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An investigation of capnography and pulse oximetry as monitors of pediatric patients sedated for dental treatment

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Abstract

Traditional methods of monitoring sedated pediatric dental patients have major shortcomings. This study evaluated the use of capnography in conjunction with pulse oximetry for monitoring children during conscious sedation for dental treatment. The specific purposes of the study were to determine if capnography would: (1) detect ventilatory changes that subsequently cause an oxyhemoglobin desaturation as detected by pulse oximetry; and (2) detect an airway obstruction.

Ten pediatric dental patients (mean age 2 years, 10 months) were sedated with 75 mg/kg of chloral hydrate in strict accordance with the Guidelines for the Elective Use of Conscious Sedation, Deep Sedation, and General Anesthesia in Pediatric Patients of the American Academy of Pediatric Dentistry and the American Academy of Pediatrics (1985). All patients were monitored continuously using both capnography and pulse oximetry. Analysis of data obtained using these monitors revealed that specific end-tidal CO_2 values were not predictive for subsequent oxyhemoglobin desaturations and that capnography was very accurate in detecting complete obstruction of the airway. Pulse oximetry revealed that all patients had mild oxyhemoglobin desaturations and that 50% had moderate desaturations.

Traditional methods of monitoring sedated patients include observation of tissue color, measurement of blood pressure, palpation of the pulse, and auscultation of heart and lung sounds using a precordial stethoscope. In recent years each method has been recognized as having serious shortcomings, especially for pediatric dental patients. Recently, 2 new instruments have been advocated for improved respiratory monitoring of sedated patients. The pulse oximeter permits noninvasive monitoring of arterial oxyhemoglobin saturation, pulse rate, and pulse strength. The capnometer permits quantitative noninvasive monitoring of respired CO_2. The overall objective of this investigation was to explore the potential of using capnography in conjunction with pulse oximetry during conscious sedation of pediatric dental patients.

Literature Review

When sedating children in the conventional dental office setting, conscious sedation is the desired technique. Even though patients under conscious sedation are sedated at a level less than deep sedation, they are at risk for respiratory compromise leading to inadequate oxygen content, or hypoxemia. This may result from airway obstruction or a drug-induced respiratory depression. Anderson and Vann (1988) noted that the monitoring recommendations of the *Guidelines for the Elective Use of Conscious Sedation, Deep Sedation, and General Anesthesia in Pediatric Patients* of the American Academy of Pediatric Dentistry and American Academy of Pediatrics (1985) are essential. They note further that the *Guidelines* do not fully address hypoxemia, the leading cause of morbidity and mortality in pediatric dental sedations (Goodson and Moore 1983).

Standard monitoring examines only the signs and symptoms that result from a decrease in the O_2 content of the patient's blood (hypoxemia). Initially, hypoxemia presents as increased ventilatory effort, increased heart rate, and increased blood pressure. These symptoms are followed by cyanosis (a bluish tint in the nailbed and lips), bradycardia, cardiac dysrhythmia, and cardiovascular collapse. Reliance only on signs and symptoms to recognize hypoxemia is very unpredictable in pediatric dental patients. Visual observation of tissue color may be obscured by dental paraphernalia such as the rubber dam, patient eye protection, and restraints covering the hands and feet. Furthermore, color changes associated with hypoxemia are not detectable until dangerously low levels have been reached (Comroe and Bethelho 1947). Moreover, color change is a subjective variable, affected by hemoglobin composition, tissue pigmentation, and the observer's skill in distinguishing color changes (Dripps et al. 1982).

The precordial stethoscope is an excellent diagnostic instrument for listening to heart and lung sounds, but its effectiveness is diminished by the noise of high-speed handpieces (Drummond et al. 1984). Blood pressure is an unreliable indicator of sedation complications because it correlates poorly with changes in O_2 saturation during mild hypoxemia (Mueller et al. 1985). Respiration has been found to increase significantly only in the presence of moderate hypoxemia (Mueller et al. 1985). In summary, even when detected, changes in blood pressure, heart rate, and respiration are not good early indicators of respiratory complications during sedation.

Pulse Oximetry

Pulse oximetry is a noninvasive method to monitor the oxygen content in arterial blood. It measures the amount of O_2 carried by the hemoglobin in the blood stream, or oxyhemoglobin saturation (SaO_2). A healthy individual has an SaO_2 of 96-100% while breathing room air.

Several studies (Yoshiya et al. 1980; Yelderman and New 1983; Anderson et al. 1988) have shown that in adults, SaO_2 values obtained using pulse oximetry correlate highly with measured arterial saturation values under a variety of clinical conditions. Pulse oximetry also has been found to detect hypoxemia in the absence of clinical signs or symptoms in adult patients. There is considerable evidence that pulse oximetry is also accurate and rapidly responsive to changes in the oxygenation in infants and children (Monaco et al. 1983; Swedlow and Stearn 1983; Cote et al. 1988). Furthermore, studies suggest that pulse oximetry is an excellent method of monitoring respiration in children sedated for dental procedures (Mueller et al. 1985; Moody et al. 1986). Whitehead et al. (1988) found that pulse oximetry provided early detection of respiratory distress such that correction was a relatively simple matter of readjusting head position.

Capnography

Capnography has been advocated as a monitor for apnea and airway obstruction and to quantify adequacy of ventilation. A small suction tube is placed in or near the patient's upper airway for continuous collection of respired air that is then analyzed for the CO_2 concentration using infrared spectroscopy. The quantity of CO_2 expired is displayed as a graphic wave form on hard copy or an oscilloscope monitor (Fig 1). The upslope of the wave correlates with the increasing amount of exhaled CO_2 as dead space gases are exhaled. A plateau occurs when primarily alveolar gas is being exhaled.

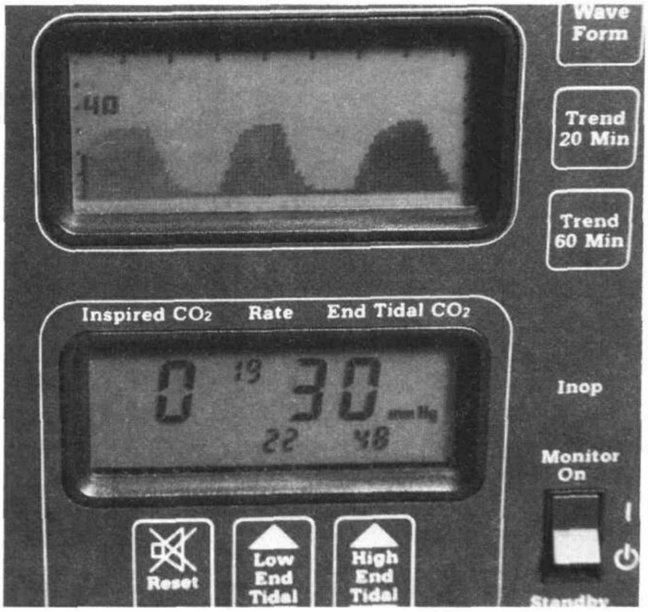


FIG 1. A graphic wave form as displayed on a capnometer's oscilloscope monitor.

The end of the plateau portion of the curve represents the end-tidal CO_2. This concentration of CO_2 most closely reflects alveolar gas and, therefore, arterial CO_2 concentration ($PaCO_2$). Inhalation results in a downslope of the graph as the amount of CO_2 decreases. When CO_2 is not being exhaled, a flat baseline results (Fig 2). This occurs when a patient is not breathing (apnea) or when there is obstruction of the airway.

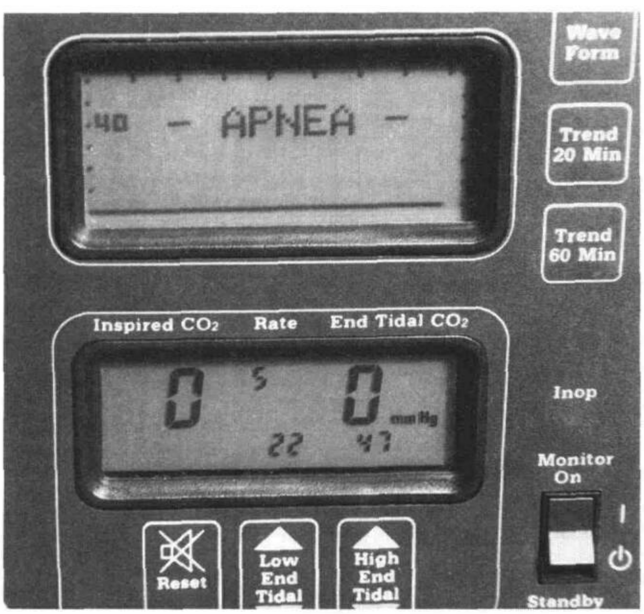


FIG 2. A flat baseline on the capnometer's oscilloscope signals that the patient is not breathing (apnea) or that there is an airway obstruction.

Kalenda and Kramer (1979) reviewed various breathing patterns detected by capnography and demonstrated that periods of apnea could be detected, as could periods of decreased breathing, or hypoventilation. Anderson et al. (1987) used a capnometer with a modified sampling tube to monitor respiration of nonintubated adult dental patients undergoing outpatient general anesthesia and concluded that capnography was an excellent method of monitoring for apnea and airway obstruction. Results suggested that capnography also could be used to indicate trends for developing hypoventilation. When all of the evidence is considered, capnography has been shown to be useful in monitoring respiration in nonintubated adults, but it has not been examined as a monitor in nonintubated pediatric patients.

In summary, a review of the literature leads to the conclusion that the standard methods of monitoring have significant shortcomings when used with sedated pediatric dental patients. Pulse oximetry is an excellent method of monitoring blood oxygenation, but it does not give an early warning of airway obstruction or hypoventilation. Capnography has the potential to complement pulse oximetry because it could give advanced warning of potential respiratory problems. The purpose of this study was to answer the following research questions:

1. Will capnography quantitatively detect ventilatory changes that subsequently cause an arterial oxygen desaturation detected by pulse oximetry in sedated pediatric dental patients?
2. Will capnography detect airway obstruction in sedated pediatric dental patients?

Materials and Methods

The patient sample included 10 child patients. Each child was 24-60 months old, required sedation to achieve cooperation and safe operating conditions, was an American Society of Anesthesia (ASA) Class I anesthesia risk, and received a presedation health evaluation by a physician.

Written parental consent was obtained for all sedation procedures, after a full explanation of the procedures and risks. Pre- and postappointment instructions were used for all patients and all sedation appointment procedures were carried out in strict accordance with the *Guidelines for the Elective Use of Conscious Sedation, Deep Sedation, and General Anesthesia in Pediatric Patients* of the American Academy of Pediatric Dentistry and American Academy of Pediatrics (1985).

Patients were required to be NPO from midnight of the night before the appointment and guardians were instructed to give only clear liquids up to 4-6 hr before the procedure. Patients were weighed and baseline measurements were obtained including blood pressure, heart rate, and respiratory rate. Patients were administered 75 mg/kg dose of liquid chloral hydrate orally via preloaded syringes, followed by 25 cc of water. Comedicaments and N_2O/O_2 were not used in an effort to eliminate confounding factors related to multiple drug interactions. This design also allowed collection of data from patients who were not supplemented with oxygen.

Administration of chloral hydrate signaled a baseline time for the appointment procedures. The patient and guardian waited for 30 min in a quiet room. The patient then was carried to a dental chair and placed in a Papoose Board® restraining device. Cloth towels were rolled up and placed behind the necks of all patients to help support their airways and prevent physical airway obstructions during dental treatment. Then, a precordial stethoscope, a pulse oximeter, and a capnometer were attached. The precordial stethoscope was placed for maximum auscultation of respiratory and cardiac sounds.

A 15-second period was allowed for the Ohmeda 3700 (Ohmeda Corp; Englewood, CO) pulse oximeter (Fig 3) to complete its self-test routines for electronics, battery status, and calibration accuracy. The pulse oximeter contained the new "M" version software program. An Ohmeda 3700 flexible pulse oximeter probe was taped to the great toe of the patient's left foot and all toes then were taped together to minimize individual toe movement (Fig 4, next page). A cloth was placed over the sensor to prevent interference from extraneous light sources. All probe placements resulted in maximum pulse signal strength as demonstrated by the

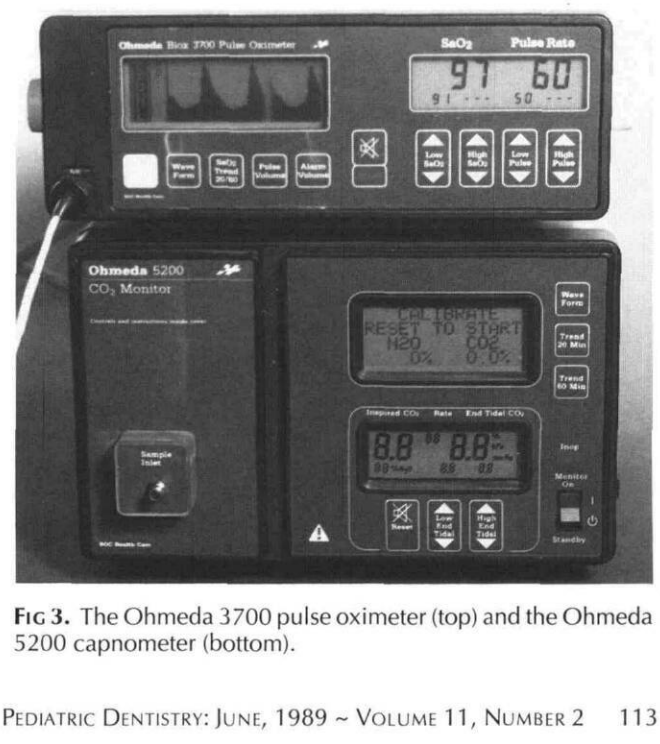
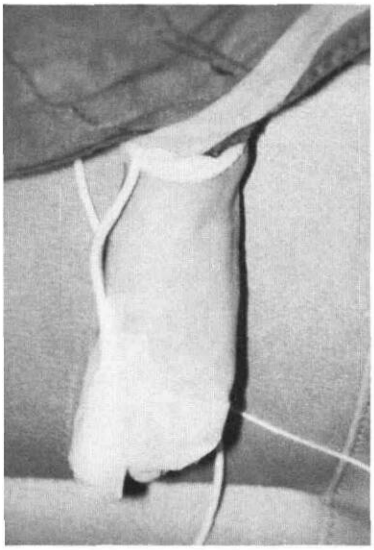


Fig 3. The Ohmeda 3700 pulse oximeter (top) and the Ohmeda 5200 capnometer (bottom).



ig 4. Flexible pulse oximeter probe ttached with tape to child patient's reat toe on the left foot.

oximeter's signal strength bar graph indicator. The pulse oximeter was set in the slow response mode (6-sec SaO_2 response time).

The Ohmeda 5200 (Ohmeda Corp; Englewood, CO) capnometer (Fig 3) was set for a 5-min warm-up period and calibrated as recommended by the manufacturer using a standard gas (5% CO_2, 65% N_2O, and 30% O_2). The sampling flow rate was set at 150 ml/min and the apnea alarm was set for a continuous tone to signal a 30-sec absence of CO_2.

A Biomed® (Biochem International lnc; Waukesha, WI) pediatric nasal CO_2 sample line was used as the capnometer sampling tube (Fig 5). Respiratory rate and heart rate were recorded every 5 min and SaO_2 and respired CO_2 were recorded continuously using a dual channel strip recorder (Ohmeda Corp; Englewood, CO).

The operating dentist was shielded from the monitoring equipment and notified to reposition the patient's head at any time the pulse oximeter revealed a saturation below 96%. The Moore head tilt maneuver (Moore et al. 1984) was performed to assess the level of sedation at times the patient was in a quiet sleep. If the patient failed to clear the airway immediately, the head was repositioned following the first evidence of desaturation.

Mechanical monitoring continued throughout the dental appointment and was discontinued after completion of the operative procedures. At that point, all baseline measurements were repeated. Patients were released when they were alert, able to sit up unaided, and walk with minimal assistance.

Data Analysis

Descriptive data analyses were used to answer the research questions. End-tidal CO_2 values were compared to SaO_2 values that occurred simultaneously below 96% SaO_2. These end-tidal CO_2 values also were compared against SaO_2 values above 95% SaO_2 to rule out false positives. Airway obstruction was examined by assessing capnographic data collected during any period of obstruction or apnea as determined by auscultation of the airway.

FIG 5. A Biomed pediatric nasal CO_2 sample line was used as the capnometer's sample tube for the child patients.

Results

The sample size included 10 patients with a mean age of 2 years, 10 months (range 2 years, 2 months to 4 years, 8 months; 8 females, 2 males). All were healthy ASA Class I patients. The patients' mean weight was 12.6 kg (range 10.5-14.5 kg). The mean dose of chloral hydrate was 920 mg (range 780-1000 mg).

Findings for Pulse Oximetry

A desaturation period was defined as the period of time in which the SaO_2 went below 96% and returned to 96%. There was an average of 11.8 desaturation periods per patient (range 4-23 desaturation periods). The number of mild and moderate desaturations for each patient is illustrated in the Table.

Findings for End-Tidal CO_2

No predictive value was found between end-tidal CO_2 values and specific SaO_2 values. The end-tidal CO_2 values ranged from 5 to 47 mm Hg for SAO_2s below 96% and 5 to 45 mm Hg for normal SAO_2s. However, there was a trend of decreasing respiratory rate as detected by capnography 30 and 20 sec prior to a desaturation.

Discussion

Pulse Oximetry Findings

Ten patients (100%) experienced mild desaturations at 90-95% and 50% experienced moderate desaturations at 88-89%. This differs from the findings of Mueller et al. (1985), who reported 25% mild desaturations and 10% moderate desaturations, and an overall prevalence of

Table Patient desaturations

Patient	$\#SaO_2$ 90–95% (mild desaturations)	$\#SaO_2$ <90%* (moderate desaturations)
1	21	0
2	23	1
3	18	0
4	7	0
5	4	0
6	8	3
7	9	1
8	14	0
9	9	3
10	5	2
Averages	11.8	1.0

* All desaturations < 90% were in the range of 88–89%.

desaturations of 35% using a dosage of 100 mg/kg oral chloral hydrate (a 33% higher dose) with 50% N_2O/O_2. The higher incidence of desaturations in our study was thought to be due to the lack of O_2 supplementation.

All patients experienced periods of crying intermixed with periods of quiet sleep. Both the mild and moderate desaturations occurred during periods of crying and in many instances, with breath holding. These desaturations may be associated with a diminished oxygen reserve as a result of accelerated basal oxygen consumption during periods of distress. No desaturations thought to be due to motion artifact were included.

Moore Head Tilt

The Moore head tilt maneuver was tested during periods of quiet sleep. Only one patient did not attempt to clear the airway during the head tilt procedure. By definition, this patient was in deep sedation. This incidence of deep sedation differs from that reported by Moore et al. (1984), who noted 27% of their patients did not respond to the head tilt when sedated with 60 mg/kg of chloral hydrate and 50% N_2O_2. In that study, all nonresponders were females younger than 36 months old. The authors speculated that the young age and female sex may render patients more susceptible to chloral hydrate and N_2O/O_2 sedation. In this study, 80% of the patients were female but only one, aged 2 years, 1 month, failed to respond to the head tilt. Five other females younger than 36 months of age responded to the head tilt. The results of Moore et al. (1984) may, therefore, reflect a deepening in the level of sedation by the addition of N_2O/O_2.

The Research Questions

Our first research question was whether capnography would quantitatively detect ventilatory changes that subsequently cause an arterial O_2 desaturation as detected by pulse oximetry in sedated pediatric dental patients. A specific end-tidal CO_2 measured by capnography was not predictive of an SaO_2 less than 96% as measured by oximetry. This may have resulted from irregular and rapid patient breathing patterns while conscious, because panting and breath holding during crying produced variable end-tidal CO_2 readings at times of no desaturation. However, evaluation of respiratory rates suggested that there was a trend of a decrease in respirations within the 30-sec period prior to the desaturation.

The second question was whether capnography would detect airway obstruction in sedated pediatric dental patients. Total airway occlusion was revealed readily by capnography in one sedated child. This was verified during the Moore head tilt procedure. When breath sounds could not be auscultated, the capnometer recorded no end-tidal CO_2. When the airway was repositioned, there were immediate breath sounds and a return of CO_2. This finding was similar to those reported by Anderson et al. (1987), who noted an immediate drop in respired CO_2 to baseline (zero) when an occlusion occurred.

Early warning of airway occlusion by the capnometer did not give a practical advantage over monitoring with pulse oximetry in these patients. Oxygen desaturations were noted within seconds of an airway occlusion. This was a period of time roughly equivalent to that necessary for verification of an occlusion. This short time difference may have been related to the young age of the patients and/or the lack of O_2 supplementation.

Advantages and Limitations of Capnography in this Study

Capnography may be used to detect the presence of apnea, airway obstruction, and hypoventilation. Apnea or airway obstruction is detected by the absence of respired CO_2. Increases in end-tidal CO_2 indicate that hypoventilation is occurring. If there is an adequate respired air sample, accurate end-tidal CO_2 can be determined. The patients who were sedated lightly sometimes became excited and panted, resulting in very rapid respiratory rates and highly erratic tracings. The exchange of gases through the nose at these rates probably did not reflect accurate end-tidal CO_2 values because rapid shallow breaths involve air exchange primarily with anatomic dead spaces. The end-tidal CO_2 would reflect lower values because anatomic dead spaces contain little CO_2. Also, gas sampling flow rates can affect the accuracy of end-tidal CO_2 measurement (Sasse 1985). High sampling rates may increase the concentration of room air in the sample, producing erroneously low end-tidal CO_2 values. However, low sampling flow rates decrease the capnometer's response time. If respiratory rates are rapid and tidal volumes are small, then true end-tidal CO_2 may not be sampled. Fromm and Scamman (1988) evaluated 5 capnometers for accuracy during rapid respiration of pediatric patients and concluded that more than 31 respirations/min resulted in an underestimation of end-tidal CO_2.

Accuracy of end-tidal CO_2 measurements was complicated further by the location of the sampling tube. Sampling accuracy would be diminished if nasal air had a different CO_2 concentration than air exhaled through the mouth. Only expired nasal air was analyzed in this study. Patients who breathed orally, especially during crying, decreased nasal air flow, and this resulted in poor air exchange and possible inaccurate end-tidal CO_2 readings. Schieber et al. (1985) reported that the accuracy of peak expired CO_2 was affected by the location of the sampling site. When a modified circle breathing circuit was used and air samples were taken at the distal end of an endotracheal tube, expired CO_2 and $PaCO_2$ correlated. Samples drawn from other locations underestimated $PaCO_2$. Anderson et al. (1987) used a similar nasal prong probe and found correlation coefficients of 0.93-0.99 between end-tidal CO_2 and $PaCO_2$ in 50% of the patients. Twenty per cent of their patients had correlation coefficients of 0.78-0.85. However, these were adult patients whose respiratory physiology may have differed from the patient population of this study.

The accuracy of the sampling in our study also may have been affected by the diameter of the nares. Patients with nares smaller than 5 mm were subject to possible nasal obstruction from the sampling tube assembly. Occlusion of either the nares or the sampling prongs occurred when the prongs were pushed too deeply into the nostrils. This was observed occasionally when inadvertent pressure was applied from finger retraction of the rubber dam in the anterior maxillary region by the operator. Excessive pressure by the operator on the nasal prongs can cause suction of either nasal mucosa or mucus into the line. Because the Biomed 5200 pediatric sampling prongs have a smaller diameter than the standard adult lines, this may have increased the likelihood of line blockage. Line blockage also occurred with excessive mucous secretions during crying. When purging by the monitor failed to clear the sample line of condensed moisture, a new nasal sample line was applied.

The capnometer was unaffected by patient movement, a practical advantage in the monitoring of children who may alternate between periods of restfulness and movement during dental sedations.

Conclusions

Based on the findings in this study, the following conclusions were made:

1. Capnography was an excellent method of monitoring for complete airway occlusions.
2. Specific end-tidal CO_2 values were not predictive of specific SaO_2 values.
3. The end-tidal CO_2 readings were not affected by motion, but were affected by nasal prong placement, mouth breathing, rapid shallow breathing, and obstruction of the sampling line from nasal tissues or mucous condensation.
4. Although capnography detected airway obstructions prior to changes detected by pulse oximetry, the time difference was too little to provide any practical advantage in these patients.
5. There appeared to be a trend of decreasing respirations 30 sec prior to a desaturation.
6. All sedated patients experienced mild or moderate desaturations, but only one patient failed to spontaneously open the airway when the Moore head tilt was administered.

Directions for Future Research

This was the first study to investigate capnography for monitoring sedated pediatric dental patients. It gave practical insight into the usefulness of capnography as a method of monitoring such patients. Future studies should examine the use of blood gas analysis to correlate end-tidal CO_2 and respired CO_2 in children. Blood gas analysis would also permit evaluation of the influence of prong placement, prong length, and prong diameter on the sampling accuracy of respired CO_2.

Future controlled clinical studies also should examine N_2O/O_2 as a comedicament with chloral hydrate. It seems almost certain that N_2O/O_2 deepens the level of sedation and thus has the potential to increase the number of patients who reach a level of deep sedation. At the same time, N_2O/O_2 may provide a level of O_2 supplementation sufficient to increase the patient's PaO_2 significantly. If this were true, a pediatric patient supplemented with N_2O/O_2 might experience fewer desaturations. Oxygen supplementation also may produce a longer time lag between airway occlusion detected by capnography and a desaturation detected by pulse oximetry.

Finally, the influence of age and sex on a child's response to sedation with chloral hydrate is a relationship that merits additional study.

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Hostility and the AIDS patient

A quarter of Americans surveyed feel hostility toward persons infected with the AIDS virus, Harvard University researchers found.

After analyzing results from 53 national and international opinion surveys, the researchers concluded that although the public is relatively aware of the low risks of contracting the disease through casual contact, education has not been very effective in reducing hostile feelings toward AIDS patients.

In analyzing the surveys, the researchers found that many people thought people with AIDS should be tattooed or quarantined in some way. Twenty per cent said patients with AIDS were "getting their rightful due,"1 in 12 said AIDS patients should not be treated with compassion, and a quarter said they didn't want their child in school with someone who had AIDS.

The researchers believe discrimination against AIDS patients can be prevented only by legislation that ensures confidentiality and such rights as security in employment and housing. Studies of the effects of anti-racism legislation have shown that even when people maintain hostile attitudes, the threat of legal action against them will generally prevent them from acting out their aggression.