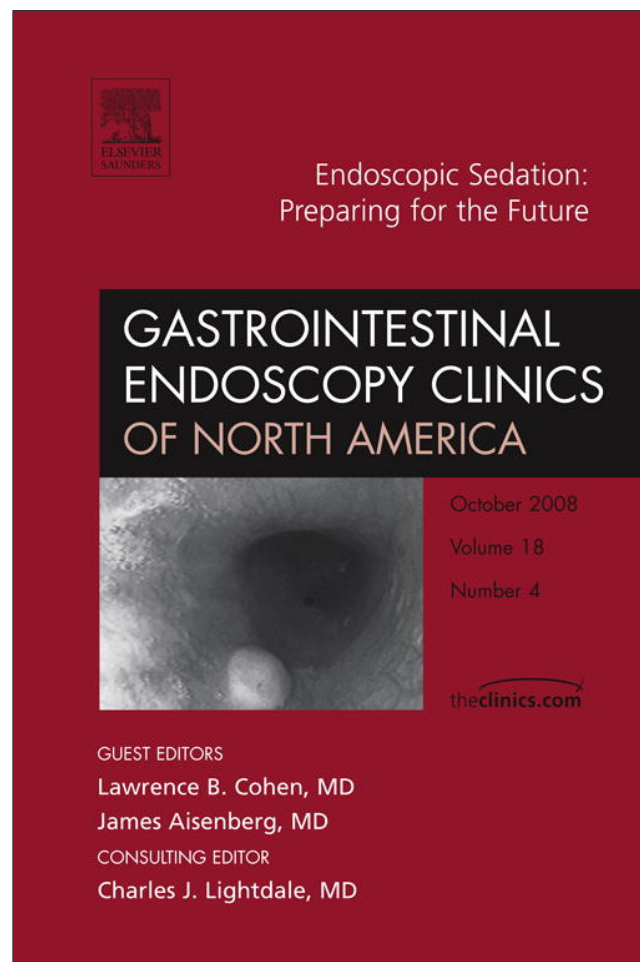


Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/copyright>

Patient Monitoring During Gastrointestinal Endoscopy: Why, When, and How?

Lawrence B. Cohen, MD*

KEYWORDS

• Patients monitoring • Endoscopy • Endoscopic sedation

Practice guidelines and position statements on patient monitoring during endoscopic sedation have been developed to standardize practice patterns and reduce the risk of sedation-related complications.^{1,2} Although the use of monitoring devices is believed to reduce the frequency of complications and improve the overall safety of endoscopy, this has been difficult to establish in clinical trials. The current recommendations for patient monitoring during moderate sedation include visual assessment and automated monitoring of heart rate, blood oxygen saturation (SaO₂), blood pressure, and in specified instances, cardiac rhythm. The role of several newer monitoring technologies including capnography, consciousness monitors, and auditory-evoked potentials is under active investigation. This article critically reviews the risks of sedation-related endoscopic complications, the practical issues pertaining to the use of monitoring technologies during endoscopy, and the evidence supporting the use of patient monitoring devices. Recommendations for patient monitoring based on consensus opinion are also presented.

WHAT IS THE INCIDENCE OF CARDIOPULMONARY COMPLICATIONS DURING ENDOSCOPY?

In 1974, an American Society for Gastrointestinal Endoscopy (ASGE) survey of endoscopic complications during an esophagogastroduodenoscopy (EGD) reported an overall complication rate of 0.13% and a mortality rate of 0.004%. (**Table 1**)³ Slightly less than half (46%) of these complications were cardiopulmonary in nature, so that the rate of sedation-related cardiopulmonary events was about 0.06%. More recently, another review of the ASGE endoscopic database observed that the risk of serious cardiopulmonary complications was 0.54%, nearly a 10-fold increase compared with the earlier findings.⁴ The marked difference in findings between these 2 studies

The Mount Sinai School of Medicine, One Gustave Levy Place, New York, NY 10029, USA

* New York Gastroenterology Associates, 311 East 79th Street, New York, NY 10021, USA.

E-mail address: lawrence.cohen@nyga.md

Gastrointest Endoscopy Clin N Am 18 (2008) 651–663

doi:10.1016/j.giec.2008.06.015

1052-5157/08/\$ – see front matter © 2008 Elsevier Inc. All rights reserved.

giendo.theclinics.com

Author	Year of Publication	N	Cardiopulmonary Complication Rate (%)
Silvis and Freeman ³⁹	1992	45,360	0.06
Arrowsmith and colleagues ⁴	1991	21,011	0.54
Seig and colleagues ⁵	2001	207,134	0.02
Nelson and colleagues ⁴⁰	2002	3,196	0.16
Gangi and colleagues ⁶	2005	—	0.31
Heuss and colleagues ⁷	2005	133,361	0.18
Cohen and colleagues ¹⁹	2007	345,633	0.37

clearly demonstrates the difficulty in comparing the results of various studies that have been designed to assess the rate of sedation-related adverse events.

Sieg and colleagues⁵ prospectively evaluated the incidence of cardiopulmonary complications among outpatients undergoing endoscopy. A total of 110,469 EGDs, and 96,665 colonoscopies performed by 94 German gastroenterologists and inter-nists during a 1-year period were assessed. Sedation, usually consisting of a sedative and/or analgesic drug, was used in 10% to 50% of EGDs and 70% to 100% of colonoscopies. Patient monitoring was limited to the use of pulse oximetry. Five patients (0.005%) experienced cardiopulmonary complications during EGD. One patient required endotracheal intubation and hospitalization, whereas the remaining 4 patients experienced hypoxemia that responded to flumazenil, a benzodiazepine antagonist. In addition, 7 patients (0.006%) experienced an unspecified adverse reaction to medication. Twelve patients (0.01%) were reported to have cardiopulmonary complications during colonoscopy including hypoxemia (n = 7), sinus bradycardia (n = 3), and hypotension (n = 2). The 2 mortalities recorded in this series were unrelated to the use of sedation. Overall, the frequency of cardiopulmonary events was 0.017%. This figure probably underestimates the true frequency of sedation-related complications, however, because not all patients in this series received intravenous sedation.

Gangi and colleagues⁶ used a financial and administrative database and chart review protocol to assess cardiovascular complications (arrhythmia, hypotension, chest pain or anginal equivalent, and myocardial infarction) during hospital-based endoscopy performed in a 9-hospital health care system. Fifty-two percent of the endoscopic procedures were performed on ambulatory patients and the remainder on hospital inpatients. The extrapolated rate of cardiovascular complications was 308/100,000 procedures (95% confidence interval [CI], 197–457), or 1 in 322 procedures (0.31%). This rate is nearly 20 times greater than that reported by Seig and colleagues.⁵

Heuss and colleagues⁷ surveyed gastroenterologists about sedation and monitoring practices in Switzerland using a postal questionnaire. The response rate to this survey was 72%. The overall rate of serious cardiopulmonary complication (arrhythmia or respiratory depression requiring intervention) in this retrospective survey was 0.18% with a reported mortality rate of 0.00014%. The complication rate during 82,000 procedures performed with propofol sedation (without the assistance of an anesthesiologist) was 0.19%. Consequently, the frequency of sedation-related complications was comparable for conventional sedation and propofol.

Recently, Sharma and colleagues⁸ analyzed cardiopulmonary unplanned events during endoscopy from the national endoscopic database of the Clinical Outcomes Research Initiative. Data on 324,737 procedures (including EGD, colonoscopy, endoscopic retrograde cholangiopancreatography [ERCP], and endoscopic esophageal ultrasound) performed under conscious sedation (opioid/benzodiazepine) were examined retrospectively for all cardiopulmonary events, ranging from transient hypoxia and bradycardia to cardiopulmonary arrest. The overall event rates ranged from 0.6% to 2.1%. Multiple logistic regression revealed that patient age (odds ratio [OR]: 1.02, CI, 1.01–1.02), American Society of Anesthesiologists' [ASA] classification physical status (OR: 1.05 ASA II to OR: 3.2 ASA IV), inpatient status (OR: 1.5, CI, 1.3–1.7), nonuniversity site of service (OR: 1.2, CI, 1.1–1.4), Veterans Affairs Medical Center (OR: 1.4, CI, 1.2–1.5), involvement of a trainee (OR: 1.3, CI, 1.1–1.4) and use of supplemental oxygen (OR: 1.2, CI, 1.1–1.3) were associated with a higher rate of unplanned cardiopulmonary events.

In summary, the reported frequency of sedation-related cardiopulmonary complications varies from 0.017% to 0.54%. This wide variation in the rate may be related to differences in study design (database review, prospective study, recall survey), method of data capture (chart review, database, billing records), patient population (ambulatory versus inpatient, mean age, gender, and physical status), sedation method (unsedated versus sedated, propofol versus standard sedation, presence of anesthetist), method of patient monitoring, and the definition of cardiopulmonary complications. If the true frequency of events lies somewhere between the extremes of all reported rates, the risk of a sedation-related cardiopulmonary complication can be approximated at 0.27%, or 1 in 370 procedures.

CAN WE IDENTIFY PATIENT- OR PROCEDURE-SPECIFIC RISK FACTORS FOR CARDIOPULMONARY COMPLICATIONS?

Several patient-specific risk factors for cardiopulmonary complications have been identified (**Box 1**).^{8,9} First, patients with a history of ischemic heart disease, cardiac arrhythmia, or moderate to severe pulmonary disease have a greater risk of

Box 1

Risk factors for cardiopulmonary complications^{6,8,10}

Patient-specific

- Ischemic heart disease
- Moderate to severe pulmonary disease
- Hospitalized patients
- Baseline SaO₂ < 95%
- Age > 70 years
- ASA III and IV

Procedure-specific

- Urgent or emergency procedures
- Method of sedation
- Use of adjunctive sedation agents
- Use of supplemental oxygen

complications.⁶ Second, patients with baseline hypoxemia (arterial SaO₂ < 95%) and hospital inpatients have a higher incidence of cardiopulmonary complications.^{8,10} Third, it is likely although not established that advanced age (>70 years) and ASA physical status III and IV confer an increased risk of complications.^{8,10}

Procedure-specific variables have also been identified. Urgent or emergent procedures are accompanied by greater risk of cardiopulmonary complications.⁶ The risk of ventilatory failure is higher during EGD than colonoscopy. Most of the studies indicate that the use of multiple drug classes (opioids, benzodiazepines, propofol) does not influence the frequency of sedation-related complications.^{6,10}

WHAT IS THE IMPACT OF ENDOSCOPY AND SEDATION ON CARDIOPULMONARY PARAMETERS?

Hypoxemia is observed during endoscopy with a reported frequency ranging from 4% to 50% or more, depending on the definition of hypoxemia, patient demographics, whether or not supplemental oxygen is used or not, and the method of sedation.^{9,11-14} In most series, the risk of hypoxemia is greater during upper endoscopy than during lower endoscopy. The proposed reasons for this include (1) a tendency to target deeper sedation during EGD than colonoscopy, (2) compression of the airway by the endoscope, and (3) risk of laryngospasm. However, the clinical significance of hypoxemia, often transient in duration, is uncertain. Furthermore, there is little evidence in the literature that the use of supplemental oxygen reduces the frequency of significant cardiopulmonary events.^{11,15}

The incidence of arrhythmia during endoscopy ranges from 4% to 72%.^{6,10,16} The most common arrhythmias are sinus tachycardia, sinus bradycardia, and supraventricular arrhythmias. Serious ventricular arrhythmias have rarely been reported during endoscopy. The physiologic mechanism(s) responsible for cardiac arrhythmia during endoscopy have not been elucidated completely. Hypoxemia has been the presumed mechanism of arrhythmias, although a causal relationship has not been established.¹⁶ An alternative explanation is vagal stimulation, resulting from distension or manipulation of the bowel. Sympathetic discharge has recently been suggested as another possible mechanism for arrhythmia. Supporting this concept is the observation that β -adrenergic blockade prevents tachycardia and reduces the observed frequency of arrhythmias during EGD.¹⁷

During endoscopy, electrocardiographic changes (other than arrhythmias) also may occur. The most commonly observed abnormality is ST segment change, reported to occur in 4% to 42% of patients. The pathogenesis of this electrocardiographic alteration remains unknown. Initially, these electrocardiographic changes were believed to be the result of hypoxemia and myocardial ischemia. More recently, however, it has been noted that the frequency of ST segment depression is unaffected by oxygen supplementation, suggesting that the changes are not ischemic in origin.^{15,16,18} Alternatively, there is evidence that tachycardia may play an important role in the pathogenesis of ST segment changes that are observed during endoscopy.¹⁸

SUPPLEMENTAL OXYGEN AND CARDIOPULMONARY COMPLICATIONS

Hypoxemia is one of the proposed pathophysiologic mechanisms of cardiopulmonary complications during endoscopy. Controlled trials have, failed to demonstrate that use of supplemental oxygen reduces the risk of complications, however.^{11,15} It is possible that methodological weaknesses account for this finding. For example, most trials have been insufficiently equipped to detect small differences in risk, especially because the frequency of such events is low. Furthermore, studies differ in their definition of cardiopulmonary event. Some studies have included all cardiopulmonary

changes, albeit minor, whereas others have included only clinically important cardiopulmonary events. Using the Clinical Outcomes Research Initiative database, the effect of oxygen supplementation on cardiopulmonary events during EGD and colonoscopy was evaluated recently. This analysis included the procedures performed under sedation with either opioid/benzodiazepine or propofol. A total of 240,000 colonoscopies and 100,000 EGDs performed by 86 endoscopists were included in the analysis. The findings of this study indicated that the use of supplemental oxygen reduced the risk of significant cardiopulmonary events during EGD (OR: 0.61; 95% CI, 0.42–0.90) but not during colonoscopy.¹⁹ In a similar study, Sharma and colleagues⁸ analyzed the frequency of unplanned cardiopulmonary complications during more than 324,000 endoscopic procedures performed under opioid/benzodiazepine sedation. He concluded that the use of supplemental oxygen was associated with a significantly higher rate of cardiopulmonary unplanned events (OR: 1.2, 95% CI, 1.1–1.3). Together, these studies question the widely held belief that routine administration of supplemental oxygen reduces the rate of sedation-related cardiopulmonary complications.

MONITORING PRACTICES DURING MODERATE SEDATION

Personnel

All patients undergoing endoscopy and sedation require visual assessment by a trained endoscopy assistant throughout the examination. According to the results of a recent nationwide survey of 5000 members of the American College of Gastroenterology, most endoscopy centers (89.5%) in the United States employ a registered nurse for patient monitoring. The individual assigned to patient monitoring should possess training appropriate for visual assessment of the patient, interpreting physiologic data, and responding appropriately as required. Because sedation occurs along a continuum and the targeted level of sedation may be exceeded, this individual must also be capable of recognizing the stages of sedation and, at a minimum, possess basic life support skills. During moderate sedation, the assistant responsible for monitoring may also perform brief, interruptible tasks, such as abdominal compression, and assist with endoscopic biopsy. Additional staff should be available upon request to assist during complex diagnostic or therapeutic procedures, or in the event that a patient requires additional attention. Patient monitoring should be provided throughout the procedure and maintained during recovery. All individuals responsible for patient monitoring should understand that the greatest risk of sedation-related complications occurs during the first 8 to 10 minutes after the administration of sedation medications and immediately after the completion of the procedure. Patients receiving an opioid or benzodiazepine reversal agent (naloxone or flumazenil) require special attention and should be monitored for up to 2 hours. Documentation of all drugs administered and a time-based record of all physiologic parameters must be maintained for all patients undergoing moderate sedation.

Pulse Oximetry

Pulse oximetry is a noninvasive technique for continuous measurement of arterial SaO₂ and is useful for the early detection of hypoxemia. SaO₂ refers to the amount of oxygen attached to the hemoglobin molecule in the red blood cell. The principle of pulse oximetry is based on red and infrared absorption characteristics of oxygenated and deoxygenated hemoglobin. A pulse oximeter contains 2 high-intensity, monochromatic, light-emitting diodes (LEDs); 1 emitting red light (660 nm) and the second infrared (940 nm). A photodetector, usually located on the opposite side of

the sensor, measures the amount of light transmitted through the finger. Oxygenated hemoglobin absorbs more infrared light, whereas deoxygenated hemoglobin absorbs more red light. By measuring the pulsatile changes in light absorption and deducting for absorption by venous blood and tissue, arterial saturation can be calculated.

Arterial SaO₂ provides a relatively insensitive measure of moment-to-moment changes in ventilatory status because the body's supply of oxygen will delay a drop in SaO₂ for several minutes. At the upper end of the oxyhemoglobin dissociation curve, large changes in partial pressure of oxygen are associated with small changes in SaO₂. For example, minute ventilation may be reduced by 50% without an appreciable change in SaO₂. The use of supplemental oxygen shifts the oxyhemoglobin dissociation curve to the left, further delaying a fall in arterial SaO₂ and the detection of hypoventilation. Hypercapnea, another manifestation of inadequate ventilation, is also undetected by pulse oximetry. Therefore, although arterial SaO₂ generally provides a reliable indicator of how well the patient is breathing, its usefulness as an early indicator of altered ventilation is limited by physiologic and technological considerations.

Dual-wavelength pulse oximeters are subject to spurious results under a variety of conditions. Methemoglobin, carboxyhemoglobin, and other structural hemoglobinopathies such as hemoglobin F will produce false readings in SaO₂. Other reasons for artifactual results during pulse oximetry include the presence of nail polish, skin pigmentation, ambient light (especially fluorescent light), anemia, peripheral vasoconstriction or hypoperfusion, and motion. Patient motion accounts for more than half of all instances in which pulse oximetry "fails" to perform satisfactorily as a monitoring device.²⁰ During the past decade, newer pulse oximeters have been produced with improved signal-processing techniques and data rejection algorithms that make them more motion resistant. These newer generation pulse oximeters have superior performance characteristics with clinical implications for patient monitoring.²¹

Although pulse oximetry provides valuable feedback about arterial SaO₂ and hypoxemia, it has been challenging to demonstrate that its use is associated with improved outcomes and fewer adverse events. An updated Cochrane review concluded that published studies have failed to establish that pulse oximetry improves the outcome of anesthesia and sedation.²² For example, Moller and colleagues²⁰ randomized 20,802 surgical patients to monitoring with or without pulse oximetry. Postoperative complications were similar in both groups and the postoperative mortality was nearly identical (1.1% versus 1.0%) in the oximeter and control groups, respectively. Nonetheless, pulse oximetry has become the de facto standard of care in the United States and throughout most other parts of the world. It is presumed, although not established by an evidence-based analysis, that the additional information provided by pulse oximetry will reduce sedation-related complications by improving sedation techniques or more timely initiation of therapeutic interventions.

Hemodynamics and Electrocardiography

Heart rate and blood pressure are important parameters of cardiovascular stability. Baseline hemodynamic measurements provide useful information regarding the patient's level of anxiety, hydration status, and the effects of various medical conditions. In some instances, these parameters may influence the selection of sedation agents. Similarly, pulse and blood pressure provide important feedback throughout an endoscopic procedure. For example, marked hypotension may indicate oversedation or dehydration. In most cases, a bolus of intravenous fluid and positioning the patient in the Trendelenburg position is adequate, although pressor agents may be required for symptomatic hypotension.

Devices are now widely available that automatically record blood pressure at pre-established intervals. In addition to displaying systolic, diastolic, and mean arterial pressure, they have audible alarms to alert personnel if the reading is outside of acceptable limits and provide a permanent record of this data. All patients receiving intravenous sedation should be monitored for heart rate and blood pressure. A baseline blood pressure should be noted before the administration of sedation, and then at 3- to 5-minute intervals throughout the procedure.

The role of continuous electrocardiography during endoscopic sedation remains uncertain. Its use was initially intended to detect arrhythmias in high-risk patients undergoing deep sedation, monitored anesthesia care, or general anesthesia. The ASA practice guidelines indicate that patients with significant cardiovascular disease or dysrhythmia should have electrocardiographic monitoring during endoscopic sedation.²³ In contrast, an evidence-based analysis of the literature recently concluded that “there is no evidence that cardiac monitoring during procedural sedation and analgesia is of benefit, especially if the patient has no underlying cardiopulmonary disease.”²⁴

DOES VENTILATION MONITORING HAVE A ROLE DURING MODERATE SEDATION?

In contrast to arterial SaO₂, which provides indirect information on respiratory function, the measurement of carbon dioxide (CO₂) in expired gas provides a breath-by-breath assessment of ventilation and may be considered to be the “ventilatory vital sign.” Two noninvasive methods of arterial CO₂ pressure measurement are commercially available: capnography and transcutaneous CO₂ monitoring. Each technique offers certain advantages and limitations.

Capnography, the measurement of CO₂ in exhaled breath, is now commonly used during general anesthesia and monitored anesthesia care. Most capnographs use infrared light to measure CO₂ concentration in the breath sample. An infrared beam is projected through the gas sample, light at a wavelength of 4260 nm is absorbed by CO₂, and the intensity of transmitted light is measured. Capnographs are configured in mainstream and sidestream designs. A mainstream device places the sensor close to the airway and is designed for use in patients who are intubated. Sidestream capnography, designed for nonintubated patients, measures CO₂ by continuously aspirating a small sample of exhaled breath into the monitor where a sensor is located. The sampling system usually consists of a nasal cannula and tubing, sometimes combined with an additional probe to sample gas from the mouth. An aspiration port allows for continuous sampling of patient gases during inspiration and expiration, while supplemental oxygen is administered simultaneously through an ancillary channel of the cannula (**Fig. 1**).

The capnograph provides a numerical display of the end-tidal CO₂ concentration and a waveform, or capnogram (**Fig. 2**). Exhaled CO₂ is most often displayed as a function of time (CO₂ concentration vs. time). The normal capnogram wave peaks during expiration, whereas the trough occurs during inspiration. The capnogram is generally interpreted by pattern recognition, analogous to reading an electrocardiogram. The essential elements of the waveform include the amplitude, width, shape, and frequency. There are specific waveform patterns that may be used to identify patterns of respiration. With a little experience, an individual can easily recognize various respiratory patterns including apnea, hyperventilation, early and late stages of hypoventilation, and normal respiration. Unlike pulse oximetry, the quality of a capnogram is unaffected by patient motion and hypoperfusion.



Fig. 1. Capnography sampling system consisting of a nasal cannula combined with an additional probe to sample exhaled gas from the mouth. This system permits continuous sampling of patient gases and simultaneous administration of supplemental oxygen.

Capnography detects hypoventilation earlier than does pulse oximetry and provides a more sensitive measure of alveolar hypoventilation than visual observation.²⁵ Lightdale²⁶ prospectively randomized children undergoing elective endoscopy with moderate sedation to standard monitoring of ventilatory function with capnography or not. Hypoventilation and apnea were detected more often with capnography (56% and 24%) compared with the control group (3% and 0%). Furthermore, as a result of appropriate intervention, capnography reduced the number of hypoxemic episodes (11% versus 24%, $P < .03$).²⁶ Notwithstanding these observations, the challenge ultimately is to demonstrate that the use of capnography can decrease complications and improve patient safety during moderate sedation. Because of the relatively small number of clinically significant adverse events during moderate sedation, it is unlikely that this will be established in randomized, controlled studies. Instead, standards of practice for patient monitoring during moderate sedation will probably be determined by expert opinion, professional societies, and accrediting agencies.

In contrast to capnography, which is widely used during general anesthesia and monitored anesthesia care, clinical applications of transcutaneous CO₂ monitoring have been limited by the shortcomings of current technology. Transcutaneous CO₂ monitoring uses a pH-sensitive glass electrode to measure pH changes that result from the diffusion of CO₂ across the skin. A transducer converts pH changes into an electrical signal that is processed and displayed by the monitor. A warming unit within the sensor heats the skin to 42°C to enhance CO₂ diffusion. Sweating, cutaneous vasoconstriction, variations in skin thickness, and hypotension limit the technical accuracy of transcutaneous CO₂ monitoring.

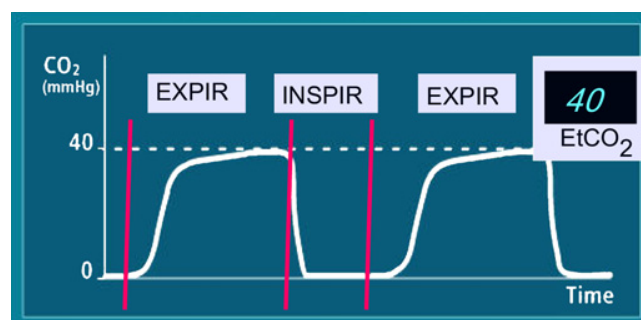


Fig. 2. Capnographic waveform.

The potential role of transcutaneous CO₂ monitoring during endoscopy was recently evaluated. Nelson randomized 395 patients undergoing ERCP under moderate sedation (opioid or benzodiazepine) to determine whether transcutaneous CO₂ monitoring was more effective than standard monitoring for the prevention of severe hypoventilation. Patients received supplemental oxygen only if arterial SaO₂ fell below 90% for more than 60 seconds. Fewer episodes of severe CO₂ retention were observed in patients with CO₂ monitoring (2.6% versus 0, $P = .03$), although there were no significant differences in sedation success, sedation-related procedure terminations, or other cardiorespiratory parameters. Technological advances in transcutaneous CO₂ monitoring have recently been introduced in an attempt to improve its clinical usefulness. One such device, combining pulse oximetry with transcutaneous CO₂ monitoring into a small earlobe sensor, has undergone validation studies successfully, and clinical evaluation during endoscopy is awaited.²⁷

WHAT OTHER METHODS OF MONITORING ARE BEING EVALUATED FOR ENDOSCOPIC SEDATION?

Bispectral index (BIS) monitoring is a noninvasive method of assessing a patient's level of consciousness. Electroencephalographic waveforms are captured using a self-adhesive forehead probe. The BIS monitor uses a complex algorithm to analyze the electroencephalogram, generating a BIS index that ranges from 0 to 100: 100 corresponds to fully awake; 70 to 90 minimal to moderate sedation; 60 to 69 deep sedation, 40 to 59 general anesthesia, and <40 deep hypnosis. The BIS monitor was designed to measure patient consciousness during general anesthesia, minimizing the risk of under- or oversedation. Its use has subsequently expanded into the outpatient setting, including use in the endoscopy unit.

BIS monitoring has been used during endoscopy in an effort to establish an objective measure of the level of sedation. Bower and colleagues²⁸ evaluated the BIS index in an observational study of 50 patients undergoing EGD, colonoscopy, or ERCP under sedation with diazepam and meperidine. The BIS index correlated moderately well ($r = 0.59$) with the level of sedation determined using the Observer Assessment of Alertness/Sedation scale. Al-Sammak and colleagues²⁹ performed a small randomized study to compare BIS with clinical assessment of sedation in 40 patients undergoing ERCP under sedation with midazolam and fentanyl. There was a statistically significant difference in terms of sedation duration, recovery rate, patient satisfaction, and the total dose of sedative drug administered favoring the group monitored with BIS. In contrast with these findings, a study by Qadeer and colleagues³⁰ reported that BIS index had low accuracy for detecting deep sedation in patients sedated with narcotic and benzodiazepine, and another study by Chen and Rex³¹ concluded that BIS index was not useful for titrating propofol to an adequate level of sedation. Further work will be required before it is known whether BIS monitoring will serve an important role in patient monitoring during endoscopy. If the current trend toward deeper levels of sedation persists, and the use of propofol by nonanesthesiologists grows, it is likely that we will see more interest in the potential applications of BIS in the endoscopy suite. In the future, BIS monitoring may be useful for training endoscopists in the use of new sedation agents, drug titration, or as part of closed-loop delivery system that uses the BIS index as a control variable for dose titration.³²

The automated responsiveness monitor (ARM) is a self-contained computerized system designed to elicit purposeful responsiveness to verbal or vibratory stimulus, the working definition of moderate sedation.^{33,34} The ARM unit consists of an earphone, a handpiece with a thumb button, and an online microcomputer.

A computerized voice prompts the participant to press the button at regular intervals. A vibrator built into the handpiece vibrates simultaneously. The voice and vibration repeat with increasing intensity over a 10-second period until the patient responds by depressing the button. Failure to elicit a response indicates that the patient is no longer at a moderate level of sedation.

When ARM is interfaced with a drug delivery system, it can be used to provide positive or negative feedback about the safety and feasibility of continued drug infusion based on the *patients' level of sedation. If an appropriate response is absent, the patient is considered to be oversedated and the infusion is reduced or halted until responsiveness returns. The sedation delivery system, also referred to as computer-assisted personalized sedation, consists of an infusion module and monitors for pulse oximetry, blood pressure, capnography, electrocardiography, and ARM. The feasibility of computer-assisted personalized sedation was evaluated in 2 identical studies, 1 in the United States and the second in Belgium, comprising a total of 96 patients.³⁵ Patients remained moderately sedated throughout the examination with no episodes of prolonged hypoxemia or hypotension requiring intervention. Satisfaction scores among patients and endoscopists were excellent. If the results of this feasibility trial are confirmed in a multicenter study, ARM could provide a mechanism for maintaining propofol delivery within the range of moderate sedation.

Auditory-Evoked Potential

Auditory-evoked potentials reflect changes in electrical activity of the brain in response to auditory stimuli. Similar to the BIS index, auditory-evoked potentials can be processed and presented as a composite index (0–99) to monitor depth of sedation. Huang and colleagues³⁶ prospectively studied 30 patients undergoing EGD and colonoscopy under sedation with midazolam and alfentanil. A significant correlation was observed between the auditory-evoked potential index and levels of sedation ($r = 0.886$), with values between 34 and 42 correlating with moderate to deep sedation. Additional studies using this interesting technology are necessary before any meaningful statement can be made about its utility during endoscopy.

CURRENT RECOMMENDATIONS FOR PATIENT MONITORING

Heart rate and blood pressure should be measured using an automated device with visual display of output and appropriate alarms. A baseline blood pressure should be recorded before the administration of sedation, and then at 3- to 5-minute intervals throughout the procedure. Pulse oximetry using a device equipped to provide continuous readout with visual display and a variable pitch audible signal is recommended for all patients undergoing endoscopy with moderate sedation.^{1,23} The use of continuous electrocardiography during moderate sedation in average-risk patients is not required. High-risk patients (including those with a history of cardiac arrhythmia or ischemic heart disease), however, may be reasonable candidates for cardiac monitoring.¹ Routine administration of supplemental oxygen during moderate and deep sedation is endorsed by the ASA and the ASGE. Nonetheless, there is evidence that routine use of supplemental oxygen might actually increase the risk of sedation-related complications by delaying recognition of hypoventilation by pulse oximetry.^{37,38}

Capnographic monitoring should be considered for the following subgroups of patients undergoing endoscopy with moderate sedation: (1) all patients sedated

* Monitoring system (ARM) is integrated into a delivery system and can regulate the rate of infusion up or down.

with propofol, (2) difficult-to-sedate patients, (3) those undergoing prolonged diagnostic or therapeutic procedures, and (4) those who cannot be adequately assessed visually throughout an examination. In addition, CO₂ monitoring may be helpful in sedated patients receiving supplemental oxygen and those with ASA status III and IV.

SUMMARY

The rate of cardiopulmonary complications during endoscopic sedation is estimated at 0.27%, or 1 in 370 procedures. Patient monitoring, both visual and physiologic, is designed to improve the quality of sedation and minimize the risk of complications. Although there is little evidence to support the concepts that monitoring improves patient outcomes and reduces complications, the standard of care at the current time requires that all patients undergoing endoscopy with intravenous sedation be monitored. In addition to routine monitoring, patients with significant comorbid diseases, those undergoing advanced endoscopic procedures, and the difficult-to-sedate patients who require deeper sedation should be considered for more advanced monitoring with continuous electrocardiography and capnography. The use of such technology, however, is not a substitute for the observational skills of a well-trained endoscopy nurse who is able to identify the earliest signs of a complication and initiate the appropriate corrective steps. Ultimately, improvements in the safety of patients will involve better education and training in endoscopic sedation combined with implementation of a performance improvement program designed to assess outcomes and strengthen areas of weakness.

REFERENCES

1. Cohen LB, DeLegge M, Kochman M, et al. AGA institute review on endoscopic sedation. *Gastroenterology* 2007;133:675–701.
2. American Society for Gastrointestinal Endoscopy. Sedation and monitoring of patients undergoing gastrointestinal endoscopic procedures. *Gastrointest Endosc* 1995;42(6):626–9.
3. Silvis SE, Nebel OT, Rogers G, et al. Endoscopic complications. Results of the 1974 American Society for Gastrointestinal Endoscopy Survey. *JAMA* 1975;235:928–30.
4. Arrowsmith JB, Gerstman BB, Fleischer DE, et al. Results from the American Society for Gastrointestinal Endoscopy/U.S. Food and Drug Administration collaborative study on complication rates and drug use during gastrointestinal endoscopy. *Gastrointest Endosc* 1991;37(4):421–7.
5. Sieg A, Hachmoeller-Eisenbach U, Eisenbach T. Prospective evaluation of complications in outpatient GI endoscopy: a survey among German gastroenterologists. *Gastrointest Endosc* 2001;53(6):620–7.
6. Gangi S, Saidi F, Patel K, et al. Cardiovascular complications after GI endoscopy: occurrence and risks in a large hospital system. *Gastrointest Endosc* 2004;60(5):679–85.
7. Heuss LT, Froehlich F, Beglinger C. Changing patterns of sedation and monitoring practice during endoscopy: results of a nationwide survey in Switzerland. *Endoscopy* 2005;37(2):161–6.
8. Sharma VK, Nguyen CC, Crowell MD, et al. A national study of cardiopulmonary unplanned events after GI endoscopy. *Gastrointest Endosc* 2007;66(1):27–34.
9. Vargo JJ, Holub J, Faigel D, et al. Risk factors for cardiopulmonary events during propofol-mediated upper endoscopy and colonoscopy. *Aliment Pharmacol Ther* 2006;24:955–63.

10. Eisen GM, Baron TH, Dominitz JA, et al. Complications of upper GI endoscopy. *Gastrointest Endosc* 2002;55(7):784–93.
11. Patterson KW, Noonan N, Keeling NW, et al. Hypoxemia during outpatient gastrointestinal endoscopy: the effects of sedation and supplemental oxygen. *J Clin Anesth* 1995;7(2):136–40.
12. Bailey PL, Pace NL, Ashburn MA, et al. Frequent hypoxemia and apnea after sedation with midazolam and fentanyl. *Anesthesiology* 1990;73(5):826–30.
13. Froehlich F, Schwizer W, Thorens J, et al. Conscious sedation for gastroscopy: patient tolerance and cardiorespiratory parameters. *Gastroenterology* 1995;108(3):697–704.
14. Froehlich F, Thorens J, Schwizer W, et al. Sedation and analgesia for colonoscopy: patient tolerance, pain, and cardiorespiratory parameters. *Gastrointest Endosc* 1997;45(1):1–9.
15. Holm C, Rosenberg J. Pulse oximetry and supplemental oxygen during gastrointestinal endoscopy: a critical review. *Endoscopy* 1996;28:703–11.
16. Bowling TE, Hadjiminias CL, Polson RJ, et al. Effects of supplemental oxygen on cardiac rhythm during upper gastrointestinal endoscopy: a randomized controlled double blind trial. *Gut* 1993;34:1492–7.
17. Oei-Lim VL, Kalkman CJ, Bartelsman JF, et al. Cardiovascular responses, arterial oxygen saturation and plasma catecholamine concentration during upper gastrointestinal endoscopy using conscious sedation with midazolam or propofol. *Eur J Anaesthesiol* 1998;15(5):535–43.
18. Rosenberg J, Stausholm K, Andersen IB, et al. No effect of oxygen therapy on myocardial ischemia during gastroscopy. *Scand J Gastroenterol* 1996;31:200–5.
19. Cohen LB, Holub J, Lieberman DA, et al. Does routine use of supplemental oxygen during endoscopy really reduce the risk of cardiopulmonary complications? *Gastrointest Endosc* 2007;65:AB102 [abstract].
20. Moller JT, Pederson T, Rasmussen LS. Randomized evaluation of pulse oximetry in 20,802 patients. *Anesthesiology* 1993;78:436–44.
21. Barker SJ. “Motion-resistant” pulse oximetry: a comparison of new and old models. *Anesth Analg* 2002;95:967–72.
22. Pedersen T, Moller AM, Pedersen BD. Pulse oximetry for perioperative monitoring: systematic review of randomized, controlled trials. *Anesth Analg* 2003;96:426–31.
23. Gross JB, Bailey PL, Connis RT, et al. Practice guidelines for sedation and analgesia by non-anesthesiologists. *Anesthesiology* 2002;96(4):1004–17.
24. Godwin SA, Caro DA, Wolf SJ, et al. Clinical policy: procedural sedation and analgesia in the emergency department. *Ann Emerg Med* 2005;45:177–96.
25. Vargo JJ, Zuccaro G Jr, Dumot JA, et al. Automated graphic assessment of respiratory activity is superior to pulse oximetry and visual assessment for the detection of early respiratory depression during therapeutic upper endoscopy. *Gastrointest Endosc* 2002;55(7):826–31.
26. Lightdale JR, Goldmann DA, Feldman HA, et al. Microstream capnography improves patient monitoring during moderate sedation: a randomized, controlled trial. *Pediatrics* 2006;117(6):e1170–8.
27. Heuss LT, Prashant N, Schnieper P, et al. Combined pulse oximetry/cutaneous carbon dioxide tension monitoring during colonoscopies: pilot study with a smart ear clip. *Digestion* 2004;70:152–8.
28. Bower AL, Ripepi A, Dilger J, et al. Bispectral index monitoring of sedation during endoscopy. *Gastrointest Endosc* 2000;52(2):192–6.

29. Al-Sammak Z, Al-Falaki MM, Gamal HM. Predictor of sedation during endoscopic retrograde cholangiopancreatography—bispectral index vs clinical assessment. *Middle East J Anesthesiol* 2005;18:141–8.
30. Qadeer MA, Vargo JJ, Patel S, et al. Bispectral index monitoring of conscious sedation with the combination of meperidine and midazolam during endoscopy. *Clin Gastroenterol Hepatol* 2008;6:102–8.
31. Chen SC, Rex DK. An initial investigation of bispectral monitoring as an adjunct to nurse-administered propofol sedation for colonoscopy. *Am J Gastroenterol* 2004;99:1081–6.
32. Leslie K, Absalom A, Kenny GN. Closed loop control of sedation for colonoscopy using the bispectral index. *Anaesthesia* 2002;57(7):693–7.
33. Doufas AG, Bakshandeh M, Bjorsten AR, et al. Automated responsiveness test (ART) predicts loss of consciousness and adverse physiologic responses during propofol conscious sedation. *Anesthesiology* 2001;94(4):585–92.
34. Doufas AG, Bakshandeh M, Bjorsten AR, et al. Induction speed is not a determinant of propofol pharmacodynamics. *Anesthesiology* 2004;101:1112–21.
35. Pambianco DJ, McRorie J, Martin J, et al. Feasibility assessment of computer assisted personalized sedation: a sedation delivery system to administer propofol for gastrointestinal endoscopy. *Gastrointest Endosc* 2006;63(5):AB189 [abstract].
36. Huang YY, Chu YC, Chang KY, et al. Performance of AEP Monitor/2-derived composite index as an indicator for depth of sedation with midazolam and alfentanil during gastrointestinal endoscopy. *Eur J Anaesthesiol* 2007;24:252–7.
37. Fu ES, Downs JB, Schweiger JW, et al. Supplemental oxygen impairs detection of hypoventilation by pulse oximetry. *Chest* 2004;126:1552–8.
38. Downs JB. Has oxygen administration delayed appropriate respiratory care? Fallacies regarding oxygen therapy. *Respir Care* 2003;48(6):611–20.
39. Silvis SE, Freeman M. The ASGE/FDA study on complications of sedation. *Gastrointest Endosc* 1992;38(1):92–3.
40. Nelson DB, McQuaid KR, Bond JH, et al. Procedural success and complications of large-scale screening colonoscopy. *Gastrointest Endosc* 2002;55(3):307–14.