Evaluation of a nasal/oral discriminate sampling system for capnographic respiratory monitoring

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Although continuous end-tidal carbon dioxide (PETCO₂ mmHg) measurements permit the earliest detection of alveolar hypoventilation, apnea and/or obstruction, technical difficulties have thus far precluded its reliable implementation in the spontaneously breathing patient with a natural (e.g., nonartifically secured) airway. Among the technical difficulties is the fact that conventional sampling devices do not take into account the possibility that breathing may take place primarily through either the nose or the mouth.

As a result, the efficacy of a new nasal/oral discriminate sampling system (NODSS) was examined for capnographic observation of respiratory adequacy. NODSS is unique because it provides the opportunity to select simultaneous or discriminate collection of carbon dioxide exhaled through the nose and/or mouth.

Twenty-four American Society of Anesthesiologists physical status I to IV patients (ages 30-88 years) were capnographically monitored in the postanesthesia care unit following general anesthesia for various surgical procedures. All patients were extubated and breathing spontaneously.

Simultaneously, direct arterial carbon dioxide (PaCO₂ mmHg) determinations were made using an indwelling radial artery catheter to determine their correlation with PETCO₂ obtained by NODSS.

A comparison between PaCO₂ values and noninvasive nasal and/or oral PETCO₂ obtained by NODSS showed a positive correlation (r value) of 0.602 to 0.849 when statistically analyzed by Pearson’s product-moment correlation coefficient. There was no significant difference between the mean (PaCO₂-PETCO₂) gradient derived through nasal sampling, as compared to the mean gradient derived by oral sampling with this device (P > 0.05). Noninvasive capnographic monitoring by NODSS is a convenient, reliable, effective, and accurate alternative to direct arterial blood gas determination that may be used for the early detection of respiratory inadequacy in the spontaneously breathing patient who has a natural airway.

Key words: Arterial blood gas PaCO₂, infrared capnography, noninvasive oral/nasal PETCO₂, spontaneous mouth/nose breathing.

Introduction

Classical methods of evaluating respiratory adequacy in the spontaneously breathing patient who has a natural airway have technical and interpretative limitations. For example, although it has been established that many patients breathe through
their mouth at least some of the time, cannula-type PETCO₂ sampling devices that are currently available focus primarily on gases exhaled through the nostrils.¹ ²

It is well recognized that identification of expired carbon dioxide is the earliest and single most effective method of determining airway patency as well as the presence and adequacy of ventilation.³ Similarly, respiratory inadequacy, manifested as hypoxemia and/or hypercarbia, is the most common complication seen in patients under the influence of various sedative and/or pain control medications during monitored anesthesia care, in the postanesthesia recovery period, during endoscopic procedures, imaging techniques, and various regional anesthetics.⁴

Respiratory events that may result in a catastrophic outcome often occur in association with patients undergoing monitored anesthesia care.⁵ In the majority of these patients, undetected respiratory embarrassment in the form of hyperventilation or central or obstructive apnea has been the instigating factor.⁶ ⁷ ⁹ ¹⁰ Early detection of respiratory insufficiency is clearly of paramount importance in monitoring patients who are spontaneously breathing and are or have been exposed to central nervous system modifying agents.¹¹

This study was undertaken to evaluate the efficacy of a new nasal/oral discriminate sampling system (NODSS) capable of simultaneously delivering supplemental oxygen and sampling carbon dioxide exhaled through the nostrils and/or mouth by comparing concomitantly obtained PETCO₂ and PaCO₂ values.

Methods and materials

Twenty-four ASA physical status I-IV postanesthesia care unit patients (ages 30-88 years; mean age, 56 years) were monitored with NODSS. The first 24 patients who had an arterial catheter intraoperatively and who gave informed consent were included in the study. Nine patients had undergone maxillofacial surgery; 14 had tumor resection of the ear, nose, or throat; one underwent muscle flap coverage of a lower extremity; and one had sternal debridement with rotation flap repair. All underwent general anesthesia and were intubated in the intraoperative period. The study was approved by the University of Pittsburgh’s Medical Institutional Review Board.

Following extubation, a NODSS, (NAZORCAP,™ Sampler, Model 9112, NASORCAP Enterprises, Inc., West Mifflin, Pennsylvania) was placed on each subject. Sampling and data collection were performed by the investigational team. Except for the fact that its nasal prongs can be telescopically extended to maintain their position in the respective nostril, NODSS is similar to a classical nasal cannula. It also contains a multiperforated oral sampling cylinder that is adjustably suspended between the upper and lower lip. (Figure 1).

Independent nasal and oral sampling lines are connected to a three-way stopcock to enable the operator to selectively sample either site independently or both sites simultaneously. For ease of access, the stopcock is situated approximately 3 feet from the nasal/oral sampling section of the device. Nasal sampling takes place using the left prong, which does not communicate with the right prong. The right prong may be utilized for delivery of supplemental oxygen by connecting an appropriate tubing source to an integral tapered fitting.

The role of the two nasal prongs may be readily reversed by modification. However, in this study, PETCO₂ data was collected only from the left nasal prong. The patency of either naris was not established in advance. Certainly, a nonpatent naris would affect PETCO₂ collection at that site. However, since capnographic waveforms of classical quality were obtained by oral sampling for those patients whose nasal sampling produced waveforms of lesser quality, sampling of the opposite naris was not evaluated.

A calibrated capnographic monitor (Nellcor® N-2500, Hayward, California) that samples at a constant flow rate of 50 cc/min was used for PETCO₂ data collection. PETCO₂ comparisons were made with an infrared capnometer (SARACAP®, PPG Biomedical Systems, Lenexa, Kansas) on 15 of 24 random subjects (65%) to corroborate the data obtained from the Nellcor capnograph.

The percentage of hemoglobin oxygen saturation (SaO₂) was obtained for each patient, using either the integral pulse oximeter of the N-2500 or a Nellcor N-100 that was available at each postanesthesia care unit station. Oxygen was administered using the apparatus at flow rates of between 2-5 L/min to maintain an oxygen saturation of at least 90%. Three patients in the study required more effective means of oxygen supplementation by use of either a face tent or a face mask in conjunction with NODSS to maintain an SaO₂ ≥ 90%.

To determine whether PETCO₂ data collection would be taken from the nose or mouth of each patient, the stopcock valve was adjusted to sample each site independently for 17 seconds (one sweep of the capnograph’s oscilloscope screen). The presence and quality of the waveforms generated by the nose and mouth were compared, and the mode that gave the higher PETCO₂ value and the best quality waveform was selected. PETCO₂
was measured and recorded, along with a waveform print.
A minimum of four sets of PaCO$_2$ versus PETCO$_2$ data was obtained on all subjects. All samples were temperature corrected to 37°C and analyzed using an Instrumentation Laboratories Model 1312 Blood Gas Analyzer that regularly self-calibrates with known gas concentrations.
Pearson's product-moment correlation coefficients were calculated to establish the strength of the association between PaCO$_2$ and PETCO$_2$. Rho was determined for the total data (nt), which included nasal and oral data combined, as well as the nasal (nn) and oral (no) data separately. This analysis was conducted for each of two subdivisions, group 1 and group 2 separately, as well as for the overall mean of the combined groups (M) for comparison. (Table I)

An abnormal mean gradient range of ≥ 7 mmHg and a normal mean gradient range of < 7 mmHg were used to distinguish groups 1 and 2, respectively.$^{12}$ All patients who demonstrated mean gradients (PaCO$_2$-PETCO$_2$) of ≥ 7 mmHg were placed in group 1 (N=9), while those having mean gradients of < 7 mmHg were placed in group 2 (N=15). The patients assigned to group 1 were also noted by history as being suspect for pulmonary dysfunction. (Table II).
As might be expected, patients in group 2 tended to be younger and healthier than those in group 1. The PETCO$_2$ waveforms generated for each patient in this study were of classical configuration, as characterized by a steep expiratory upstroke and a readily discernible plateau followed by a brisk return to baseline with inspiration.
Previous investigators have established reli-

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**Figure 1**

Nasal/oral discriminate sampling system

A. Tapered O$_2$ fitting
B. Oral O$_2$ delivery port
C. Telescoping nasal prong inserts
D. Septum dividing nasal prongs
E. Multiperforated oral CO$_2$ sampling chamber
F. Three-way stopcock for selection of oral and/or nasal CO$_2$ sampling.
### Table I
Results of statistical analysis by group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total data (n)</th>
<th>Nasal data (n)</th>
<th>Oral data (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1 (N = 9)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of data sets</td>
<td>37</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>PaCO$_2$</td>
<td>43.8 ± 4.67</td>
<td>43.8 ± 3.76</td>
<td>43.9 ± 6.04</td>
</tr>
<tr>
<td>PETCO$_2$</td>
<td>34.4 ± 3.35</td>
<td>34.3 ± 2.93</td>
<td>34.7 ± 4.05</td>
</tr>
<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>9.4 ± 2.86</td>
<td>9.5 ± 2.47</td>
<td>9.2 ± 3.49</td>
</tr>
<tr>
<td>r value</td>
<td>0.795</td>
<td>0.754</td>
<td>0.831</td>
</tr>
<tr>
<td>95% CI$^2$</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>8.434-10.339</td>
<td>8.432-10.568</td>
<td>7.181-11.219</td>
</tr>
<tr>
<td><strong>Group 2 (N = 15)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of data sets</td>
<td>63</td>
<td>46</td>
<td>17</td>
</tr>
<tr>
<td>PaCO$_2$</td>
<td>40.2 ± 4.17</td>
<td>40.5 ± 4.02</td>
<td>39.5 ± 4.6</td>
</tr>
<tr>
<td>PETCO$_2$</td>
<td>36.4 ± 4.96</td>
<td>37.0 ± 4.24</td>
<td>34.7 ± 6.37</td>
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<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>3.8 ± 2.89</td>
<td>3.5 ± 2.28</td>
<td>4.8 ± 4.06</td>
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<tr>
<td>r value</td>
<td>0.812</td>
<td>0.849</td>
<td>0.772</td>
</tr>
<tr>
<td>95% CI$^2$</td>
<td></td>
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<td></td>
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<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>3.118-4.577</td>
<td>2.809-4.165</td>
<td>2.735-6.912</td>
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<tr>
<td><strong>M (combined data) N = 24</strong></td>
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<td></td>
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</tr>
<tr>
<td>Number of data sets</td>
<td>100</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>PaCO$_2$</td>
<td>41.6 ± 4.67</td>
<td>41.56 ± 4.2</td>
<td>41.5 ± 5.66</td>
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<tr>
<td>PETCO$_2$</td>
<td>35.7 ± 4.51</td>
<td>36.1 ± 4.05</td>
<td>34.7 ± 5.36</td>
</tr>
<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>5.9 ± 3.93</td>
<td>5.5 ± 3.68</td>
<td>6.8 ± 4.36</td>
</tr>
<tr>
<td>r value</td>
<td>0.634</td>
<td>0.602</td>
<td>0.688</td>
</tr>
<tr>
<td>95% CI$^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaCO$_2$-PETCO$_2$</td>
<td>5.117-6.677</td>
<td>4.606-6.376</td>
<td>5.201-8.399</td>
</tr>
</tbody>
</table>

1. Values are means ± SD in mmHg
2. Values are in mmHg
r value—Correlation coefficient
CI—Confidence interval

The total nasal/oral data (PaCO$_2$ versus PETCO$_2$) for group 1 is 37. The nasal data totals 23 and the oral 14. Group 2 totals are 63, 46, and 17, respectively. The respective values for M are 100, 69, and 31. (Table I)

### Table II

<table>
<thead>
<tr>
<th>Group population characteristics</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects in group</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Male/female (%)</td>
<td>78/22</td>
<td>53/47</td>
</tr>
<tr>
<td>Age (years) mean ± SD</td>
<td>67 ± 10</td>
<td>45 ± 14</td>
</tr>
<tr>
<td>Age (years) range</td>
<td>46-80</td>
<td>27-73</td>
</tr>
<tr>
<td>Percent ASA physical status I</td>
<td>—</td>
<td>7</td>
</tr>
<tr>
<td>Percent ASA physical status II</td>
<td>22</td>
<td>80</td>
</tr>
<tr>
<td>Percent ASA physical status III</td>
<td>67</td>
<td>13</td>
</tr>
<tr>
<td>Percent ASA physical status IV</td>
<td>11</td>
<td>—</td>
</tr>
<tr>
<td>Percent with smoking history</td>
<td>67</td>
<td>60</td>
</tr>
<tr>
<td>Percent with cardiovascular history$^1$</td>
<td>78</td>
<td>13</td>
</tr>
<tr>
<td>Percent with other pulmonary history$^2$</td>
<td>44</td>
<td>7</td>
</tr>
</tbody>
</table>

1. Includes hypertension, congestive heart failure, coronary artery disease, cardiomegaly, significant ECG changes, valvular disease, and old myocardial infarction.
2. Includes chronic obstructive pulmonary disease, dyspnea on exertion, lung masses, chronic fibrotic changes, previous surgery for collapsed lung, and pulmonary embolus.
In evaluating NODSS, no effort was made to alter the prevailing route of breathing (nasal versus oral) in any of the 24 patients. Thirty-one percent of the total PETCO₂ data was collected using the oral sampling capability of the device. Forty-two percent of the total subject population (10 of 24) demonstrated intervals during which the optimal capnographic information was obtained by oral sampling.

As previously noted, both oral and nasal sampling were performed to compare capnographic waveform quality prior to the collection of recorded data. Figures 2 and 3 depict oral and nasal waveforms for representative patients from group 1 and group 2, respectively.

During nasal sampling for group 1, the PaCO₂ ranged from 38.4 to 52.0 mmHg (mean ± SD = 43.8 ± 3.76 mmHg). The PETCO₂ range was 30 to 40 mmHg (mean ± SD = 34.3 ± 2.93 mmHg), with oxygen supplementation varying between 2 to 5 L/min. With higher flows, there is a risk of dilution of CO₂ secondary to gas flow of O₂.

However, Figure 4 clearly shows that classical waveforms can be obtained by oral sampling in an

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**Figure 2**

Shown are oral and nasal waveforms for a representative patient from group 1. Plethysmograph signal and SaO₂ are absent because an N-100 pulse oximeter was used for some patients.
atmosphere of substantially increased O₂ flow and concentration while using NODSS. It should also be noted that, for this investigation, a portion of NODSS' O₂ flow was delivered to the right nostril and around the mouth as a function of the device's design.

The PaCO₂ range for group 1 during oral sampling was 34.3 to 52.3 mmHg (mean ± SD = 43.9 ± 6.04 mmHg). The PETCO₂ range was 28 to 41 mmHg (mean ± SD = 34.7 ± 4.05 mmHg), with supplemental oxygen as noted.

The PaCO₂ range of group 2 with nasal sampling was 32.7 to 49.8 mmHg (mean ± SD = 40.5 ± 4.02 mmHg), and the PETCO₂ range was 26 to 48 mmHg (mean ± SD = 37 ± 4.24 mmHg).

For the majority of patients in group 2, supplemental oxygen was delivered by NODSS at flows of 2-5 L/min. However, because of low O₂ saturation levels, three patients in group 2 required additional O₂ supplementation. Two patients received 70% O₂ at 10 L/min by face tent, and one received 100% O₂ by face mask at 8 L/min with double O₂ reservoirs.

The PaCO₂ range for group 2 during oral sam-

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**Figure 3**

Oral and nasal waveforms for a representative patient from group 2

![Waveforms](image)
This figure shows oral waveforms for a patient from group 2. Nasal/oral discriminate sampling system mounted under oxygen face mask 100% at 8L/min—double reservoirs.

The graph side is now frozen

The graph side is now frozen

The graph side is now frozen

Discussion

The results of this study suggest that NODSS is a reliable and effective method of noninvasively sampling PETCO₂ obtained from either the nose or mouth in spontaneously breathing subjects who have a natural airway. The device was also used to qualitatively determine the frequency of primarily oral or nasal breathing during emergence from general anesthesia. SaO₂ ≥ 90% could be maintained for 21 of 24 patients (88%) who received oxygen by NODSS at flow rates of 2-5 L/min. For groups 1 and 2 this corresponds to a mean arterial oxygen concentration (PaO₂ mmHg) of 91 mmHg and 120 mmHg, respectively.

Three patients in the study (all from group 2) required enhanced oxygen supplementation from an additional source (e.g., face tent or face mask) in order to maintain their SaO₂ ≥ 90%. One patient had nasal congestion subsequent to the logistics of the maxillofacial procedure. This individual was also receiving repeat doses of narcotic analgesic, which led to intermittent apneic intervals. A second patient had a tamponading catheter situated in the right nostril (the O₂ delivery side of NODSS) following excision of a maxillary sinus tumor. The optimal quality PETCO₂ data for this patient was collected from the left nostril; therefore, a face tent was used to deliver sufficient oxygen. The third patient had sustained multiple trauma secondary to a 40-foot fall. This patient’s postoperative chest x-ray showed pleural effusions, making it necessary to apply a face mask deliver-
ing 100% oxygen to provide adequate oxygenation.

Continuous capnographic monitoring during mechanical ventilation has become essential to ensuring patient safety, and its adoption as a standard has been strongly encouraged. Continuous capnographic monitoring of the nonintubated, spontaneously breathing patient is becoming increasingly popular, and numerous studies have been performed to evaluate it. Various methods have been devised for the collection of carbon dioxide from the population of patients noted above. The insertion of an angiocatheter through the prong of a conventional nasal cannula allows collection of respired gases through one nostril while delivering oxygen to the other. However, such a technique works well during nasal breathing, but it may fail completely or result in artificially low values during episodic/predominant mouth breathing. In addition, artificially low PETCO₂ readings may also be obtained from individuals with a perforated nasal septum, because crossover oxygen may be delivered to the opposite nostril, resulting in a washout of CO₂.

**Figure 5**

\( \text{PaCO₂-PETCO₂ (gradient in mmHg) for each patient's number of data sets} \)

PETCO₂ sampling by an oxygen face mask may be achieved by placing a capnographic sampling line inside the face mask. This technique functions well regardless of the breathing route, but its accuracy is inversely related to the flow of oxygen. At typical flow rates of 6-8 L/min, dilution of the sample is such that waveform quality is poor and PETCO₂ is grossly underestimated.

Various nasopharyngeal tubes or catheters have also been devised to allow carbon dioxide sampling. If they are inserted inferior to the soft palate, they allow for reliable sampling regardless of whether oral or nasal breathing is occurring. Drawbacks to this method include intolerance in the awake patient, a tendency for the device to become blocked with secretions or debris, retching and vomiting if it is inserted too deeply, nasal bleeding, and laryngospasm.

Human beings are capable of breathing by their mouth, nose, or both simultaneously. It is difficult to predict a sleeping subject's principal route of breathing based on his or her preferred route while awake. Therefore, in order to be reliable, any device that collects airway gas samples...
Figure 6
Scatter plot of PaCO₂ versus PETCO₂ (mmHg) for combined oral/nasal data in Group 1

Figure 7
Scatter plot of PaCO₂ versus PETCO₂ (mmHg) for combined oral/nasal data in Group 2
proximal to the soft palate (e.g., nares and lips) should be able to effectively sample both the nose and mouth simultaneously and, ideally, in a selective fashion. A determination should be made as to which naris is most patent so the NODSS can be modified, if necessary, to sample the most patent nostril.

Patients placed in the supine position are subject to increased nasal resistance. Engorged venous beds in the nasal mucosa enlarge, causing increased resistance to air flow. However, the resistive properties of air passage through the nose and mouth do not by themselves account for different patterns of oronasal air flow. The distance of the soft palate from the tongue (oropharyngeal isthmus) and the amount of mouth opening regulates the resistance of air passage through the mouth and nose, thereby affecting the partitioning of air flow between them.

Other nasopharyngeal factors, such as enlarged tonsils and/or adenoids, distorted turbinates, deviated nasal septum and/or polyps, can impede air flow as well. Peripheral chemoreceptors that detect SaO_2 or PaCO_2 have been implicated in a greater incidence of mouth breathing. Activation of receptors in the nasal passages also may be involved in reflex initiation of oral breathing.

The frequency of mouth breathing during sedation apparently has not been formally studied. However, circumstances surrounding the emergence of subjects from general anesthesia in the recovery room may serve as appropriate models for study.

In group 1, 14 of 37 sets of PaCO_2 versus PETCO_2 data or 38% were collected orally. Four of the nine members in that group (44%) were responsible for all the oral sampling data. In group 2, 17 of the 63 total sets of PaCO_2 versus PETCO_2 data or 27% were collected during oral sampling. Six of the 15 members in that group (40%) demonstrated intervals during which oral breathing predominated.

The amount of PaCO_2 versus PETCO_2 data collected during oral sampling in this study was 23/64 or 36% for men and 8/36 or 22% for women. The data also showed that 53% of the men and 22% of the women demonstrated intervals during which mouth breathing predominated. No attempt was made to alter any patient's mode of breathing during the data collection phase of this study.

When practicable, it is common to establish the gradient between PaCO_2 and PETCO_2. Barring any acute/appreciable changes in pulmonary ventilation and/or perfusion, the PaCO_2 can be expected to increase or decrease in direct propor-
tion to changes evidenced in PETCO₂. By examining Figure 5, it can be seen that the PaCO₂-PETCO₂ gradient remained relatively constant over the sampling period for each patient. For all 24 patients, the mean change in gradient was 4.05 ± 2.42 mmHg.

Recovery from general anesthesia represents a time during which the PaCO₂-PETCO₂ gradient is in a dynamic state of flux. In addition, emergence can be a time of turmoil. Patients may experience pain, become nauseated, and are frequently confused. They may present with a plethora of physiologic aberrations in blood pressure, heart rate, and respiration, all of which may influence the PaCO₂-PETCO₂ gradient. Certainly, a better arena for evaluation of NODSS would be in a sleep laboratory with physical status I patients. Under such conditions, variables could be controlled to enable more precise evaluation of the NODSS.

However, in light of the present findings, it is apparent that the results of these types of analyses are substantially dependent upon the prevailing PaCO₂-PETCO₂ gradient range. Similar investigations and analyses have been conducted for evaluation of both lesser gradient ranges and comparable, broader gradients.²⁻⁷,¹⁹⁻²³,³⁵

Upon close examination of the characteristics of patients who comprise groups 1 and 2 in this investigation (Table II), it can be seen that this study’s criteria for differentiating patients with abnormal gradients (greater physiologic dead space) from those with gradients considered to be in the normal range (lesser alveolar dead space) are fairly reliable.¹² At the very least, these results suggest that future studies should involve not only healthy subjects but should evaluate populations of patients that can be expected to have wider PaCO₂-PETCO₂ gradients established by pulmonary function tests. For example, individuals who present with varying degrees of chronic obstructive pulmonary disease should be investigated to substantiate that these monitoring methodologies are qualitatively and quantitatively reliable within any given pulmonary health status population.

Conclusion

Various methods of capnographic monitoring have been devised for spontaneously breathing patients who have a natural airway. However, it is essential to realize that currently available noninvasive methods and devices that focus solely or primarily on sampling nasal respiration cannot provide a reliable evaluation of changes with each breath. Nasal cannula samplers do not address the need to monitor oral breathing patterns, and simultaneous oral/nasal configurations offer limited potential.

In addition, various intrinsic and extrinsic factors might cause an alternating breathing pattern, thereby negating a dependable clinical use of the monitoring devices currently employed. At this time, it is apparent that the NODSS examined in this study is the only reliable noninvasive generator of accurate capnographic information that is useful for determining oral/nasal breathing patterns.

Such a system provides a reliable, accurate, qualitative and quantitative evaluation of respiratory adequacy. It can be of inestimable value in preventing morbidity and mortality that result from the delayed recognition of respiratory inadequacy.

REFERENCES


AUTHORS
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