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A Comparison Of Transcutaneous And End-Tidal Carbon Dioxide Monitoring Among Three Devices Providing Supplemental Oxygen To Volunteers

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Abstract

Purpose: The aim of this study was to compare the accuracy of TC-CO2 measurement and PETCO2 measurement using three devices: two types of nasal cannulas (nasal cannula, nasal prong) and one nasal mask (modified nasal mask), and to assess which device is the most useful.

Measurements: The capnometer measured the PETCO2 in expired gas from the nasal cavity via each of the three devices attached to the nostril or nose. Volunteers received supplemental O2 through each device at flow rates of 1, 2, 3, 4, 6, 8 and 10 L/min for 2 minutes each. The accuracy of the three devices was compared.

Main Results: The accuracy was greater for all three devices with increases in supplied O2. With the nasal cannula, the mean accuracy increased from 1.2±0.6 to 6.5±3.0. With the modified nasal mask, the mean accuracy increased from 1.8±0.6 to 7.1±1.4. And with the NP, the mean accuracy increased from 3.4±0.4 to 7.5±0.7.

Conclusions: The accuracy trends to increase with increasing supplemental O2 among three devices and when used at O2 flow rates of 1, 2 or 3 L/min, any of the three devices can provide good qualitative information. Within O2 flow rates of 1-4 L/min, the most useful device is nasal cannula may be assessed since the accuracy is smallest in three devices.

INTRODUCTION

End-tidal carbon dioxide (PETCO2) refers to the partial pressure of carbon dioxide at the end of expiration and reflects arterial carbon dioxide tension (PaCO2) [1]. PETCO2 is an important indicator of intraoperative ventilatory problems in patients undergoing general anesthesia with tracheal intubation [2]. PETCO2 monitoring is frequently necessary in sedated non-intubated patients, both during the intra- and post-operative periods. Sedation for medical and dental procedures is a common practice and risks excessive respiratory depression [3].

In general, when anesthetists are assessing whether excessive respiratory depression or apnea is occurring during sedation, they look for the presence of breathing (oral or nasal) and cyanosis, and they monitor facial color, movement of the chest wall, and changes in the pulse oximetry reading. However, in oral-maxillofacial surgery dental anesthetists are unable to readily use these parameters 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 the quality of respiration itself, and hence is not an early indicator of problems [4]; additionally, supplementary oxygen can delay the detection of respiratory depression by pulse oximetry [2]. Monitoring breath-by-breath PETCO2 has the advantage of alerting health care professionals to compromised respiratory status much more rapidly than a pulse oximeter can [3]. The absence of PETCO2 indicates that a state of apnea may have occurred [3].

PETCO2 monitoring is useful but usually requires some modification of the standard oxygen delivery systems [5,6]. There are three commonly used standard oxygen delivery devices that are available for dental treatment: three types of nasal cannulas and one nasal mask. This study is designed to compare the PETCO2 sampling characteristics among these three devices in volunteers receiving supplemental oxygen at increased flow rates. These cannulas deliver O2 to and sample CO2 from both nostrils simultaneously. It is unknown whether the delivered O2 significantly dilutes the exhaled gases, which might provide a falsely low measurement of PETCO2.

Arterial blood gas (ABG) analysis, which includes measurement of the partial pressure of carbon dioxide in arterial blood (PaCO2), is an invasive procedure involving either arterial puncture or the placement of an arterial cannula. While ABG analysis provides only a single measurement of PaCO2, transcutaneous devices can be used for continuous, noninvasive PaCO2 monitoring [7]. Previous studies [7-9] have demonstrated a linear correlation between PaCO2 and transcutaneous carbon dioxide (TC-CO2). Therefore, the aim of this study was to compare the accuracy of TC-CO2 measurement and PETCO2 measurement using four devices, and we assessed which of the three devices is the most useful.

MATERIALS AND METHODS

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.

Cannula & mask

The nasal cannula (NC) used in this study was the Adult CO2 Nasal Sampling Cannula with O2 Administration Cannula® manufactured by Novametrix Medical Systems Inc. (Wallingford, CT). This four-pronged nasal cannula delivers O2 via a prong in each nostril and samples exhaled gases via another set of prongs in each nostril.

The modified nasal mask (MNM) used in this study was the F mask® manufactured by Sekimura Co. (Tokyo, Japan). A CO2 sampling line was attached to the hub of a mixing cannula, which was inserted into a perforation in the nasal mask (Fig. 1).

The nasal prong (NP) used in this study was the Microcap Capnoline H/O2® manufactured by Oridion Medical Inc. (Needham, MA). This cannula has two prongs dedicated to sampling exhaled gases via both nostrils. O2 is delivered to both nostrils via a cannula with two prongs.

Capnometry

A sidestream capnometer (Capnomac Ultima®, Datex-Engstrom, Helsinki, Finland) was used with the NC and MNM.

A microstream capnometer (Capno Stream 20®, Oridion Medical Inc., Needham, MA) was used with the NP.

Transcutaneous CO2 monitoring

Transcutaneous CO2 was measured with a surface monitor (9900MKII; Kohken Medical Co., Ltd., Tokyo, Japan). Transcutaneous measurement of CO2 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 eight 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. An electrode was placed on the right palmar surface of the forearm and set to a temperature of 43°C. The sidestream measured the PETCO2 in the gas expired from the nasal cavity via the four devices that were attached to the nostril or nose. The volunteers received supplemental O2 through each device at flow rates of 1, 2, 3, 4, 6, 8 and 10 L/min for 2 minutes per flow rate after lying quietly for 5 minutes without additional O2. Next, these capnometers were connected to an amplifier. The TC-CO2 and CO2 waveforms were recorded simultaneously with a PowerLab 16/30T data acquisition system (AD Instruments, Bella Vista, Australia). The measurements were repeated for each nasal breathing device. We compared with the mean accuracy of TC-CO2 and PETCO2 by flow rates of 1, 2, 3, 4, 6, 8 and 10 L/min for 2 minutes per flow rate.

Statistics

Values are presented as mean ± SEM. Statistical analysis was performed using SPSS, version 11.0 (SPSS, Inc., Chicago, IL, USA). Comparisons between the O2 concentrations in each group were made using one-way repeated measures analysis of variance and Dunnett’s multiple comparison test. Within each group, the value obtained immediately before supplying supplemental O2 served as the control. Two-way repeated measures analysis of variance was used to examine between-group differences. Differences were considered statistically significant at P values < 0.05.

RESULTS

Figure 2 shows the effects of several different oxygen flow rates on the capnometer waveforms for each of the devices. The capnometers showed lower peak CO2 concentrations compared with the respective TC-CO2 values (Fig. 2). Figure 3 shows that the accuracy of TC-CO2 and PETCO2 monitoring was greater for all three devices with increases in supplied O2. In the table, with the NC, the mean accuracy of TC-CO2 and PETCO2 increased from 1.2±0.6 to 6.5±3.0 with increasing supplemental O2 flow rates. With the MNM, the mean accuracy of TC-CO2 and PETCO2 increased from 1.8±0.6 to 7.1±1.4 with increasing supplemental O2 flow rates. And with the NP, the mean accuracy of TC-CO2 and PETCO2 increased from 3.4±0.4 to 7.5±0.7 with increasing supplemental O2 flow rates. There were significant differences between control and 10 L/min with NC and between control and 8 and 10 L/min with MNM. There was no significant difference with NP.

DISCUSSION

We found out that accuracy of TC-CO2 and PETCO2 trends to increase with increasing supplemental O2 among three devices and when used at O2 flow rates of 1, 2 or 3 L/min, any of the three devices (NC, MNM or NP) can provide good qualitative information.

Accuracy of TC-CO2 and PETCO2 trends to increase with increasing supplemental O2 among three devices. As a spontaneously breathing patient receives supplemental oxygen, the oxygen flowing around the nose and mouth can dilute the expired CO2 and cause a capnometer to report falsely low readings [3]. As can be seen by the CO2 waveforms in Figure 2 oxygen dilution caused attenuation of both the magnitude and duration of the CO2 waveforms. The capnometers showed higher peak CO2 concentrations relative to the corresponding TC-CO2 values at both low and high O2 flow rates. With all four devices, the accuracy of TC-CO2 and PETCO2 tended to increase with increases in the O2 supplied because the oxygen flowing around the nose and mouth caused more dilution of expired CO2 as O2 flow rates increased. It is generally accepted that PETCO2 is usually less than PaCO2 [2,10,11]. This is because CO2 moves down its concentration gradient from a comparatively higher partial pressure in the pulmonary capillary to a lower concentration in the alveolus in several conditions, such as increases in the anatomical dead space, increases in the physiologic dead space, and the presence of pulmonary embolism.

Any of the three devices (NC, MNM or NP) can provide good qualitative information. when used at O2 flow rates of 1, 2 or 3 L/min. If we judge that a mean accuracy of 5 mmHg is within the clinically acceptable range, this degree of agreement between TC-CO2 and PETCO2 2 values is obtained at oxygen flow rates of approximately 4 L/min with the NC, MNM, and 2 L/min with NP. When we use these three devices during dental treatment, we usually supply O2 at flow rates of 2–3 L/min since PaO2 measurements of 110 and 132 torr when using the Adult CO2 Nasal Sampling Cannula with O2 Administration Cannula (Novametrix Medical Systems Inc., Wallingford, CT) at oxygen flow rates of 2 and 4 L/min, respectively [12]. Therefore, we think that O2 flow rates of 2–4 L/min provide sufficient O2 delivery through three devices. The distribution of PaCO2 relative to PETCO2 was a function of the close proximity of the CO2 sampling prong to the O2 delivery prong with this cannula and postulated that O2 was probably entrained, diluting the expired gas [12]. Our data indicate that any of the three devices (NC, MNM or NP), when used at O2 flow rates of 1, 2 or 3 L/min, can provide good qualitative information (that the patient is breathing). Within O2 flow rates of 1-4 L/min, the most useful device is nasal cannula may be assessed since the accuracy of TC-CO2 and PETCO2 is smallest in three devices

Our goal was to observe changes in the PETCO2 and PaCO2 with using three devices. However, arterial blood gas analysis is an invasive procedure that involves either arterial puncture or placement of an arterial cannula. We could not puncture the artery in awake volunteers. TC-CO2 monitoring is the optimal method for continuous noninvasive monitoring of PaCO2 and can be used to detect changes in CO2. Moreover, a linear correlation between PaCO2 and TC-CO2 has been found. Therefore, we compared TC-CO2 and PETCO2 among three devices at several oxygen flow rates in spontaneously breathing healthy volunteers. Because we studied subjects who were awake, the majority maintained TC-CO2 within a narrow range around normocapnia.

If a patient is deeply sedated for dental treatment, the accuracy of TC-CO2 and PETCO2 may be greater because some of these patients may predominantly mouth breathe or experience respiratory depression, which would be expected to affect the CO2 sampling function of these devices. In this study, we did not investigate changes in the accuracy of TC-CO2 and PETCO2 measurement in deeply sedated patients; this topic needs further investigation. However, we believe that the data provide accurate and reliable information on the changes in TC-CO2 and PETCO2 among three devices and are clinically useful for management of anesthesia.

CONCLUSIONS

The accuracy of TC-CO2 and PETCO2 trends to increase with increasing supplemental O2 among three devices and when used at O2 flow rates of 1, 2 or 3 L/min, any of the three devices (NC, MNM or NP) can provide good qualitative information. Within O2 flow rates of 1-4 L/min, the most useful device is nasal cannula may be assessed since the accuracy of TC-CO2 and PETCO2 is smallest in three devices. Nevertheless, we studied volunteers who were awake, we did not investigate changes in the accuracy of TC-CO2 and PETCO2 measurement in deeply sedated patients; this topic needs further investigation. When used in awake volunteers, these four devices can provide good qualitative information demonstrating that breathing is occurring.

Table 1

Mean accuracy among three devices at several oxygen flow rates All values are given as Mean±SEM. *p< 0.05 compared with control.

	Nasal cannula (mmHg)	Modified nasal mask (mmHg)	Nasal prong (mmHg)
Control	1.2±0.6	1.8±0.6	3.4±0.4
1 L/min	1.4±0.5	2.0±0.9	3.6±0.5
2 L/min	2.2±1.9	3.1±1.2	4.7±0.7
3 L/min	3.3±2.1	4.2±0.8	5.3±0.6
4 L/min	4.4±1.9	4.8±1.0	5.6±0.6
6 L/min	5.5±2.3	5.2±0.9	6.3±0.7
8 L/min	5.6±3.0	6.6±0.9*	6.9±0.8
10 L/min	6.5±3.0*	7.1±1.4*	7.5±0.7

Figure 1

Nasal cannula, modified nasal mask and nasal prong A: Nasal cannula B: Modified nasal mask The carbon dioxide sampling line is attached to the hub of a mixing cannula, which is inserted into a perforation in the mask. C: Nasal prong

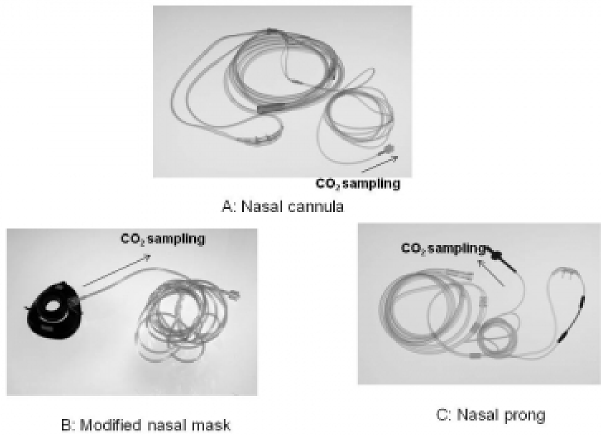

Fig. 1 Nasal cannula, modified nasal mask and nasal prong

Figure 2

Changes in PETCO2 at different O2 flow rates with the use of a nasal cannula, modified nasal mask and nasal prong The capnometers shows lower peak CO2 concentrations than the indicated TC-CO2 at several different O2 flow rates.

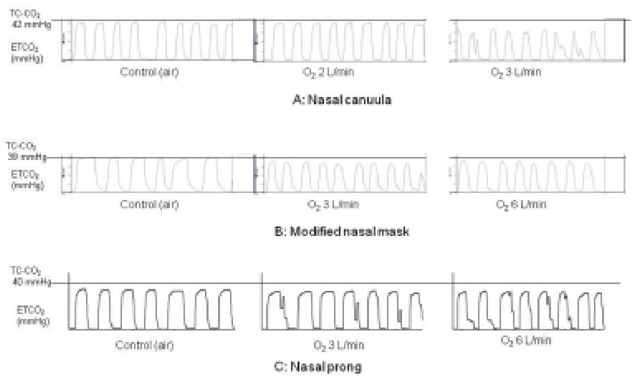

Fig.2 Changes in at different O_2 flow rates with the use of a nasal cannula, modified nasal mask and nasal prong

Figure 3

Accuracy of TC-CO2 and PETCO2 at different O2 flow rates with the three devices The accuracy of TC-CO2 and PETCO2 are greater with increases in supplied O2 for all three devices.

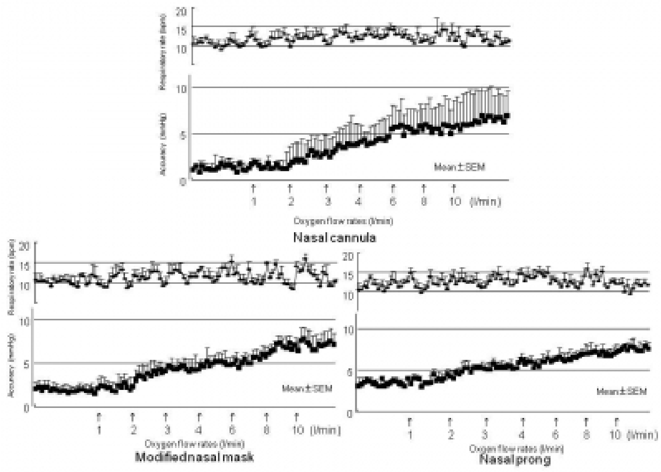

Fig. 3 Accuracy of TC-CO_2 and $ETCO_2$ at different O_2 flow rates with the four devices

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