clinically acceptable range. Both devices are useful during intravenous sedation in volunteers.

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