The use of capnography during general anesthesia has become not only state of the art but also a recommended standard of care. In intubated patients, measurements of partial pressure of carbon dioxide in exhaled pulmonary gases approximate partial pressure of carbon dioxide in arterial blood under stable conditions. End-tidal carbon dioxide measurement has allowed anesthetists to continuously follow carbon dioxide concentration in exhaled gases; indirectly, it has enabled them to continuously monitor carbon dioxide concentration in arterial blood. This information has proven indispensable in the care of patients receiving general anesthesia, with its accompanying respiratory depressant effects.

Recently, attention has focused on the utilization of capnography in sedated, nonintubated patients to follow carbon dioxide concentrations and assess respiratory system function. This review of the current body of literature outlines development in capnography monitoring for sedated, nonintubated patients. Emphasis is placed on current techniques of measurement, the degree of correlation, and ramifications for clinical practice.

Key words: Capnography, end-tidal carbon dioxide, monitored anesthesia care, monitors, spontaneous ventilation.

Introduction
Luft introduced capnography to the medical community in 1943. Its popular utilization was realized in the 1980s as a result of advances in design technology, which prompted recommendations for routine use of capnography in anesthetic management of patients receiving general endotracheal anesthesia. This was due, in large part, to previous studies documenting anesthesia mishaps and numerous adverse events related to inadequate ventilation, such as hypoventilation, esophageal intubation, and ventilator disconnection. These mishaps have resulted in severe patient injury and major anesthetic liability costs.

Capnography has been shown to be effective in early detection of these potentially disastrous events. Furthermore, Tinker and associates concluded in a recent review of closed claims that 93% of anesthetic mishaps resulting in cash settlements could have been detected with application of capnography and pulse oximetry monitors. Justifiably then, it appears prudent to employ capnography on all patients undergoing general anesthesia that requires endotracheal intubation.
Recently, attention has focused on the utilization of capnographic monitoring for awake, nonintubated patients, especially in light of a report chronicling the total pulmonary and cardiovascular collapse of 14 patients who received spinal anesthesia with sedation that resulted in mortality or significant neurological morbidity. As a result, many practitioners and researchers have asked whether capnography would be a useful monitor of ventilatory function in awake, nonintubated patients who required anesthetic care.

**Historical perspectives**

Evaluation of ventilatory function has always been paramount in anesthesia practice. As early as 1947, Comroe and Botelho cautioned the medical community against assessing ventilatory adequacy through the presence of cyanosis. Cyanosis was documented to be an unreliable indicator of ventilation, because the arterial saturation of hemoglobin with oxygen fell to 70% or 75% before cyanosis was detected. These extremely low levels of oxygenation would not be tolerated for extended periods in patients who exhibited less than optimal health during surgery and anesthesia. Yet, inadequate observational skills continued to be utilized for oxygenation assessment.

Not until the early 1960s did attention again focus on capnography for assessment of ventilation. During the Association of Anaesthetists of Great Britain and Ireland Annual Meeting, Burton presented findings that documented the many uses and reliability of capnography in clinical practice. Yet, capnography has only recently been applied in clinical practice.

**Present day perspectives**

Currently, capnographic monitoring is strongly recommended during general anesthesia. This is due in part to respiratory complications that may occur during anesthesia which result in significant patient mortality and morbidity and malpractice disbursements. The effectiveness of capnography in providing early detection of endotracheal tube accidents in a dog model supports earlier admonitions to monitor partial pressure of end-tidal carbon dioxide (PETCO2) gases in anesthetized patients.

A study of pediatric patients documented capnography's ability to rapidly assess function and diagnose alterations in ventilatory and metabolic status. In addition, a retrospective analysis of major errors and equipment failures during anesthesia administration found that 14 of 70 incidents (20%) with substantive negative outcomes probably would have been detected had PETCO2 been monitored.

Similar large-scale studies of closed claims insurance reports have been conducted that document the significant devastation, albeit rare occurrence, of respiratory critical incidents in anesthesia practice. In response, many now advocate the routine use of PETCO2 monitoring during general anesthesia.

Not all those in the anesthesia community support PETCO2 monitoring. For example, Duncan and Cohen voice dissent, stating that the supposed levels of improvement cited by previous studies fail to achieve significant levels of importance because the occurrence rates of catastrophic respiratory incidents are usually rare, making it impossible to truly demonstrate improvement. However, when the emotional and societal costs of just one incident are so high, most practitioners find it imperative to employ these monitors for the safety and well-being of their patients.

**Current trends in PETCO2 monitoring**

Because of the demonstrated reliability and validity of capnography in the estimation of PETCO2 during general anesthesia with intubated patients, current attention has focused on expanded uses for capnographic monitoring. Of special interest is the theoretical usefulness of capnography for awake, nonintubated patients.

Caplan and associates' now classic paper chronicling 14 cases of sudden cardiac arrest in otherwise healthy patients who received spinal anesthesia questioned the adequacy of ventilation and the need for improved and expanded ventilatory monitoring. In their report, 14 patients, despite being relatively healthy and classified as ASA physical status I or II risks, who were undergoing relatively peripheral procedures experienced sudden and unexpected cardiac arrest during their surgical course while they were under spinal anesthesia. All were successfully resuscitated; however, the majority suffered significant morbidity or mortality.

In reviewing the anesthetic and surgical course, one common factor emerged: All patients were sedated to achieve a sleeplike state in which they did not voluntarily communicate. Cyanosis also seemed to herald the eminent onset of cardiac arrest, suggesting a significant degree of respiratory insufficiency may have been present and unnoticed.

With the advent of pulse oximetry (Spo2), the diagnosis of respiratory dysfunction has been made easier and more precise. Remember that respiratory function consists of two components: oxygen-
Oxygenation refers to the processes of oxygen uptake across lung membranes and delivery to tissue cells. It is reflected by the arterial partial pressure of oxygen (Pao2) value and is indirectly measured by pulse oximetry (Spo2).

On the other hand, ventilation refers to the mechanics of inspiration and expiration that move gases, most importantly carbon dioxide and oxygen, in and out of the pulmonary airway system. Ventilation is reflected by arterial partial pressure of carbon dioxide (Paco2) and PETco2 values.

Because pulse oximetry examines oxygenation indirectly (by percentage of saturation and not by partial pressure), one must be cognizant of the limitations of oxyhemoglobin saturation monitoring. In patients who are receiving supplemental oxygen, significant reductions in Pao2 must be realized before changes are demonstrated in Spo2 measurements that represent a significant degree of respiratory depression. This is due to the nonlinear relationship of oxygen partial pressure and oxygen saturation in hemoglobin (Figure 1.).

Conversely, the relationship between carbon dioxide partial pressure and saturation in blood is almost linear. At each level of Paco2, differing and incremental saturation values are present. Each change in partial pressure of carbon dioxide corresponds directly to changes in saturation of carbon dioxide in blood (Figure 2). This relationship, along with the high solubility of carbon dioxide across lung tissue membranes, explains the strong correlation between arterial saturation of carbon dioxide and PETco2 and the efficacy of PETco2 monitoring as a measure of respiratory function. Because most awake, nonintubated patients receive supplemental oxygen during their surgical course, oxygen and carbon dioxide partial pressures and saturations become important.

Accurate estimates of Paco2 by PETco2 measurements, whether taken from intubated or nonintubated patients, are influenced by many factors, particularly those that affect ventilation-perfusion relationships within lung tissues. Normally PETco2 is lower than Paco2, because ventilated but underperfused or nonperfused alveoli will supply gases that are practically devoid of carbon dioxide. When gases from underperfused alveoli mix with gases from ventilated and perfused alveoli, end-tidal partial pressures of carbon dioxide are reduced. Body position, mechanical ventilation, temperature, pulmonary emboli, and cardiac output are a few factors that affect ventilation-perfusion status.

Measurement mechanics also affect accuracy. High ventilatory frequency lowers PETco2 measurements, usually resulting from gaseous mixing of adjacent tidal volumes within the sampling cath-
eter and analysis chamber. Capnographs also must respond quickly to changes in carbon dioxide concentration. Slower responding capnographs (those that require more than 285 milliseconds to change from 10% to 70% of the final \( \text{PETCO}_2 \) value, also known as \( T_{70} \)) spuriously underestimate \( \text{PETCO}_2 \) at respiratory rates greater than 30 breaths per minute, such as in pediatric, anxious, or ventilatory compromised (chronic obstructive pulmonary disease, pulmonary edema) patients. Capnography transport delay (the time needed to aspirate end-tidal gases through the sampling catheter) may also underestimate measured \( \text{PETCO}_2 \) values in rapid ventilatory states due to dilutional gaseous mixing in the sampling catheter as well.

Measurement accuracy becomes even more difficult in awake, nonintubated patients. Supplemental oxygen administration spuriously lowers recorded \( \text{PETCO}_2 \) values, depending on the administration site and rate. Nasal obstruction, a perforated septum, hypoventilation, and mouth breathing will also lower \( \text{PETCO}_2 \) values, depending on the measurement technique and site. These issues have rendered use of the capnograph problematic in awake, nonintubated patients, especially children and patients who have rapid ventilatory rates or mouth breath.

**Current research trends**

The debate over the proper utilization of \( \text{PETCO}_2 \) monitoring in awake, nonintubated patients has both proponents and opponents. Early measuring devices consisted of a standard 16-gauge intravenous catheter inserted into one side of a nasal cannula port. The capnographic waveforms obtained resembled those from endotracheal tubes. However, some questioned the dilutional effects of atmospheric gases and supplementally administered oxygen. Modifications were made to improve accuracy by adding a second nasal cannula or inserting an intravenous catheter 5-10 mm beyond the nasal prong tip for measurement, thereby decreasing dilution of carbon dioxide at the measurement site. The measurements were purported as being qualitative measures of \( \text{PETCO}_2 \), and as such they would provide valuable warnings before deleterious oxyhemoglobin desaturations and/or apnea had occurred.

Studies to date document widely varying degrees of correlation between \( \text{Paco}_2 \) and \( \text{PETCO}_2 \) values in awake, nonintubated patients. Two studies obtained measurements from nasal cannulas placed at the nares. One port administered supplemental oxygen, while the other provided measurement access. Three studies attempted to decrease air and oxygen admixture by placing catheters further back in the nasopharyngeal area through nasopharyngeal Airways and catheters.

In an attempt to limit the influence of mouth breathing on measurement, one study utilized measurement devices that were capable of selectively sampling from either nasal or oral routes.

<table>
<thead>
<tr>
<th>Study</th>
<th>Method</th>
<th>Correlation</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brampton et al, 1990</td>
<td>Long catheter to nasopharynx</td>
<td>( r = 0.75 )</td>
<td>15</td>
</tr>
<tr>
<td>Dunphy, 1988</td>
<td>Catheter 8 cm into nasopharyngeal airway</td>
<td>( r = 0.59 )</td>
<td>15*</td>
</tr>
<tr>
<td>Lenz et al, 1991</td>
<td>Rusch nasal catheter 8-10 cm into nasopharyngeal area</td>
<td>Spearman rank: ( r = 0.82 )</td>
<td>19*</td>
</tr>
<tr>
<td>Roy et al, 1991</td>
<td>Syringe tip into nasal cannula port</td>
<td>Student t test: ( t = 0.89 )</td>
<td>21</td>
</tr>
<tr>
<td>Derrick et al, 1993</td>
<td>Nasal/oral discriminate sampling system</td>
<td>Total group: ( r = 0.634 )</td>
<td>24*</td>
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<tr>
<td></td>
<td></td>
<td>Subgroup 1</td>
<td>9*</td>
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<tr>
<td></td>
<td></td>
<td>(Pulmonary dysfunction)</td>
<td></td>
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<td></td>
<td></td>
<td>Oral: ( r = 0.83 )</td>
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<td></td>
<td></td>
<td>Nasal: ( r = 0.754 )</td>
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<td>Subgroup 2</td>
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<td></td>
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<td>(Healthy)</td>
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<td></td>
<td></td>
<td>Nasal: ( r = 0.849 )</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Oral: ( r = 0.772 )</td>
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* Several measures of the sample population were taken.
(nasal/oral discriminate sampling system, a modified nasal cannula device that can detect PETCO2 from nasal or oral sites). Interestingly, reliable measurements are more often found by nasal prong/nasal cannula devices than by more invasive nasal catheters and airways, causing one to question catheter patency inside nasal passages.

The overall correlations obtained by nasal/oral discriminate sampling systems trended lower ($r = 0.634$); however, subgroup correlations warrant further assessment. Interestingly, patients with suspected pulmonary dysfunction correlated better with oral measurements, while healthy patients displayed improved correlations with nasal samples; thereby raising speculation regarding the importance of measuring sites in relation to pulmonary functioning.

Spurious readings, large arterial to end-tidal carbon dioxide gradients, mouth breathing, obstruction of catheters/measuring sites, and dilution by supplemental administered oxygen are commonly cited problems that cause reductions in measurement accuracy. However, it was felt that attention to capnography waveforms and respiratory patterns would help diminish problems and enhance arterial and end-tidal carbon dioxide correlations. Likewise, the use of linear regression and correlation has been questioned in determining the accuracy and correlation between two measurement techniques. Linear regression is a poor index of measurement accuracy, as is correlation, which merely describes the strength of association between two sets of data. Instead, a description of the error around the means may more optimally present measurement accuracy. In any case, care should be exercised in overinterpreting correlation and regression values.

At present, studies seem to document a varying degree of reliability in the measurement of PETCO2 from nasal pharyngeal sites when compared to arterial carbon dioxide measurements or a PETCO2 measurement obtained from endotracheal tube sites. Measurement problems due to air and/or oxygen entrainment, periods of mouth breathing, and episodes of hypoventilation/hyperventilation must be remedied before consistent and reliable measurements of PETCO2 in awake, nonintubated patients can be achieved. The use of capnography for “trending” in the nonintubated patient has been advocated by some. However, measurement reliability and accuracy are questionable, considering the numerous spurious readings encountered within study groups. Mouth breathing, administered oxygen levels above 4 L/min, perforated nasal septums, and nasal con-


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