Review of monitors and monitoring during sedation with emphasis on clinical applications

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There are many different types of monitors on the market including nonelectronic and electronic instruments (e.g., precordial stethoscope and pulse oximeter, respectively). Table 1 offers a summary of monitors often used during sedation in dentistry. No study has demonstrated clearly the impact that electronic monitors have had on clinical studies involving sedations. However, a recent article offers strong evidence that they have had a dramatic impact.[1] It shows that prior to the 1980s (and the advent of electronic monitors), only two papers reported the recording of physiologic measures compared with more than 30 thereafter. In fact, less than five reports of 42 since the 1980s failed to report physiologic measures compared with 12 of 14 prior to that decade.

Electronic monitors began to flood the market in the early 1980s, although the technology for monitors like oximetry had been recognized for years.[2] Probably the greatest facilitator for the widespread marketing of such monitors was the microchip, which allowed monitors to be packaged in small, convenient units.

What should be required in terms of the type and number of monitors needed during any sedation? No easy answers exist because clinical situations vary dramatically, although guidelines[3] provide some direction. Several relevant, but controversial issues are associated with the constellation of monitors needed during sedations. These may be summarized as follows:

1. Philosophical differences among practitioners in terms of interpretation of guidelines and perceived need for relevant monitors for different types of sedation
2. Degrees and frequencies of patient noncompliance and uncooperative behaviors during sedations, the need for monitors under such circumstances, and the extent to which monitors contribute to such behaviors (e.g., a precooperative child who is not well-sedated may be further annoyed by a probe attached to his/her finger or limb)
3. Cost implications of monitors in light of no well-documented evidence that monitoring alters the risk/benefit ratio of adverse outcomes in dental sedations
4. Importantly, practitioner training and experiences.

The best philosophy from a child advocate's position is that it does not matter which type of drug(s) or dose is selected; the safety net — theoretically and empirically — will become increasing larger from a medicolegal viewpoint as one adds more appropriate, sophisticated monitors and understands their functions and implications. Of course, this philosophy requires appropriate training in monitoring and sedation techniques. The following is an overview of specific monitors frequently used in sedation trials with an emphasis on clinical considerations.

Pulse oximetry

The pulse oximeter (PO) is considered by most anesthesiologists and sedationists the gold standard for monitoring. Reviews of its functional operation can be found elsewhere.[4,5] The PO measures, indirectly and on a continuous basis, the oxygen saturation (and heart rate) in the blood via noninvasive probes.

In brief, the oxisensor (the probe that attaches to the patient) contains two elements: one emits light in red and infrared wavelengths and the other detects light transmitted through tissue. Oxygenated hemoglobin absorbs more red wavelengths of light while deoxygenated hemoglobin absorbs proportionately more infrared. Simultaneously, the oxisensor determines tissue expansion or pressure from the arterial pulse passing through tissue bed (plethysmography). Thus, pulse oximeters theoretically measure only arterial saturation of hemoglobin. The oximeter's processor determines the balance between the two detected wavelengths of light at a very high rate (500 Hz), which makes it possible for some monitors to display a representation of pulse pressure waves. Any interference with information processing can produce an erroneous reading (e.g., patient movement affects tissue bed pressures and signal transmission causing motion artifact, and some finger nail polishes absorb light whose wavelength overlaps that of red).

TABLE 1. SUMMARY OF MONITORS USED IN SEDATING PEDIATRIC DENTAL PATIENTS

Monitor	*Measurement*	*Critical Factors Affecting Signal*	*Advantages*	*Disadvantages*
Pulse oximeter	Absorption and ratio of red and infrared light representing degree of hemoglobin saturation. Also, determines heart rate via plethysmography	1. Sensors must be directly opposite each other 2. Patient movement. 3. Crying, sobbing, and Valsalva's maneuver 4. Pressure on vascular vessels above probe (e.g., blood pressure cuff)	1. Safe and noninvasive 2. Simple to use 3. Information rapidly available for clinical decisions 4. Indirectly and secondarily indicates respiratory exchange	1. Nonreusable probes are expensive 2. Finger probes can be easily dislodged by uncooperative patient. Toes work well with probe taped (gently) in place 3. Emitted light source may cause burning 4. Does not directly determine airway patency
Automated Blood Pressure Cuff	Simultaneously records oscillations and bladder pressure Also, determines heart rate via plethysmography	1. Cuff size must be appropriate for arm. Too narrow increases absolute parameters; too broad decreases absolute parameters	1. Safe and noninvasive 2. Simple to use 3. Determination time usually less than 30 sec	1. Determination time increased with moving uncooperative patient 2. Because of #1, may decrease patient cooperation
Capnography	Expired carbon dioxide	1. Nasal probe must not be blocked by mucus or physical barrier (e.g. nasal septum or alae)	1. Safe and slightly invasive (i.e., probe inserts 2 or 3 mm into nasal aperture) 2. Simple to use 3. Information rapidly available for clinical decisions 4. Indirectly indicates respiratory exchange 5. Directly determines airway patency	1. Temporary block of sample line by mucus 2. May register low CO_2 values when child is crying
Pre-Cordial Stethoscope	Sounds of heart and lungs/airways	1. Placement of the bell on the chest wall (best location for determining airway patency with faint heart sounds is over presternal notch below thyroid cartilage) 2. Extraneous sounds (e.g., noise from handpiece) 3. Fixation to chest wall	1. Inexpensive 2. Simple to use 3. Noninvasive 4. Durable	1. Picks up interfering vibratory sounds (e.g. from handpiece) 2. Does not determine degree of airway patency 3. If improperly placed, decreases usefulness in auscultating sounds

Clinically, it is important to attach the oxisensor to accessible, well-perfused tissue. The toe next to the great toe seems best suited in the young toddler. The oxisensor can be placed around the tissue and secured by comfortably taping the great toe, second (on which the oxisensor is placed), and middle toe together as a unit. It is also wise to tape the oxisensor lead to the plantar surface of the foot; otherwise its movement can cause either dislodging of the oxisensor during struggling or electromagnetic (motion) artifacts.

Fingers also are useful sensor sites in the older child or adult, but most uncooperative toddlers will tend to remove the oxisensor if they struggle. The ear lobe is another convenient site in older children, but again, for toddlers whose head may need to be stabilized for certain procedures (i.e., injections or tooth preparation), this site becomes inconvenient.

The oxisensor must be placed optimally so that the two diodes are directly opposite each other and the tissue is perpendicular to an imaginary straight line con-

necting the two diodes. As the angle between the two diodes changes (the imaginary line is no longer straight and perpendicular to the tissue), the emitted light is not detected as readily. In such a compromised arrangement, the overhead lighting can interfere with the monitor's ability to readily detect a strong signal, hence the monitor becomes less sensitive. Also, disposable oxisensors when reused have a tendency to cause lower oxygenated readings probably due to contaminated diodes (i.e., oils from sebaceous glands).

Although the first published report on the use of PO in pediatric dentistry was in 1985,[6] almost every article on sedation of the pediatric dental patient published today reports the use of PO. Generally speaking, most reports indicate the oxygen saturation to be very stable during sedations with only an occasional desaturation episode. Unfortunately, these desaturation episodes can be erroneously associated with the sedative agent, including questionable assignment of the agent's purported effects on airway compromise. Other conditions do and have been shown to account for what appears to be temporary "desaturations" that are of no clinical significance (see Table 1).

The clinician needs to be aware that distinct clinical situations can cause bogus signals unrelated to hemoglobin saturation. These are: motion artifact; crying that may involve a Valsalva's maneuver (airway is momentarily closed while muscular efforts are made to compress air in the lungs — grunting); cold limbs or tissue bed; cessation of a prolonged crying bout; some nail polishes; profound tissue pigmentation in some blacks; some hemoglobinopathies; or any condition that reduces blood flow into the tissue bed (blood pressure cuff inflation or straining against the wraps of a Papoose Board® (Olympic Medical Group, Seattle, WA). Interestingly, there have been a few reports suggesting that local anesthetics may cause desaturations in otherwise nonsedated patients, possibly mediated by a temporary methemoglobinemia.[7,8] This association needs to be confirmed.

Blood pressure cuffs

The use of blood pressure cuffs (BPCs) has a longer history than PO in pediatric dentistry. Automated BPCs indicate indirectly the systolic and diastolic blood pressures, as well as heart rate at discrete intervals. With many automated units, the cycle period for sampling blood pressure can be varied over a wide range. BPCs use a transducer positioned in the cuff's bladder to determine vibrations within a limb. The vibrations emanate from and are due to the passage of blood through blood vessels in a limb.

Functionally, the bladder is inflated over a few seconds to a pressure that essentially occludes blood flow in arteries. Then the bladder is deflated in small steps at each of which the transducer monitors oscillatory signals. When the first increase in the size of oscillatory signals is repeatedly detected, the BPC reports this pressure value as the systolic blood pressure. The cuff continues to deflate in steps and the pulse pressure initially increases, then declines, until finally no further change in oscillatory signals is detected. The bladder pressure at that point represents the diastolic blood pressure. The pulsating oscillatory signals also are used to determine heart rate.

There are a few factors that cause artifact information with BPCs, including: inappropriate-sized cuffs (too large a cuff tends to cause erroneously low, whereas too small a cuff causes erroneously high blood pressure readings); air leaks anywhere within the system; and patient movement. The latter is clinically significant, however, because in an uncooperative child, movements or attempts to dislodge the cuff result in recycling of the algorithm (the microchip mechanism for identifying, capturing, and reporting each type of blood pressure [systolic and diastolic]). Under normal circumstances, most automated BPCs require less than 30 sec to determine blood pressure. In a struggling child, the prolonged inflation pressure of the cuff (often greater than a minute or so) can cause pain, which aggravates the behavior.

It has not been determined whether baseline blood pressure prior to sedation is of any clinical value (except as a baseline comparison) in the uncooperative but healthy patient. A combative or uncooperative child would be expected to have a somewhat elevated blood pressure value, which tends to decrease to normal resting values as the child becomes sedated. A manual BPC can be used more efficiently than an automated BPC in gathering baseline readings — especially in obtaining systolic pressures.

In dosages designed to produce conscious sedation, most sedative agents do not cause significant clinical changes in blood pressure from that of the unprovoked, resting child. In general, the blood pressure and heart rate vary with age (the younger the child, the lower the resting blood pressure and the higher the heart rate).

Capnography

Capnography probably represents one of the least understood and least utilized monitoring techniques in dentistry, but it is the only monitor on the market that can give an indication of the airway patency when used properly.[4,5] Capnographs determine the expired carbon dioxide concentrations. Capnographs can be classified as either main- or side-stream units. The main-stream is used in intubated patients whereas the side-stream units are appropriate for sedated, nonintubated patients. For side-stream units, air is vacuumed or sucked through a port that is either inserted into the nostrils or placed in close approximation to the orifice of the nostril or mouth. Sucked air is delivered to a chamber inside the capnograph where the concentration of carbon dioxide can be determined by infrared absorption technology. The amount of infrared absorption in the test chamber is compared to a standardized chamber

containing a known amount of carbon dioxide. The microchip processor determines and displays the carbon dioxide concentration. Capnographs can display single excursions each of which represents the concentration of expired carbon dioxide during the expiratory cycle of breathing, and some can display trended data in which each excursion is compressed and appears as a single vertical line.

Importantly, most capnographs have an alarm to indicate an obstruction anywhere along the sampling route including the airway. Mucous blockage is one possible clinical situation causing the alarm mechanism to indicate an obstruction. Crying is a clinical event that causes most of the expired air to exit via the mouth, thus the capnograph will detected a lower concentration of expired carbon dioxide (i.e., the majority was shunted through the mouth leaving proportionately less to be sucked into the port). This phenomenon is also true of predominant mouth breathers.

Interestingly, meperidine causes the rise and fall segment of each single excursion to waver slightly because it causes increased tension in the respiratory muscles during expiration. In a nonsedated patient expiration involves a passive relaxation of elastic tissues and little muscle involvement. When a patient has received a narcotic such as meperidine, the carbon dioxide concentration in the body tends to increase slightly over time due to mild depression of the respiratory centers and the carbon dioxide drive of respiration. Normal carbon dioxide concentrations in children range from 33 to 40 mm Hg.

The selection of the port type is very important. The best port I have investigated is one shaped like a sewing thimble with both ends open. The smaller end is inserted into the nostril (the ports can be custom made to match the nostril orifice using a mold and dental acrylic). A small plastic tube is inserted into the body of the port midway between openings, and the tube connects directly to the capnograph. The tubing can be taped to the side of the face for stability. Also, many capnographs can electronically filter out the wavelength associated with nitrous oxide absorption, hence the port can be placed under a nitrous hood.

The two-pronged tubing system often seen and used in older patients requiring therapeutic oxygen delivery does not work well in children. The prongs are too long (they project too deep into the orifice of the nostrils and are easily clogged), often too wide, and need to be trimmed to prevent obstruction of the openings by the inner septal or alar portion of the nostril.

I believe that in the future this monitor will become the most important monitor in the hierarchy of monitors used in sedating children for dentistry. This opinion is based on extensive clinical experience with the simultaneous use of many monitors — including the capnograph and pulse oximeter.[9-11] Sooner or later, a study will demonstrate definitively that the capnograph, with its ability to detect airway blockage rapidly (< 15 sec usually) and with appropriate operator response, prevents desaturations (the measure of a response seen *after* the compromised airway) from occurring. (I am aware of data that, at the time of the development of this paper, confirm this premise.)

Precordial stethoscopes

Stethoscopes have been available for decades and can obtain heart, respiratory, gastrointestinal, and joint sounds, and cardiovascular anomalies (e.g., arteriovenous malformations). They are particularly useful for monitoring airway and heart sounds during sedations. However, optimizing either the airway or heart sounds is very dependent on the placement of the stethoscope's bell on the chest wall.

To facilitate maximizing airway sounds, an imaginary triangle can be useful. The base of the triangle is a line joining the patient's nipples with the apex formed by remaining sides each joining the nipple to the precordial notch at the junction of the neck and chest. In a reclined patient, placement of the stethoscope bell at the precordial notch will cause breathing sounds to be loud and dominant compared with the faint sounds of the heart. As the stethoscope bell is moved along the imaginary line connecting the precordial notch to the left nipple, the sounds of breathing become more faint and the heart's dominate. Airway sounds are more important during sedation, thus the bell should be placed toward the apex of the triangle. Also, the bell should be well attached to the chest wall either with tape or 3M Double-Stick Discs® (3M Medical Device Division, St Paul, MN).

Competing sounds come from various sources including handpiece noise, a metal rubber dam frame touching the bell will conduct sounds when the handpiece contacts the frame, and room noise (e.g., talking or music). Often these sounds can be comparatively loud and drown out the airway sounds, increasing the need for additional monitoring. A study of sedated children undergoing dental care comparing the precordial stethoscope to other monitors of airway patency has not been reported.

Guidelines, monitoring, and compliance

To my knowledge, there has never been a study determining the degree of compliance of dental practitioners in the use of procedures, monitors, and classification of depths of sedation in published guidelines. One study did show that physicians in the emergency room do not comply well with sedation guidelines.[12] Probably, good reasons exist why such a study could not be easily accomplished with a useful outcome. In any such process, there would be problems of interpretation grounded within the vagueness of guidelines. The following is an example.

With the exception of a sophisticated electroencephalogram, no direct means of physiologically or clinically monitoring the depth of drug-mediated sleep

exists, and by corollary, no way to assess the patient's ability to control the airway independently without risking a dangerous associated liability. This fact brings the concept and validity of "consciousness" as currently defined by *all* guidelines on the use of conscious sedation into question. With current technologies and understanding of sedation, terms like "consciousness" and "deep sedation" are no longer meaningful.

The capnograph does indicate when the airway is partially or fully blocked[4, 5, 10] and the electromyograph has been shown to indirectly indicate depth of sedation.[11, 13] Presently, no guideline requires either of these instruments to be used even during deep sedation in children (capnographs are highly recommended, not required).[3, 14]

In my opinion, the "depth" of sedation can and should be clinically redefined using the current American Association of Pediatric Dentistry (AAPD) guidelines as a baseline. Table 2 shows a proposed plan for redefining sedation types couched within the framework of AAPD guideline definitions. It is designed to be operationally meaningful to the dental provider who is quite familiar with sedation experiences.

Readers must recognize that the best operative condition involving precooperative toddlers is that of the noninteractive, arousable state (see Table 2). The important distinction between this state and deeper states (nonarousable and/or general anesthesia) is that the child can be aroused with a strong stimulus (e.g., a pinch of the trapezius muscle). Furthermore, the aroused child should respond in a purposeful fashion: withdrawal from the noxious stimulus and awakening with crying occurs. However, it would be clinically inefficient to continually "test" if the child is arousable. If appropriate monitoring (pulse oximeter, capnograph [or stethoscope to determine good air exchange], blood pressure cuff, and clinical signs) demonstrates stable physiological parameters, then attempts to arouse the child are unnecessary. Appropriate didactic and clinical training to recognize the distinctions in the depth of sedation is necessary and can be easily accomplished in most postgraduate programs in pediatric dentistry.

Physiological measurements are important in the outcome of sedations. Because of the deserved emphasis on monitoring for the irrefutable benefit of the child's safety, any time- or procedural-based record should be analyzed and related to the child's behavior. Specific physiologic findings should be categorized with the occurrence of prominent and acknowledged nonpharmacologic factors with the outcome designed

TABLE 2. SUBCATEGORIZATION SCHEME FOR CURRENT AAPD GUIDELINES ON SEDATION

	Conscious Sedation		*Deep Sedation*
	Interactive	*Noninteractive, Arousable*	*Noninteractive, Nonarousable*
Goals	a. Decrease patient anxiety b. Facilitate patient coping skills c. Maintain patient in drowsy state	a. Decrease or eliminate patient anxiety b. Pharmacologic-induced sleep	a. Eliminate patient anxiety
Characteristics	a. Patient drowsy, but awake b. May have eyes open or temporarily closed (< 1 min) c. Can communicate verbally	a. Eyes closed b. Mimics sleep behaviorally and physiologically c. Arousable with minimal or moderate stimulus (e.g., trapezius pinch)	a. Sleep b. Inseparable behaviorally from general anesthesia c. Nonarousable with moderate to intense stimuli
Personnel	a. Minimum of 2 b. At least 1 trained at level required in guidelines c. BLS	a. Minimum of 2 b. At least 1 trained at level required in guidelines c. BLS	a. Minimum of 3 b. At least 1 trained at level required in guidelines. c. PALS or ACLS required.
Facilities	a. O_2 at 10 L/min for 60 min b. Emergency kit	a. O_2 at 10 L/min for 60 min b. Emergency kit	a. O_2 at 10 L/min for 60 min b. Oxygen analyzer *required* c. Emergency kit
Monitors	a. Pulse oximeter b. Precordial stethoscope	a. Pulse oximeter b. Precordial stethoscope c. Capnograph *highly desirable* d. Blood pressure cuff	a. Pulse oximeter b. Pre-cordial stethoscope c. Capnograph d. Blood pressure cuff e. Electrocardiograph f. Defibrillator *available as needed*

to discriminate between drug- and patient-mediated effects. For instance, it is known that patient movement of limbs, Valsalva's maneuvers during crying, and straining against restraints can cause a pulse oximeter to register a desaturation. Such factors should be recorded during sedations to minimize the allocation of assumed desaturations to the drug.

New and more sophisticated monitors will be marketed in the future. If sleep continues to be a desired state to attain during some sedations, monitors need to be designed to assess such a state. Their development should focus on giving the practitioner more discriminant functions designed to follow the depth of sedation and awareness of the patient's state. No doubt, brain mapping functions in conjunction with other sensitive measures (e.g., muscle tension or activity) will afford a better appreciation of the patient's absolute state at a specific moment of time or will signal changes in the patient's state indicating the need for operator intervention (or preparedness to anticipate patient responsiveness).

Likewise, newer drugs may be developed that will not induce a state of sleep, but possibly render analgesic and cognitive dissociation not unlike ketamine's effects. Monitors to determine such effects probably can be developed, but will require testing. Regardless, the practitioner who sedates children must embrace the concept and understanding of a continuous, multimonitoring system. Updating one's skills in monitoring, like any other activity, becomes imperative.

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