Potent Inhalational Anesthetics for Dentistry

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Nitrous oxide and the volatile inhalational anesthetics have defined anxiety and pain control in both dentistry and medicine for over a century. From curious experimentation to spectacular public demonstrations, the initial work of 2 dentists, Horace Wells and William T. G. Morton, persists to this day in modern surgery and anesthesia. This article reviews the history, similarities, differences, and clinical applications of the most popular inhalational agents used in contemporary dental surgical settings.

Key Words: Inhalational anesthesia; Nitrous oxide; Desflurane; Isoflurane; Sevoflurane; Anesthesia induction; Solubility; Malignant hyperthermia; Minimum alveolar concentration; Coronary artery steal; Ambulatory.

The trend to perform office-based inhalation anesthesia for dental and oral/maxillofacial procedures continues to increase with the introduction of more compact and portable anesthesia equipment. From the age-old use of nitrous oxide/oxygen sedation units to portable desktop anesthesia machines with multiple vaporizers, a thorough understanding of the pharmacology and practical use of inhalation agents is necessary to continue offering safe and effective treatment options.

Inhalational anesthesia has become synonymous with general anesthesia. Although there are multiple agents that can be utilized, whether inhaled or intravenous (IV), to achieve general anesthesia, inhalational anesthesia is still the most common modality utilized today in many ambulatory and hospital settings.¹

With the advancement of surgical techniques and availability of newer, short-acting drugs, particularly the introduction of the IV agent propofol, there has been a rapid increase in ambulatory surgery in the last 2 decades,²⁻⁴ with over 35 million patients utilizing it for various surgical procedures yearly.³ Inhalational anesthesia still has a very significant role in the ambulatory

and office-based setting, particularly with pediatric and needle-phobic patients.⁵ Ideally, an anesthetic agent should possess the following characteristics: it should be highly potent, nonflammable, and nontoxic; it should be stable in light, alkali, and soda lime; it should have low blood solubility; it should be nonirritating to respiratory mucosa; and it should have minimal or no biotransformation and minimal cardiovascular and respiratory effects.⁶

HISTORY

Throughout history, recorded writings have shown use of agents for surgical procedures, from use of herbal extracts to potions and concoctions to narcotic-soaked sponges. Discoveries in the 18th century paved the way for modern anesthesia. Diethyl ether was synthesized by Valerius Cordus in 1540 and shortly thereafter was noted to reduce pain. Nitrous oxide was synthesized by Joseph Priestly in 1772, and in 1800, Sir Humphrey Davy noted its ability to reduce pain. On October 16, 1846, William Morton demonstrated the surgical anesthetic properties of diethyl ether at the Massachusetts General Hospital. Today, October 16 is known as Ether Day. That same year, a Scottish obstetrician has been attributed to have discovered chloroform. The years 1920 to 1940 brought the discovery of ethylene,

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cyclopropane, and divinyl ether. These agents, with the exception of nitrous oxide, were found to be flammable and nephrotoxic and have since ceased to be used clinically. Nitrous oxide is the oldest anesthetic agent in clinical use, predating diethyl ether.⁷

From the 1950s forward came the introduction of the modern inhaled anesthetics with agents being partly or entirely halogenated, making them more stable and less toxic.⁸ Fluroxene was introduced in 1951, the same year halothane was first synthesized. Halothane, an ethane, was then introduced for clinical use in 1956, followed by methoxyflurane, the first of the methyl-ethyl ethers, in 1960. Enflurane was introduced in 1972 and isoflurane in 1980, and both of these agents limited the nephrotoxicity and hepatotoxicity of methoxyflurane. Desflurane and sevoflurane were synthesized in the 1960s and 1970s but did not become commercially available for clinical use in the US until 1992 and 1994, respectively.⁹ All are methyl-ether ethers with various halogen substitutions, but the latter 2 agents utilize only fluorine, which is thought to provide the low blood : gas solubility characteristic discussed below.

Xenon was first discovered in 1898 by British chemists Sir William Ramsay and Morris W. Trave, and, as suggested by its etymology from the Greek word for “stranger,” it is a rare noble gas that was first used as an anesthetic agent in 1951 by Cullen after its anesthetic properties were first noted by J. H. Lawrence in the 1940s. Its properties make it close to an ideal anesthetic agent, but the cost to make it commercially available for clinical use is prohibitive.^{10,11}

PHARMACOLOGY

The pharmacologic properties of the currently used agents, isoflurane, sevoflurane and desflurane, are all fairly similar. These 3 halogenated methyl-ethyl ether derivatives are all nonflammable and exist as clear liquids at room temperature. All 3 volatile anesthetics discussed in this review produce central nervous system depression with expected decreases in electroencephalogram (EEG) frequencies and amplitude. As a reflection of brain metabolic activity, the EEG will display global decreases in central nervous system metabolic demand, but, interestingly, desflurane, isoflurane, and sevoflurane cause increases in cerebral blood flow (CBF). These inhaled anesthetics also suppress the autoregulatory response to CBF. It is important to note that although volatile anesthesia increases CBF, this is offset by the decrease in cerebral metabolic requirement for oxygen as general anesthesia suppresses neuronal activity. Interestingly, they do not have any effect upon cerebral circulatory regulation in response to arterial concentra-

tions of carbon dioxide (CO₂).¹² Increases in intracranial pressure also result from increases in CBF.

Cardiovascularly, the 3 volatile anesthetics provide dose-dependent reductions in blood pressure by decreasing systemic vascular resistance. The resultant compensatory increases in heart rate to preserve cardiac output despite peripheral vasodilation and reductions in systemic vascular resistance are seen in both desflurane and isoflurane administration, yet sevoflurane administration remains unassociated with tachycardia. Isoflurane, the most potent peripheral vasodilator in comparison to sevoflurane and desflurane, was once thought to precipitate coronary artery steal syndrome, but, as we will discuss below, this finding has been challenged by recent studies. In contrast to the volatile anesthetics, nitrous oxide in high concentrations may mildly increase cardiac output owing to a possible sympathomimetic response.

In terms of respiration, all 3 volatile anesthetics provide dose-dependent increases in respiratory rate with a decrease in tidal volume. This tachypneic response eventually leads to decreases in total minute volume and increases in arterial CO₂. In contrast to the rapid and deep breathing often seen in states of metabolic acidosis or diabetic ketoacidosis (Kussmaul breathing), the breathing pattern seen under general anesthesia with volatile agents alone is rapid but shallow. The mechanism driving this inhalational anesthesia mediated respiratory depression is attributed to medullary depression of the central nervous system (CNS) ventilatory drive and possibly reductions in the contractility of the muscles involved in respiration. The volatile anesthetics and nitrous oxide also blunt the ventilatory response to decreases in arterial oxygen concentration and increases in arterial CO₂ concentration. Finally, animal studies have shown an effective decrease in the amount of airway resistance with the administration of volatile anesthetics, but in humans, bronchial smooth muscle tone is generally low and difficult to quantify. Deep planes of anesthesia provided by inhalational anesthetics, however, are generally accepted to prevent stimulation of the airway, and inhalation anesthetics have been used to treat bronchospasm.

MINIMUM ALVEOLAR CONCENTRATION

The concept of minimum alveolar concentration (MAC) was first introduced by Egar et al in the 1960s and is a measure of the potency of inhaled anesthetics.¹³ MAC is among the most useful concept in anesthetic pharmacology as it establishes a common measure of potency. It allows potencies to be compared among inhaled anesthetics.¹⁴ MAC values for different anesthetics are additive (Table 1).

Table 1. Minimum Alveolar Concentration (MAC)

	MAC (Volume %) Adult in 100% Oxygen
Volatile agent	
Isoflurane	1.15
Halothane	0.76
Sevoflurane	2.0
Desflurane	6.0
Gas	
Nitrous oxide	104
Xenon	71

MAC is the alveolar concentration of an anesthetic at 1 atm that prevents purposeful movement in response to a surgical stimulus in 50% of patients.^{13,15} MAC can be thought of as the anesthetic equivalent of the 50% effective dose of an oral medication. Different levels of MAC have predictable endpoints. The concentration necessary to suppress response to verbal and tactile stimulation is MAC-Awake. Memory is usually lost at MAC-Awake.¹⁵ MAC-BAR is the concentration necessary to block adrenergic response to surgical stimulation.¹⁶ MAC 95 is the concentration necessary to produce immobility in 95% of the population. MAC-EI is the concentration necessary to prevent laryngeal response to endotracheal intubation.

$$\begin{aligned}\text{MAC-Awake} &= \sim 0.4 \text{ MAC} \\ \text{MAC-BAR} &= \sim 1.6 \text{ MAC} \\ \text{MAC 95} &= \sim 1.2 \text{ MAC} \\ \text{MAC-EI} &= \sim 1.3 \text{ MAC}\end{aligned}$$

There are multiple factors that affect MAC. It can be altered by physiologic (age) or pharmacologic (opioids, sedatives) variables but is unaffected by gender or duration of anesthesia. Table 2 lists some of these variables.¹⁷

PHARMACOKINETICS

Like IV agents, the inhalation agents are titratable. The pharmacology of inhalation drugs is, however, unique. Absorption takes place at the alveolar-pulmonary blood interface.

Uptake of Inhaled Anesthetics

Three factors influence the uptake of inhaled anesthetic agents via the lungs: solubility, alveolar to venous partial pressure, and cardiac output.

Solubility. Solubility is the relative affinity of an anesthetic in a particular tissue. The blood : gas partition coefficient is a measure of the solubility of an anesthetic gas between the pulmonary venous blood and the

alveolar gas at equilibrium. For example, if the concentration of an anesthetic in pulmonary blood is 3%, and the concentration in alveoli is 6%, the partition coefficient is 0.5 ($3\% \div 6\%$). Therefore, at equilibrium, there are twice as many molecules in the alveoli versus the blood, indicating that the blood does not highly accept the gas in the plasma. An anesthetic with a low blood : gas partition coefficient will reach maximum blood saturation more quickly, leading to faster induction times and likewise faster recovery after anesthesia is discontinued and inhaled concentration returns to zero. The values for brain : blood, muscle : blood, and fat : blood are also known for the various anesthetics and have significant influence, particularly for longer duration anesthetic exposures as the drug is redistributed to body compartments. The uptake of the anesthetic to different tissue groups will depend on the perfusion of that tissue and solubility of the gas with that tissue. The brain with its high perfusion will equilibrate faster than muscle or fat. The tissue : blood coefficient for fat is relatively high, with desflurane's being the lowest. This enormous capacity of fat for inhaled anesthetic means that most of the anesthetic in the blood perfusing the fat will transfer to the fat.¹³ Anesthetic agents with higher affinity for certain tissues, like fatty tissues, will prolong awakening from anesthesia (Table 3).^{4,18}

Alveolar to Venous Partial Pressure Difference.

Alveolar to venous partial pressure difference is the difference between the partial pressure of the anesthetic in the alveoli and pulmonary venous blood. The higher the difference, the greater the uptake of the inhaled anesthetic, as the concentration gradient between the 2 compartments favors movement from the alveoli to the blood.¹⁸ If there were no tissue uptake, the venous blood returning to the lungs would contain the same amount of anesthetic as when it left the lungs.

Alveolar Blood Flow. As cardiac output increases, anesthetic uptake will decrease. This seems counterintuitive, as it would appear that increased cardiac output would lead to more anesthetic getting to the brain more quickly. In reality, CBF is autoregulated and increases in cardiac output do not lead to increases in CBF. However, the anesthetic alveolar partial pressure is decreased more readily as anesthetic is transferred to pulmonary blood. This drop in alveolar partial pressure actually lowers the alveolar to venous partial pressure difference and thus slows induction.¹⁷

CLINICAL CONSIDERATIONS

The advent of the modern volatile anesthetics, such as sevoflurane and desflurane, has increased their utility in today's ambulatory surgery practices as well as many clinical situations. Although these agents have many excellent characteristics, each agent possesses certain

Table 2. Factors Affecting MAC*

Variable	Effect on MAC	Comments
Temperature		
Hypothermia	Decrease	
Hyperthermia	Decrease	Decrease if >42°C
Age		
Young	Increase	
Elderly	Decrease	
Alcohol		
Acute intoxication	Decrease	
Chronic abuse	Increase	
Anemia		
Hematocrit <10%	Decrease	
PaO ₂ <40 mm Hg	Decrease	
PaCO ₂ >95 mm Hg	Decrease	Caused by decrease in pH in CSF
Thyroid		
Hyperthyroid	No change	
Hypothyroid	No change	
Blood pressure		
Mean arterial pressure <40 mm Hg	Decrease	
Electrolytes		
Hypercalcemia	Decrease	
Hypernatremia	Increase	Caused by altered CSF
Hyponatremia	Decrease	Caused by altered CSF
Pregnancy	Decrease	MAC decreased by one third at 8 wk gestation, normal by 72 h postpartum
Drugs		
Local anesthetics	Decrease	Except cocaine
Opioids	Decrease	
Ketamine	Decrease	
Barbiturates	Decrease	
Benzodiazepines	Decrease	
Verapamil	Decrease	
Lithium	Decrease	
Sympatholytics	Decrease	
Sympathomimetics		
Amphetamine		
Chronic	Decrease	
Acute	Increase	
Cocaine	Increase	
Ephedrine	Increase	

* Reprinted with permission from Butterworth et al.^{16(p164)} MAC indicates minimum alveolar concentration; CSF, cerebral spinal fluid.

features that may limit its use in some patients and in certain clinical applications. Although this article focuses on the potent volatile agents, a brief description of nitrous oxide will be provided.

Nitrous Oxide

Of the common inhalational agents used in dentistry, nitrous oxide is the most utilized agent for most dental procedures and surgeries. With an extremely high MAC value (104%), nitrous oxide cannot be utilized as a general anesthetic alone. It is often coadministered with oxygen and the other volatile anesthetics. The gas is contained within cylinders that store the gas as a liquid at

a pressure of 760 psi. Once released into atmospheric conditions, the liquid changes phases into a gas and is then delivered in combination with oxygen for dental sedation or as described above for general anesthesia.

Nitrous oxide was once implicated in diffusion hypoxia when administration was abruptly discontinued. It was speculated that because of its low blood solubility, the diffusion of nitrous oxide from the bloodstream into the alveolar spaces would result in a relative decrease in alveolar oxygen concentration. Clinically, this phenomenon is insignificant and the enriched oxygen concentrations of at least 30% delivered by modern nitrous oxide sedation units prevent clinically observable hypoxia.

As stated earlier, nitrous oxide can stimulate the sympathetic nervous system, but can indirectly cause

Table 3. Volatile Gas Solubilities

<i>Agent</i>	<i>MAC %</i>	<i>Blood : Gas</i>	<i>Brain : Blood</i>	<i>Muscle : Blood</i>
Xenon	71	0.115	0.23	0.10
Nitrous oxide	104	0.47	1.1	1.2
Isoflurane	1.15	1.4	2.6	4.0
Sevoflurane	2.0	0.59	1.7	3.1
Desflurane	6.0	0.42	1.3	2.0

decreases in blood pressure and heart rate in anxious patients because of its sedative effect.

Nitrous oxide can rapidly diffuse across membranes faster than nitrogen can leave, thus enlarging closed spaces. In the dental setting, caution in the use of nitrous oxide is warranted in patients with acute otitis media (middle ear infection) because of possible eardrum rupture or in patients with emphysema because of rupture of emphysematous blebs. Sinus infection limits nasal hood administration.

Lastly, nitrous oxide has been implicated in inhibiting enzymes that are vitamin B₁₂-dependent by irreversibly oxidizing the cobalt atom in the vitamin. These enzymes include methionine synthetase, necessary for myelin formation, and thymidylate synthetase, necessary for DNA synthesis. Prolonged exposure to nitrous oxide, either by occupational exposure or through direct administration, can also result in bone marrow depression (megaloblastic anemia). Patients with methylenetetrahydrofolate reductase deficiency and resultant increases in serum homocysteine have been extensively studied to perhaps be at risk for cardiovascular events during sedation or anesthesia, but more exploration into this subject is needed.

Sevoflurane

Perhaps the most employed volatile anesthetic in ambulatory and office-based anesthesia, this relatively pleasant-smelling and nonirritating inhalational anesthetic can be used as a mask induction agent as well as a maintenance agent with low blood solubility (0.69) and rapid uptake and offset. MAC is 2.4%. With minimal effects on cardiovascular output and minimal irritation to the lungs and respiratory tract, sevoflurane can be employed in “slow” mask induction techniques concurrently with or without nitrous oxide. This incremental dosing with tidal volume breaths is a readily acceptable and gradual means of inducing patients into general anesthesia. Most sevoflurane vaporizers deliver a maximum delivered concentration of 8%, and incremental administration of this gas over a period of time up to this maximum can provide ideal intubating conditions for pediatric patients. Emergence agitation is, however, common in pediatric patients and is

thought to occur because of the rapid awakening but persistence of confusion as the full effects of the agent are eliminated more slowly.

Rapid mask inductions into general anesthesia with high percentages of sevoflurane are generally used for those patients unable to tolerate prolonged face-mask application or are uncooperative. For instance, “single-breath” inductions into general anesthesia with sevoflurane can be achieved when a patient exhales at near or full capacity and then inhales with a full-vital-capacity breath from a breathing circuit primed with 8% sevoflurane. The addition of nitrous oxide may also accelerate the rate of general anesthesia induction.

For a maintenance anesthetic, its use in longer cases (>2 hours) may not be as cost-effective as using another more economical agent such as isoflurane, especially when employing fresh gas flow rates over 2 L per minute.

Desflurane

Desflurane, with its extremely low blood : gas coefficient (0.42), makes for an extremely rapid emergence from anesthesia even with prolonged surgical times, in part because of the fact that it has the lowest fat : blood solubility of any potent inhalation agent. However, this agent may precipitate tachycardia and sympathetic nervous stimulation with rapid changes in inhaled concentration that some patients with cardiovascular compromise may not be able to tolerate.

Additionally, desflurane has a pungent aroma and can be extremely irritating to pulmonary tissues and the respiratory tract, which makes it unsuitable for use as an inhalation-induction agent. This, coupled with the need for a heated and pressurized vaporizer, which is very heavy, makes it an unpopular choice in mobile office-based anesthesia. Lastly, desflurane is the most expensive of the volatile agents considering it is the least potent, with a MAC of 6%.

Emergence agitation or dysphoria is also commonly seen when desflurane is used as a sole agent in pediatric patients. Some studies have demonstrated that desflurane has the potential for more emergence delirium than other agents such as sevoflurane and halothane.¹⁹

Isoflurane

Although it is the longest used of the current inhalational anesthetics in North America, isoflurane still continues to be used as a maintenance anesthetic in ambulatory settings for its cost-effectiveness and potency. Having the lowest MAC value (1.15%) of the currently available volatile anesthetics, isoflurane can provide surgical planes of anesthesia with relatively low concentrations and with lower material cost.

Isoflurane also possesses potent peripheral vasodilating properties with a resultant reduction in systemic vascular resistance. Isoflurane has also been once associated with coronary artery steal syndrome, where reduction in systemic vascular resistance is significant enough to shunt oxygenated blood away from coronary arteries to the main systemic vasculature to cause transient myocardial ischemia and possible infarction. However, recent studies examining isoflurane's cardioprotective preconditioning by opening adenosine triphosphate-dependent potassium channels may show this syndrome to be insignificant to preclude its use in patients with coronary artery disease.²⁰

Potent inhalation anesthetics are complete anesthetics: they produce unconsciousness, amnesia, analgesia, and muscle relaxation. However, because of cardiovascular and respiratory depression, inhalation anesthetics are commonly combined with opioids, other IV anesthetic agents, and neuromuscular blockers to produce "balanced anesthesia." In this way, potent inhalation anesthetics are generally one of many drugs used to provide general anesthesia.

Where patients are cooperative for IV catheter placement, induction of general anesthesia generally takes place with IV drugs. Inhalation induction can be carried out, however, with sevoflurane, which has a pleasant enough smell and is nonirritating to the airways. Gradually increasing doses or brief exposure to high concentrations are common techniques for inhalation induction. Nitrous oxide can be coadministered. In the past halothane was used for this purpose as it had a particularly pleasant smell.

Inhalation agents were delivered by open systems in the distant past. Open-drop ether was used for many years. Eventually, specialized equipment such as copper kettles was used. Depending on the amount of fresh gas passed over the volatile agent, the temperature of the copper and atmospheric pressure determined the amount of agent delivered to the patient. Eventually, variable bypass vaporizers were developed that allowed for dialing in the exact amount of anesthetic in volume percentage delivered to the patient independent of fresh gas flow and temperature.

To limit environmental contamination of the operating room from anesthetic gases and to protect patients, inhalation anesthetics are delivered by endotracheal tube or laryngeal mask. This allows for precise control of delivered anesthetics directly to the lungs. Knowledge of the blood : gas and tissue : blood partition coefficients allows the anesthesiologist to make generally accurate predictions of induction time, changes in moment-to-moment anesthetic concentrations for varying degrees of surgical stimulation, and awakening shortly after surgical completion. The newer agents, desflurane and sevoflurane, have relatively low blood : gas solubility, making them more easily titratable than the older agents, isoflurane and halothane. The latter agent became no longer available for human use in the United States and most first-world countries in the early 2000s because of an increased incidence of cardiac dysrhythmias, hepatitis, and other undesirable characteristics.

MALIGNANT HYPERTHERMIA

All volatile anesthetic agents are triggers for malignant hyperthermia (MH). MH is a rare, life-threatening, autosomal-dominant inherited disorder characterized by disturbance of calcium homeostasis in skeletal muscles of susceptible individuals after exposure to a triggering agent. Functionally altered calcium channels cause uncontrolled calcium release from the sarcoplasmic reticulum, which leads to a fatal, hypermetabolic state. MH has been attributed to a mutation of the ryanodine receptor 1 isoform (RYR1), predominant in skeletal muscles. RYR1 is not the sole gene responsible for MH; other variants have been linked.^{19,20} All volatile anesthetic and succinylcholine are triggers for MH.

Diagnosis is based on clinical presentation. Laboratory testing with halothane-caffeine-induced contractures in skeletal muscle specimens from MH-susceptible individuals is diagnostic.^{19,20} Research on genetic testing continues.

Denborough²¹ first defined MH in 1960 after numerous reports of anesthesia-related deaths associated with perioperative hyperthermia. Ironically, a rapid rise in temperature (to >38.8°C) is a relatively late sign. Clinical presentation includes tachycardia, rapid rise in end-tidal CO₂ concentration, tachypnea, muscular rigidity, arrhythmia usually secondary to hyperkalemia, and combined metabolic and respiratory acidosis. If untreated, progression to rhabdomyolysis, acute renal failure and circulatory collapse can occur. Isolated masseter spasm following succinylcholine administration is associated with a higher presentation of MH.

It is vital that as soon as MH is suspected, rapid, appropriate treatment be instituted. This includes immediate cessation of all triggering agents and ideally utilizing

a new source of oxygen and mechanical ventilation for the patient. Anesthesia may be maintained with non-triggering agents (IV sedatives, opioids, IV hypnotics, and nondepolarizing muscle relaxants if needed). Hyperventilate the patient with 100% oxygen at maximum fresh gas flow, increasing minute volume by 2–3-fold, aiming for an end-tidal CO₂ within normal range. Administer dantrolene 2.5 mg/kg initially and increase to 10 mg/kg or more as needed. Dantrolene acts as a specific ryanodine receptor antagonist and inhibits the release of calcium from the sarcoplasmic reticulum. Institute cooling measures. Obtain blood gas and chemistries and treat accordingly. In the office setting, if symptoms of hyperkalemia present (eg, peaked T waves), treatment with hyperventilation, insulin and dextrose, beta-2 agonists, etc, is indicated prior to obtaining blood gases.^{22,23}

SUMMARY

In the hospital and ambulatory surgery center operating rooms, inhalation anesthesia is by far the most commonly used method for obtaining general anesthesia. Although IV administration is still the most common form of sedation and general anesthesia in the dental office, there is an increasing use of inhalation anesthesia in the dental office. Having multiple methods for delivery of general anesthesia can allow the anesthesiologist in the dental office to choose from an array of appropriate anesthetics for a given patient versus fitting one technique to all patients. The choice to use an inhalation agent involves whether it is to be used for induction or maintenance of anesthesia, the patient's comorbid conditions, presence or absence of an IV line, need for rapid emergence and discharge, postanesthesia care, and cost.

With an increasing number of surgical procedures done on an outpatient basis, the choice of inhalation agent becomes even more important to be able to meet rapid discharge criteria in a cost-effective way.

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CONTINUING EDUCATION QUESTIONS

This continuing education (CE) program is designed for dentists who desire to advance their understanding of pain and anxiety control in clinical practice. After reading the designated article, the participant should be able to evaluate and utilize the information appropriately in providing patient care.

The American Dental Society of Anesthesiology (ADSA) is accredited by the American Dental Association and Academy of General Dentistry to sponsor CE for dentists and will award CE credit for each article completed. You must answer 3 of the 4 questions correctly to receive credit. Articles are eligible for CE credit for one year following the date of publication.

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CE questions must be completed within three months and prior to the next issue.

1. The inhaled anesthetics desflurane, isoflurane, and sevoflurane affect the central nervous system by
 - A. Increasing cerebral blood flow and decreasing metabolic demand
 - B. Decreasing cerebral blood flow and increasing metabolic demand
 - C. Decreasing intracranial pressure and decreasing metabolic demand
 - D. Increasing intracranial pressure and increasing metabolic demand
2. The administration of the volatile anesthetic desflurane is often accompanied by
 - A. Kussmaul breathing patterns
 - B. Coronary artery steal syndrome
 - C. Tachycardia
 - D. Increases in respiratory tidal volume
3. Nitrous oxide administration should be avoided in patients with
 - A. Acute otitis media
 - B. Malignant hyperthermia genotype
 - C. Hypertension
 - D. Developmental delays
4. What concentration of volatile anesthesia is needed to blunt sympathetic response to surgery?
 - A. Minimum alveolar concentration (MAC)
 - B. MAC-BAR
 - C. MAC-Awake
 - D. MAC 95