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Local anesthesia: advances in agents and techniques

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The improvements in agents and techniques for local anesthesia are possibly the most important advances in dental science to have occurred in the past 100 years. The agents currently available in dentistry have most of the characteristics of an ideal local anesthetic:

- Administration is nonirritating
- Anesthetic has little or no allergenicity
- Rapid onset and adequate duration of anesthesia
- Provides anesthesia that is completely reversible
- Minimal systemic toxicity
- Selective to nocioception (pain) pathways

Today's anesthetics can be administered with minimal irritation and little concern for stimulating allergic reactions. A variety of agents are available that provide rapid onset of surgical anesthesia with adequate duration. Persistent nerve impairment and systemic toxicity are rarely reported. Unfortunately, local anesthetic agents that selectively inhibit pain pathways without interrupting transmission of other sensory pathways are not currently available.

This article provides a brief review of the local anesthetic agents, formulations, and techniques used in dentistry with special emphasis on newly introduced agents and procedures. Adverse reactions related to local anesthetic formulations used in dentistry are presented in a separate article, "Adverse reactions associated with local anesthesia." Important

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considerations regarding the clinical pharmacology of vasoconstrictors are presented in "Vasoconstrictors: indications and contraindications."

Clinical pharmacology of local anesthetics

For the past 20 years, the primary local anesthetics used in dentistry are those classified as amides. Lidocaine and mepivacaine, two of the most commonly used dental anesthetic agents, have a 50-year history of effectiveness and safety in providing regional anesthesia for dental therapies. Practitioners prefer the amide local anesthetic agents over the ester agents (ie, procaine and propoxycaine) because amides more rapidly and reliably produce profound surgical anesthesia. The availability of effective amide agents that provides anesthesia of varying duration (Table 1) has dramatically improved patient care, permitting the development of many of the sophisticated surgical outpatient procedures now available in dentistry [1].

Variations in the physical and clinical characteristics of the local anesthetic agents can be attributed to differences in chemical properties of their molecular structures. The pK_a of an anesthetic determines the pH at which the drug's ionized (charged) and nonionized (uncharged) forms are in equal concentrations. This is critical for effective anesthesia because the uncharged form of a local anesthetic can readily diffuse across lipid nerve sheaths and cell membranes, whereas only the charged form can diffuse through the extracellular fluid and intracellular cytoplasm. An agent's pK_a is therefore the most important factor in determining an agent's diffusion properties and rate of onset. Procaine, with a pK_a of 8.9, is 98% ionized at a normal tissue pH of 7.4. Most of this drug is in a charged state and unable to cross cell membranes. The onset of procaine anesthesia is therefore unacceptably prolonged. Amide anesthetics having pK_as in the range of 7.6–8.0 have less of the drug in an ionized state and therefore diffuse through tissue more readily [2,3].

Table 1
Local anesthetics

Anesthetic	Brand names	Formulations	Duration
Surgical anesthetics			
Articaine	Ultracaine®, Septocaine®	4% with epinephrine	1.5–3 hours
Lidocaine	Xylocaine®	2% with epinephrine	1.5–3 hours
Mepivacaine	Carbocaine®	3% plain	1–2.5 hours
		2% with levonordefrin	1.5–3 hours
Prilocaine	Citanest®	4% plain	1–2.5 hours
		4% with epinephrine	1.5–3 hours
Long-acting agents			
Bupivacaine	Marcaine®	0.5% with epinephrine	4–8 hours
Etidocaine	Duranest®	1.5% with epinephrine	4–8 hours

The lipid solubility characteristics of a local anesthetic best predicts potency. Procaine is one of the least lipid-soluble and least potent local anesthetics, whereas bupivacaine is very lipid-soluble and therefore the most potent. Protein binding characteristics are a primary determinant of the duration of anesthesia. Agents that attach to protein components of nerve membranes are less likely to diffuse from the site of action and into the systemic circulation. Lidocaine's short duration and bupivacaine's long duration are caused, in part, by their distinctly different protein binding characteristics [4].

It is clear that lipid solubility, ionization, and protein-binding properties contribute to the clinical characteristics of local anesthetics. But factors such as the site injection, drug and vasoconstrictor concentration, volume of injection, and inherent vasoconstrictive properties of the anesthetic will also influence the clinical performance of a local anesthetic.

Ester anesthetics: procaine/propoxycaine

A combination of ester anesthetics, procaine and propoxycaine, was available in dental cartridges until 1989. The formulation in dental cartridges was the combination of 0.4% propoxycaine (Ravocaine®) and 2% procaine (Novocain®) with 1:20,000 levonordefrin as a vasoconstrictor. As stated earlier, ester anesthetics are generally less effective than amides because they have poor diffusion properties. Additionally, procaine has significant allergenicity and has been known to affect both the patient and practitioners. Procaine is a potent vasodilator and is not effective if used without a vasoconstrictor.

The termination of effect is through hydrolysis by plasma and tissues cholinesterases to para-aminobenzoic acid (PABA) and diethylamino alcohol. The PABA appears to be the allergen associated with procaine's allergenicity.

In the 1980s, there was some concern about the use of amide anesthetics with patients diagnosed with "malignant hyperthermia." This rare genetic syndrome causes a rapid and potentially fatal rise in body temperature during general anesthesia. Ester anesthetics at one time were considered to be the local anesthetic agents of choice for these patients. Recent evidence has determined, however, that this concern is unfounded and the use of an amide anesthetic for patients at risk for malignant hyperthermia is no longer contraindicated [5].

Lidocaine hydrochoride

Lidocaine hydrochloride (Xylocaine®, Octocaine®) was introduced into practice in the 1950s and, because of its excellent efficacy and safety, has become the prototypic dental local anesthetic in North America. Besides having excellent anesthetic efficacy, lidocaine has limited allergenicity with

fewer than 20 reports of allergic reactions in the literature in the past 50 years. Given the frequent use of local anesthesia in dentistry (500,000–1,000,000 injections a day in the United States and Canada), the rare incidence of hypersensitivity reactions is an extremely important clinical advantage.

Lidocaine is formulated in cartridges as 2% lidocaine with 1:50,000 epinephrine, 2% lidocaine with 1:100,000 epinephrine, and 2% lidocaine with 1:200,000 epinephrine. The 2% lidocaine with 1:100,000 epinephrine is considered the standard for comparison with newer anesthetics. Lidocaine with epinephrine rapidly induces oral anesthesia and provides surgical anesthesia that last 90–180 minutes.

Mepivacaine hydrochloride

Mepivacaine hydrochloride (Carbocaine®, Polocaine®) has an important place in dental anesthesia because it has minimal vasodilating properties and can therefore provide profound local anesthesia without being formulated with a vasoconstrictor such as epinephrine or levonordefrin. The availability of a 3% formulation not containing a vasoconstrictor is a valuable addition to a dentist's armamentarium. It is available in dental cartridges as 3% mepivacaine plain or 2% mepivacaine 1:20,000 levonordefrin. Mepivacaine plain is often reported to have a short duration of soft tissue anesthesia, although a recent investigation suggests that although pulpal durations of mepivacaine plain are shorter than 2% lidocaine with epinephrine, soft tissue anesthesia for mepivacaine and lidocaine with epinephrine are nearly identical [6].

Prilocaine hydrochloride

Prilocaine hydrochloride (Citanest®) can provide excellent anesthesia with or without a vasoconstrictor. One of its metabolic products, toluidine, has been associated with the development of methemoglobinemia (see following article "Adverse reactions to local anesthetics"). It is available in preparations of 4% prilocaine plain and 4% prilocaine with 1:200,000 epinephrine. The formulation containing epinephrine has anesthetic characteristics similar to 2% lidocaine 1:100,000 epinephine. The 4% prilocaine plain formulation provides a slightly shorter duration of surgical anesthesia. Although the pH of the solution in dental cartridges is somewhat less acidic, there is little indication that prilocaine causes less discomfort upon injection [7].

Articaine hydrochloride

The local anesthetic articaine hydrochloride (Ultracaine®, Septocaine®) has been available in Europe (1976) and Canada (1982) for several decades. Recently, the United States Food and Drug Administration (FDA) approved use of articaine in the United States. Because of its unique chemistry and pharmacologic profile, 4% articaine with epinephrine may provide

practitioners with an alternative to the currently available dental local anesthetics. In Canada, articaine is marketed under the brand name of Ultracaine® and Septanest®, and in the United States as Septocaine®. The United States formulation contains 4% articaine hydrochloride 1:100,000 epinephrine bitartrate in a sterile 1.7 mL. glass cartridge.

Similar to most dental anesthetics available to the dental practitioner, articaine is classified as an amide anesthetic. The molecular structure of articaine additionally contains a thiophene (sulfur-containing) ring and an ester side chain (Fig. 1). As articaine is absorbed from the injection site into the systemic circulation, it is rapidly inactivated by hydrolysis of the ester side chain to articainic acid and therefore has an extremely short plasma half-life (27 minutes) [8].

The onset time, duration, and anesthetic profundity of articaine is comparable to 2% lidocaine with 1:100,000 epinephrine [9]. Articaine and prilocaine have been associated with a slightly higher incidence of mandibular and lingual paresthesia [10]. Articaine does not appear to have a greater allergenicity than other available dental anesthetic agents, probably because the ester metabolite is not the allergen PABA. Reports of toxicity reactions following the use of articaine for dental anesthesia are extremely rare. The rapid inactivation of articaine by plasma esterases may explain the apparent lack of overdose reactions reported following its administration, even though it is marketed as a 4% solution.

Clinical studies indicate that 4% articaine 1:100,000 epinephrine is an effective and useful local anesthetic for dental procedures. When reinjection

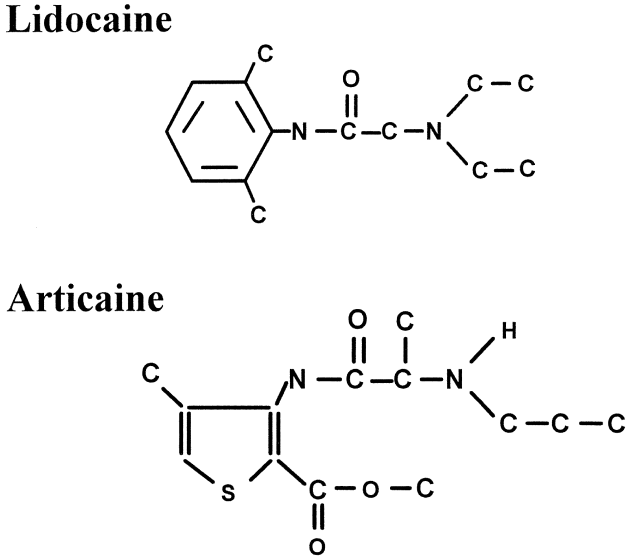

Fig. 1. Molecular structures of lidocaine and articaine.

of anesthesia is anticipated because of long appointments required for cosmetic dentistry, full mouth restoration, full mouth periodontal surgery, or multiple implant placements, articaine may be considered as a desirable anesthetic.

The 4% articaine solution with epinephrine has been reported to have an onset of 1.5–3.0 minutes for maxillary infiltrations, and only slightly longer for inferior alveolar blocks. The duration of soft tissue anesthesia ranges from 2–3 hours for maxillary infiltration anesthesia and 3–4 hours for mandibular block anesthesia [11].

There is little data to support the claim that articaine has superior diffusion properties or that lingual/palatal anesthesia can be induced following buccal infiltration. The establishment of maxillary and mandibular pulpal anesthesia following buccal infiltration with articaine has been compared with prilocaine using electrical stimulation of tooth pulp and lingual soft tissue. Results showed no statistically significant differences between articaine and prilocaine in their ability to induce anesthesia for any tissue at any of the sites tested [12,13].

Long-acting amide anesthetics: bupivacaine and etidocaine

In the past few decades, two long-acting amide local anesthetics, bupivacaine and etidocaine, have found a place in the dentists' armamentarium. These agents play a valuable role in the overall management of surgical and postoperative pain associated with dental care. As illustrated (Fig. 2), etidocaine and bupivacaine are chemical analogues of lidocaine and mepivacaine. Bupivacaine (1-butyl-2′, 6′pipecoloxylidide) (Marcaine®) is identical to mepivacaine except for a butyl (4 carbon) substitution of the methyl (1 carbon)

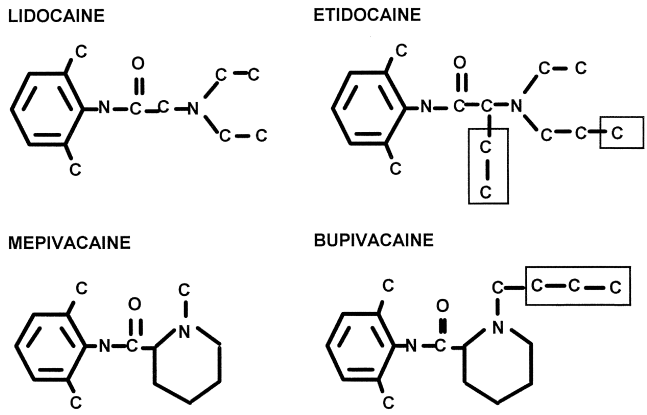

Fig. 2. Comparison of the molecular structures of standard anesthetics to long-acting anesthetics.

group at the aromatic amine. Etidocaine (2-N-ethylpropylamino-2′ butyroxylidide) (Duranest®) is identical to lidocaine except for a propyl (3 carbon) substitution and an ethyl (2 carbon) addition. These additions to the chemical structures of lidocaine and mepivacaine provide enhanced lipid solubility and, especially, protein-binding properties as compared with their shorter-acting analogues [14,15].

Although both bupivacaine and etidocaine may provide adequate surgical anesthesia, they are most useful for postoperative pain management. Clinical trials have shown that bupivacaine has a slightly longer onset time than conventional anesthetics [4]. The profundity of anesthesia, however, appears to be comparable. Onset times and profundity are optimized when preparations of bupivacaine include epinephrine [16]. Etidocaine, although less well studied in dentistry, appears to have a slight advantage over bupivacaine with regard to onset times. Onset times for etidocaine have been found to be slightly more rapid than bupivacaine (less than 1 minute difference) when the agents were compared in endodontics and oral surgery [17,18]. The profundity of mandibular anesthesia provided by etidocaine with epinephrine appears to be equivalent to conventional agents. The profundity of etidocaine anesthesia following maxillary infiltrations may be somewhat less [19].

When duration of soft-tissue anesthesia is evaluated, inferior alveolar blocks using bupivacaine have durations 2–3 times those of lidocaine and mepivacaine [20,21]. As might be expected, durations are somewhat shorter when maxillary infiltrations are evaluated. Bupivacaine provided soft tissue anesthesia for 4–5 hours after infiltration, and 5–8 hours following nerve blocks. Etidocaine provides similar increases in soft-tissue anesthesia duration following block injections. Because the epinephrine concentrations are lower in formulations of bupivacaine and etidocaine, increased bleeding during surgery has been demonstrated.

The use of long-acting local anesthetics to alleviate pain following third molar extractions has been consistently and repeatedly demonstrated [4, 22–24]. Patients undergoing third molar extractions involving bone removal were administered 0.5% bupivacaine without epinephrine, 0.5% bupivacaine 1/200,000 epinephrine, or 3% mepivacaine. The patients receiving bupivacaine with epinephrine had a mean duration of anesthesia of 7.0 hours (versus 2.9 hours for mepivacaine) and required the fewest doses of postoperative narcotic analgesics [24]. A combination strategy for managing postoperative pain using a nonsteroidal anti-inflammatory drug (NSAID) prior to surgery and a long-acting anesthetic may provide maximal comfort [23].

Additionally, it has been noted that some patients may be concerned about prolonged anesthesia. If a clear explanation of expectations is not provided, some patients may worry about possible dysesthesias caused by surgical trauma. Delays in recovery following local anesthetic using long-acting agents beyond 10 hours are not uncommon. Patient preparation and a thorough explanation of this pain control strategy are essential [19].

Bupivacaine and etidocaine have been used in the overall management of chronic pain either as symptomatic, diagnostic, or definitive therapy. Prolonged anesthesia and pain relief may facilitate physical therapy of certain skeletal muscle disorders. Some myofascial pain dysfunction syndromes may benefit from injection of a long-acting local anesthetic into "trigger points." Injections of long-acting agents, sometimes repeatedly over a course of weeks, may be useful in stimulating complete recovery from postherpetic neuralgias and reflex sympathetic dystrophies [25].

Advances in local anesthetic techniques

Dental patients have become increasingly less tolerant of a dentist who hurts them. The control of intra- and postoperative pain presents an age-old challenge: Will there ever be a perfect local anesthetic technique or delivery system? Through the past 3 decades, it appears that attempts to increase success rates, especially in the mandible with its dense, infiltration-resistant cortical bone, have accelerated.

The conventional inferior alveolar nerve block (IANB) sometimes misnamed as a mandibular block, has served the dental profession admirably since being formally documented by Halstead in 1905. In view of the fact that there were no anatomically proven alternatives until 1973 (Gow-Gates Condylar Neck Mandibular Block) and 1977 (Akinosi Closed Mouth Mandibular Block), the conventional approach offered advantages such as standardized landmarks, reasonable success (69–85%), relative simplicity, and almost universal practitioner acceptance from institutional teaching standards.

Disadvantages include, however, inadequate anesthesia for some patients, obscure and visually obstructuive landmarks (ie, buccal fat pad and tongue), risk of dysesthesia or paresthesia, and high vascularity enhancing local anesthesia and vasoconstrictor systemic absorption. The reasons for failure may include local anesthesia solution or vasoconstrictor, pK_a–pH incompatibility, needle-jaw size discrepancy, tissue vector forces, inadequate volume of solution, anatomical variations (hard tissue anatomy, neuroanatomy), and the uncooperative patient.

Some of the most recent advances in anesthetic techniques that provide alternatives to conventional methods include lingual infiltration, periodontal ligament injections, intraosseous anesthesia, computer-controlled injections, needleless injections, and electronic dental anesthesia.

Lingual infiltration

A relatively new concept, lingual infiltration of the mandible, theoretically and practically has merit but may also pose some disadvantages (Table 2). As with any technique, patient (anatomical) selection is important. It should be reinforced that, although mandibular infiltration is

Table 2
Advantages and disadvantages of local anesthetic techniques

Technique	Advantages	Disadvantages
Lingual infiltration injection	Thin cortical plate Lingual foramina Patient acceptance	Ballooning of tissue Avoiding submandibular salivary gland
Periodontal ligament injection	Immediate onset of anesthesia No collateral anesthesia Operate bilaterally in the mandible Less volume Abscessed tooth	Post-operative pain Decrease in pulpal blood flow Decrease in pulpal blood flow Presence of periodontal disease Pressure required to inject Multiple injections for multi-rooted teeth Access to posterior areas
Intraosseous injections	Immediate onset of anesthesia No collateral anesthesia Operate bilaterally in the mandible	Short duration of anesthesia "Intravascular" injection/ toxicity Palpitations Access to posterior areas Periodontal disease 3 steps (Stabident®) Anatomical limitations
Computer controlled injection devices	Controlled pressure/volume ratio Operator confidence Practice builder PDL injections	Set-up time Cost (disposable items) Loss of volume (Wand®) Needle remains in tissue for longer time Aspiration

PDL, periodontal ligament injection.

generally regarded as not reliably successful, certain conditions may establish profound anesthesia via the combination of facial (buccal) and lingual injection. A demonstration of this technique may be researched on the web at www.septocaine.com.

Periodontal ligament injections

The introduction of the intraligamentary injection techniques, an actual intraosseous delivery of local anesthesia, provides a supplement to routine submucosal anesthesia. For the route of administration commonly known as the periodontal ligament injection (PDL), it must be understood that the PDL space is simply the anatomical medium to deliver an intraosseous injection. Popularized by the Ligmaject® in the 1970s, the advantages and disadvantages are summarized below (see Table 2).

With a special syringe, the solution is introduced into the periodontal tissue. Success rates with the intraligamentary technique are variable, depending on practitioner experience, volume of solution injected, and the tooth being anesthetized [26]. Malamed has reported a success rate of 63% following first injection and an overall success rate of 92% with this technique [27].

Although intraligamentary injections appear to have a slightly lower success rate, their use for diagnostics in referred pain states, with uncontrolled hemophiliacs and as an adjunct following failed mandibular blocks, appears quite valuable.

Initially, injection into the PDL tissue occurs by advancement of a 30- or 27-gauge short needle to the point of obtaining significant back pressure on injection, a criterion required for the local anesthesia successfully to penetrate the cribiform plate and circumferentially anesthetize even in an abscessed or "hot" tooth. The volume of solution required is approximately 0.4–0.9 mL per administration, and recommendations for mandibular molars include a 2-site approach (mesial lingual and distal lingual). The duration will vary from 5 to 25 minutes, depending on volume, clearance, protein binding, and vasoconstrictor concentration. Reports of temporary cessation of pulpal blood flow suggest a potential introgenic result from this approach for vital or pediatric scenarious. But for endodontic treatment this is obviously not an issue.

Intraosseous anesthesia

Intraosseous anesthesia is often characterized as anesthetizing "a single tooth" by injecting local anesthesia directly into cancellous bone. This technique also offers both advantages and disadvantages (see Table 2). There are two standardized systems that perform the essentials of perforating (in this order) the epithelium (keratinized gingiva), connective tissue, periosteum, and cortical (compact) plate of bone.

Stabident® (Fairfax Dental, Miami, FL)

The principles of intraosseous anesthesia have been in the literature since the turn of the century. The procedure involved using a #1/2–#1 round bur to penetrate cortical bone, followed by the introduction of a slightly smaller circumference needle. Dr. Frank Dillon introduced the technologic concept of a perforator needle compatible with the injection of local anesthesia directly into the cancellous bone, thereby anesthetizing individual (and often multiple) teeth and adjacent hard tissue and soft tissue.

Understandably, with groundbreaking technology, this system has had some scrutiny. "Finding-the hole" seems to be the chief complaint among practitioners of this technique, although certain adjustments to visual acuity may reduce the hole-finding variable. Onset is almost instantaneous and duration may be from 15–30 minutes, depending on the site and choice of local anesthesic formulation.

X t.i.p.® (x t.i.p. Technologies, Lakewood, NJ)

Interest in intraosseous anesthesia escalated in 1999 with the introduction of the "cannula-insert" system marketed as the X t.i.p. (Dr. Arthur "Kit" Weathers, Griffin, GA). Initial anesthesia of the attached gingiva, via the mucobuccal fold or infiltration of the gingiva directly, must preclude the contra-angle guide sleeve. Leaving the guide sleeve in place, the ultra-short 27-gauge needle (0.5 inches) is introduced into the lumen and local anesthesia in the volume of 0.7–1.7 mL is slowly injected. Whether there is a need to use an anesthetic formulation containing epinephrine is controversial. Except for a potential rapid systemic uptake, the vasoconstrictor seems to be only minimally responsible for duration and efficacy. Post-op sequelae seem to be infrequent and are rarely reported (see Table 2).

Computer controlled injections

There are currently a number of computer-controlled injection devices available. Computer systems offer a variety of advantages and disadvantage (see Table 2). Compared to a standard syringe, computer-controlled injection devices are larger, require more operatory space, and are more expensive. Because the needle and handle generally appear less threatening and are more aesthetic, patient acceptance is generally high. The ability of the computer to control and limit the rate of the injection and subsequently limit patient discomfort has created considerable popularity for these devices.

The Wand® (Milestone Scientific, Inc, Livingston, NJ)

When first introduced, the Wand® was the first computer-controlled dental anesthetic delivery system. Product promotion and training has inundated the profession with suggestions that slow, controlled injections could be an "efficient practice builder and time saver." The lightweight and easily manipulative hand piece is a significant asset. A bidirectional rotation technique has been shown to eliminate needle deflection and is suggested to reduce discomfort of mucogingival penetration. True to the resolve of Milestone Scientific, Inc, the Wand Plus® introduced improvements requested by dental practitioners. These included verbal prompts, aspiration time reduction from 14 to 5 seconds, and streamlining and simplifying the technology.

The technique-enhancing suggestions include the Anterior Middle Superior Alveolar Block (AMSA), Palatal Anterior Superior Alveolar Nerve Block (PASA), and the modified PDL-Local Anesthesia Delivery, all of which the author (JMH) has received and has found personally impressive with respect to comfort of the injection delivery.

Comfort Control Syringe® (Midwest Dentsply, Des Plaines, IL)

This preprogrammed local anesthesia delivery system offers a selectable choice of rate of administration by technique. A unique concept developed by Dr. Mark Smith of Ontario, Canada, uses a hand-activated drive unit (as

opposed to a foot-activated rheostat) for preprogrammed delivery of slow injection, increased speed of injection, and aspiration modes. Once the injection format and flow rate is selected, 10 seconds allows the initial slow-solution deposition. Then subsequently, the flow rate will increase to the preselected speed.

Needleless local anesthesia: Madajet®/Syrijet®
(Mada Equipment Company, Inc, Carlstadt, NJ)

Over 30 years ago, Mada Equipment Company, Inc, developed a revolutionary "no needle" technology that successfully captured a portion of the dental local anesthesia market. Based on a piston/pressure expulsion principle, the system offered demonstrable patient acceptance of "no invasiveness" and very effective soft tissue and possibly hard tissue anesthesia. But because of factors such as the armamentarium not accepting a standard dental local anesthesia cartridge, the "one setting" force of injection, and the necessity of priming the system to eliminate air, it appears that the professional market for this device is hesitant yet still active. The Madajet® and Syrijet® nonetheless have made a successful presence in the dental anesthesia field.

Electronic dental anesthesia (EDA)

One of the latest developments in local pain-control techniques in dentistry is electronic dental anesthesia (EDA). Manufacturers have been involved with many electrical wave forms and voltage/amperage parameters. According to the literature, there is some merit to the strategy, though the success rates, particularly for the more painful procedures seen in dental practice, seem not to be satisfactory for routine use in dentistry.

The documentation of EDA is well known, although the therapeutic results are reportedly varied. Based on the transcutaneous electronic nerve stimulation (TENS) principle, its use in medicine is widely documented (back pain, sports injuries). The successful transfer to the acute pain seen in dental practice has been questioned. Allowing patient control of the level of EDA needed for minor periodontal scaling, noninvasive restorative dentistry and other procedures depends on the so-called "Gate-Control Theory." In essence, a path of nerve impulses to the brain delivered by an electrical stimulation can gridlock a highway potentially capable of trafficking pain impulses from dental sources. It is also surmised that pain threshold may be elevated by naturally occurring biochemicals such as endorphins, enkephalins, serotonin, or even a placebo effect.

Research is ongoing in the quest for efficient delivery and effective results in many local anesthesia categories. The safety and patient acceptance have enhanced the development of this science, and the future will surely demonstrate the answers to questions such as "Will a perfect local anesthsia/vasoconstrictor/system ever be found?" and "Will traditional block anesthesia ever become obsolete?"

References

[1] Yagiela J, Malamed SF. Injectable and topical local anesthetics. In: Ciancio SG, editor. ADA guide to dental therapeutics. Chicago: ADA Publishing Co; 1998.
[2] Covino BG, Vassallo HG. Local anesthetics: mechanisms of action and clinical use. New York: Grune & Stratton; 1976.
[3] Moore PA. Manual of local anesthesia in dentristry. 4th edition. Rochester (NY): Eastman-Kodak Co; 1996.
[4] Moore PA. Bupivaciane: a long-lasting local anesthetic for dentistry. Oral Surg 1984; 58:369–74.
[5] Malignant Hyperthermia Association of the United States (MHAUS). Malignant hyperthermia—a concern in dentistry and oral & maxillofacial surgeryAvailable at: http://www.mhaus.org/dentoral.htmL. Accessed December 28, 2001.
[6] Hersh EV, Hermann DG, Lamp CL, Johnson PD, MacAfee K. Temporal assessment of soft tissue anesthesia following mandibular block injection. JADA 1995;126:1531–5.
[7] Wahl MJ, Overton D, Howell J, Siegel E, Schmitt MM, Muldoon M. Pain on injection of prilocaine plain vs. lidocaine With epinephrine: a prospective double-blind study. J Am Dent Assoc 2001;132:1396–1401.
[8] Oertel R, Rahn R, Kirch W. Clinical pharmacokinetics of articaine. Clin Pharmacokinet 1997;33(6):417–25.
[9] Malamed SF, Gagnon S, Leblanc D. Efficacy of articaine: a new amide local anesthetic. J Am Dent Assoc 2000;131(5):635–42.
[10] Haas DA, Lennon D. A 21 year retrospective study of reports of paresthesia following local anesthetic administration. J Can Dent Assoc 1995;61(4):319–30.
[11] Donaldson D, James-Perdok L, Craig BJ, Derkson GD, Richardson AS. A comparison of Ultracaine DS (articaine HCl) and Citanest forte (prilocaine HCl) in maxillary infiltration and mandibular nerve block. J Can Dent Assoc 1987;53(1):38–42.
[12] Haas DA, Harper DG, Saso MA, Young ER. Comparison of articaine and prilocaine anesthesia by infiltration in maxillary and mandibular arches. Anesth Prog 1990;37(5):230–7.
[13] Haas DA, Harper DG, Saso MA, Young ER. Lack of differential effect by Ultracaine (articaine) and Citanest (prilocaine) in infiltration anaesthesia. J Can Dent Assoc 1991: 57(3):217–23.
[14] Aberg G, Dhuner KG, Sydnes G. Studies on the duration of local anesthesia: structure/activity relationships in a series of homologous local anesthetics. Acta Pharacol Toxicol 1977;41:432–43.
[15] Tucker T, Mather LE. Clinical pharmacokinetics of local anesthetics. Clin Pharmacokinet 1979;4:241–78.
[16] Laskin JL, Wallace WR, DeLeo B. Use of bupivacaine hydrochloride in oral surgery—a clinical study. J Oral Surg 1977;35:25–9.
[17] Dunsky JL, Moore PA. Long-acting local anesthetics: a comparison of bupivacaine and etidocaine in endodontics. J Endodont 1984;10:457–60.
[18] Giovannitti JA, Bennett CR. The effectiveness of 1.5% etidocaine HCL with epinephrine 1:2000,000 and 2% lidocaine HCL with epinephrine 1:100,000 in oral surgery: a clinical comparison. J Am Dent Assoc 1983;107:616–8.
[19] Moore PA, Dunsky JL. Bupivacaine anesthesia: a clinical trial for endodontic therapy. Oral Surg 1983;55:176–9.
[20] Feldman G, Nordenram A. Marcaine in oral surgery. Acta Anaethesiol Scand 1966;23: 409–13.
[21] Nespaca JA. Clinical trials with bupivacaine in oral surgery. Oral Surg 1976;42:301–7.
[22] Davis WM, Oakley J, Smith E. Comparison of the effectiveness of etidocaine and lidocaine as local anesthetic agents during oral surgery. Anesth Prog 1984;31:159–64.
[23] Dionne RA, Wirdzek PR, Fox PC, Dulber R. Suppression of postoperative pain by the combination of a nonsteroidal anti-inflammatory drug, flurbiprofen and a long-acting local anesthetic, etidocaine. J Am Dent Assoc 1984;108:598–601.

[24] Trieger N, Gillen GH. Bupivacaine anesthesia and postoperative analgesia in oral surgery. Anesth Prog 1979;20:23–7.
[25] Burney RG, Moore PA, Duncan GH. Management of head and neck pain. Int Anes Clin 1983;21(40):79–96.
[26] Kaufmen E, Dworkin SF, LeResche L, Truelove EL, Sommers E. Intraligamentary anesthesia: a double-blind comparative study. J Am Dent Assoc 1984;108:175–8.
[27] Malamed SF. The periodontal ligament (PDL) injection: an alternative to inferior alveolar nerve block. Oral Surg 1982;53(2):117–21.