

Local anesthesia for endodontic pain

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The purpose of the following paper is to discuss problems with mandibular anesthesia, the success of intraosseous anesthesia, and the clinical management of endodontic anesthesia.

Why do patients avoid going to the dentist? According to a survey from the American Dental Association (1), fear of pain is the greatest factor that prevents patients from visiting their dentist. Additional surveys (2, 3) have found that 90% of dentists have some anesthetic difficulties during restorative dentistry procedures. In endodontics, Wallace and coworkers (4) surveyed Diplomates of the American Board of Endodontics and found 84% of the respondents did not achieve anesthesia after a clinically successful nerve block.

Recognizing that adequate pulpal anesthesia is a clinical problem, we have performed research on local anesthesia over the last 17 years. Some of the findings we are reviewing in this paper. Because failure occurs most often with the inferior alveolar nerve block (2), we would like first to concentrate on mandibular anesthesia.

Mandibular anesthesia

How do we traditionally confirm anesthesia clinically?

Traditional methods to confirm anesthesia usually involve questioning the patient ('Is your lip numb?'), clinical testing (e.g., responsiveness to mucosal needle sticks), or simply commencing with treatment. The problem with these approaches is they may not be effective for determining pulpal anesthesia (5–8).

Objective means of determining pulpal anesthesia

A more objective measurement of anesthesia is obtained with an electric pulp tester (EPT) (e.g. Analytic Technology, Redmond WA, USA), or application of a cold refrigerant (Endo-Ice, Hygienic Co., Akron, OH, USA). The Analytic Technology EPT provides a readout on a scale of 0–80, with 80 representing maximal stimulation for this device. Accordingly, the lack of response at the 80 reading with this EPT is an end point which can be used to verify pulpal anesthesia over time and allows comparisons of anesthetic solutions and techniques without the variation inherent in traditional testing methods using clinical procedures.

Clinically, the electric or cold pulp testing methods can be used to test the tooth under treatment for pulpal anesthesia *prior* to beginning a clinical procedure. Clinical studies (9, 10) have demonstrated that the lack of response at an 80 reading (maximum output of the pulp tester) predicts pulpal anesthesia in vital asymptomatic teeth. Additionally, Certosimo & Archer (10) showed that a positive response at EPT readings less than 80 reliably predicted patient perception of pain during restorative procedures. Therefore, the lack of response at an 80 reading of the EPT can be used to indicate if pulpal anesthesia would be obtained clinically. We have used the EPT to experimentally monitor pulpal anesthesia. Our general experimental approach is to administer the local anes-

thetic injection and then repeatedly pulp test the teeth every two to four minutes for approximately an hour (Fig. 1).

Conventional inferior alveolar nerve block

As a frame of reference, we will first review expected outcomes following administration of a conventional inferior alveolar nerve block, to asymptomatic patients, using 1.8 mL of 2% lidocaine with 1:100,000 epinephrine (a standard cartridge).

Anesthetic success

As alluded to above, we defined anesthetic success as the percentage of subjects who achieved two consecutive 80 readings within 15 min and continuously sustained this lack of responsiveness for 60 min. In other words, our objective is achieve anesthesia within 15 min and have anesthesia that lasts 1 h. This objective is equally important to restorative procedures as well as endodontic treatment. It is important to realize that 100% of these subjects reported profound lip numbness. But, that does not predict anesthetic success since we are interested in pulpal anesthesia and not lip anesthesia. What then is the percentage of anesthetic success? For the first molar it was 53%, for the first premolar it was 61%, and for the lateral incisor it was 35% (5–8, 11–15). Thus, anesthetic success, as defined by pulpal anesthesia, is not predicted by a positive lip sign and appears to vary across different

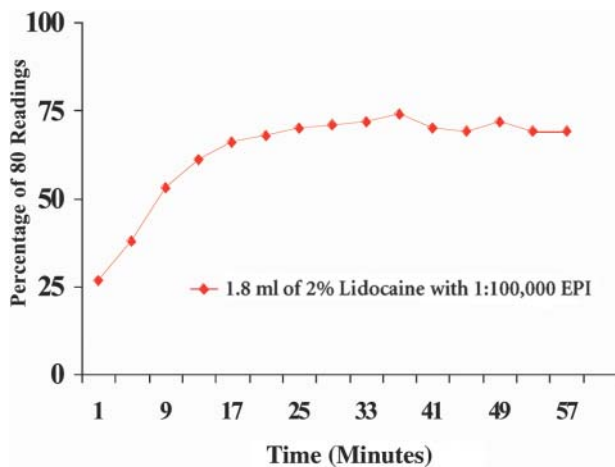


Fig. 1. Incidence of first molar anesthesia as determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 min.

teeth following a conventional inferior alveolar nerve block injection.

Anesthetic failure

We defined anesthetic failure as the percentage of subjects who do not achieve two consecutive 80 readings at any time during the 60 min period. These patients have the highest potential for pain during the dental procedure. How often does failure occur? For the first molar it was 17%, for the first premolar it was 11%, and for the lateral incisor it was 32% (5–8, 11–15).

Noncontinuous anesthesia

In addition to anesthetic success and failure, there are other considerations in mandibular anesthesia such as noncontinuous anesthesia. Noncontinuous anesthesia means that the patient does not have a continuous duration of anesthesia during the appointment but instead, reports episodes of anesthesia followed by a lack of clinically detected anesthesia. This may be related to the action of the anesthetic solution on the nerve membrane (blocking and unblocking of the sodium channels). This occurs about 12–20% of the time in mandibular teeth (5–8, 11–15).

Slow onset

In most cases following conventional inferior alveolar nerve block injection, the onset of pulpal anesthesia usually occurs within 10–15 min (5–8, 11–15) (Fig. 1). However, in some patients onset will be delayed. Slow onset was defined as the percentage of subjects who achieved an 80 reading after 15 min. Slow onset occurs about 19–27% of the time in mandibular teeth and about 8% of patients have onset after 30 min (5–8, 11–16). In contrast to the onset of pulpal anesthesia, the onset of lip anesthesia occurs usually occurs within 5–7 min (5–8, 11–15).

Duration

Duration of pulpal anesthesia in the mandible is very good (5–8, 11–15). Therefore, if patients are anesthetized initially, this *usually* persists for approximately 2½ h (14).

Timecourse of pulpal anesthesia

Figure 1 depicts the time course for complete pulpal anesthesia for a healthy mandibular first molar, as defined by percentage of patients who do not respond to an 80 EPT stimulus across time. As you can see, the majority of patients achieved pulpal anesthesia within 15 min. However, some patients had slow onset (19%) as indicated by the sloping plateau of anesthesia after the 15 min. The duration of anesthesia is very good for at least the hour, but the success rate is not 100%. This graph illustrates the criteria for anesthetic success, that is, an onset of a lack of responsiveness to EPT within 15 min and duration of 60 min.

What does lip numbness mean?

As described, the presence of soft tissue anesthesia (usually measured by 'lip numbness' or lack of mucosal responsiveness to needle stick) does not adequately indicate pulpal anesthesia (5–8, 11–15). This is in contradiction to the traditional view. However, the lack of soft tissue anesthesia is a useful indicator that the block injection was not properly administered for that patient. This occurs about 5% of the time, and should prompt the clinician to re-administer the local anesthetic before continuing with treatment.

Previous difficulty with anesthesia

Another consideration in mandibular anesthesia is patients who report previous difficulty with anesthesia. These patients are likely to subsequently experience unsuccessful anesthesia (2). These patients will generally identify themselves with comments such as 'Novocaine never seems to work very well on me' or 'A lot of shots are always necessary to get my teeth deadened.' These patients can be identified by simply asking whether they have had prior difficulty getting numb. If they have had these experiences, supplemental injection techniques, such as an intraosseous injection, should be considered.

Procedures that have tried to increase success of the inferior alveolar nerve block

The following reviews several alternative mandibular injection studies evaluating methods to increase the success of the inferior alveolar nerve block.

Increasing the anesthetic volume

One potential method to increase anesthesia success is to double the injection volume of the local anesthetic. However, increasing the volume of 2% lidocaine with epinephrine to 3.6 mL (two cartridges) does not increase the incidence of pulpal anesthesia with the inferior alveolar nerve block (5, 15, 17–21).

Increasing the epinephrine concentration

A second approach for increasing the success of mandibular blocks is to increase the concentration of epinephrine. However, when evaluated in clinically normal teeth, there was no advantage to using a higher concentration (1:50,000) of epinephrine in an inferior alveolar nerve block (12, 22).

3% Mepivacaine (Carbocaine)

A third approach to improving the clinical success of mandibular blocks was to evaluate 3% mepivacaine as an alternative anesthetic. McLean et al. (6), in an experimental study, and Cohen et al. (23), in a clinical study of patients with irreversible pulpitis, have shown that 3% mepivacaine plain is as effective as 2% lidocaine with 1:100,000 in an inferior alveolar nerve block. Clinically, this is an important finding because when medical conditions or drug therapies contraindicate the use of epinephrine-containing solutions, 3% mepivacaine can be used as an alternative. However, the clinical success is not greater than with 2% lidocaine with epinephrine.

Articaine

The available literature indicates that articaine (Septodont™, New Castle, DE, USA) is a safe and effective local anesthetic agent (24–28). However, repeated clinical trials have failed to detect any superiority of articaine over lidocaine (29–33). Additional studies, particularly in endodontics, are warranted.

Hyaluronidase

Hyaluronidase decreases the viscosity of the injected tissue permitting a wider spread of injected fluids (34). Early studies in dentistry (35, 36) found that an inferior alveolar nerve block was more easily at-

tained and was more complete when hyaluronidase was added to an anesthetic solution. However, Rid-enour et al. (37) found that adding hyaluronidase to a lidocaine solution with epinephrine did not statistically increase the incidence of pulpal anesthesia in inferior alveolar nerve blocks. Additionally, the combined lidocaine/hyaluronidase solution resulted in a significant increase in postoperative pain and trismus.

Carbonated anesthetic solutions

Experimentally, carbonated anesthetic solutions are more effective due to the trapping of the anesthetic within the nerve (7). Additionally, CO₂ has a synergistic relationship to local anesthetics and a direct depressant action on nerves (7). However, Chaney et al. (7) was not able to demonstrate a superior effect of lidocaine hydrocarbonate in inferior alveolar nerve blocks.

Long-acting anesthetics

Clinical trials with bupivacaine (Marcaine™) and etidocaine (Duranest™) have been performed in oral surgery (38, 39), endodontics (40, 41), and periodontics (42, 43). Recently, etidocaine has been withdrawn from the market by Dentsply Pharmaceuticals. Bupivacaine provides a prolonged analgesic period and is indicated when postoperative pain is anticipated. However, not all patients want lip numbness for extended periods of time (39) and patients should be questioned regarding their preference. Bupivacaine, as compared to lidocaine, has been shown to have a somewhat slower onset but almost double the duration of pulpal anesthesia (approximately 4 h), in the mandible (14).

A relatively new long-acting local anesthetic is ropivacaine (Naropin™). It is a structural homologue of bupivacaine (44). A number of studies have demonstrated that ropivacaine has a lower potential for central nervous system and cardiovascular toxic effects than bupivacaine (44). Kennedy et al. (44) concluded that 0.5% ropivacaine with 1:200,000 epinephrine was equivalent to 0.5% bupivacaine with 1:200,000 epinephrine in pharmacologic action. Therefore, ropivacaine with epinephrine has the potential to replace bupivacaine with epinephrine, in clinical dental

practice, due to the decreased potential for cardiac and central nervous system toxicity.

Infiltration injections

Labial or lingual infiltration injections alone are not very effective for pulpal anesthesia in mandibular teeth (29, 30, 45). Adding a labial infiltration (1.8 mL of 2% lidocaine with 1:100,000 epinephrine) to a conventional inferior alveolar injection increases the success of anterior pulpal anesthesia (46). However, adding a supplemental intraosseous injection should be more efficacious (46). Adding a labial or lingual infiltration injection after an inferior alveolar nerve block does not significantly result in more profound anesthesia in the first molar (47).

Alternate injection locations

Neither the Gow-Gates (48) nor Akinosi-Vazirani (49) techniques are superior to the standard inferior alveolar injection (20, 50). These techniques do not replace the conventional inferior alveolar nerve block. The Akinosi-Vazirani technique may be indicated when there is limited mandibular opening.

Incisive nerve block at the mental foramen

Nist et al. (18) and Joyce & Donnelly (51) demonstrated the incisive nerve block alone was successful in anesthetizing the premolar teeth. However, Nist et al. (18) showed that the technique did not anesthetize the central and lateral incisors. Although this study demonstrated an increased success rate in the first molar when the incisive nerve block was combined with the inferior alveolar nerve block, an intraosseous injection would be a better choice for supplemental anesthesia of the first molar when the inferior alveolar nerve block fails.

Cross innervation

Cross innervation from the contralateral inferior alveolar nerve has been implicated in failure to achieve anesthesia in anterior teeth after an inferior alveolar injection. Experimentally, cross innervation occurs in incisors (21, 52) but plays a very small role in failure with the inferior alveolar nerve block.

Needle deflection and success

Needle deflection has been theorized as a cause for failure with the inferior alveolar nerve block (53–55). Various authors (53–58), using *in vitro* methods, have reported that beveled needles, when passed through substances of varying densities, will deflect toward the non-beveled side. That is, the needle will deflect away from the bevel. Recently, Hochman & Friedman (55) developed a bi-directional needle rotation technique using the computer-assisted Wand™ (CompuDent, Milestone Scientific Inc., Deerfield, IL, USA). The bi-directional technique rotates the Wand handpiece assembly and needle in a manner similar to rotation of an endodontic hand file. The technique was found to reduce needle deflection during needle insertion. Kennedy et al. (59) compared the anesthetic efficacy of the conventional inferior alveolar nerve block, administered with the needle bevel oriented away from the mandibular ramus (so the needle would deflect toward the mandibular foramen), to the bi-directional needle rotation technique, administered using the computer-assisted Wand anesthesia system, in patients diagnosed with irreversible pulpitis. There were no significant differences between the success rates (50% for the conventional and 56% for the bi-directional technique) of the two techniques. Neither technique resulted in an acceptable rate of anesthetic success in patients with irreversible pulpitis.

Accessory innervation

Judging from clinical and anatomical studies (60, 61), the mylohyoid nerve is the accessory nerve most often cited as a cause for failure with mandibular anesthesia. Clark et al. (19) compared the inferior alveolar nerve block alone to a combination injection of the inferior alveolar nerve block plus the mylohyoid nerve block, which was aided by the use of peripheral nerve stimulator. The investigators found that the mylohyoid injection did not significantly enhance pulpal anesthesia of the inferior alveolar nerve block. Therefore, the result of the study does not lend much credibility to the notion that the mylohyoid nerve is a major factor in failure with the inferior alveolar nerve block.

Accuracy of the injection

It has been theorized that an inaccurate injection contributes to inadequate mandibular anesthesia. Hanan et al. (11) used a medical ultrasound unit to guide needle placement for inferior alveolar nerve blocks. While they found that the nerve block administered with ultrasound was accurate, it did not result in more successful pulpal anesthesia. Therefore, accuracy of needle placement is not the primary reason for anesthetic failure with this block. Two studies performed 30 years ago reached similar conclusions. Berns & Sadove (62) and Galbreath & Eklund (63) used radiographs to locate the mandibular foramen and found that accurate needle location did not guarantee successful anesthesia. Twenty-five percent of accurate blocks resulted in anesthetic failure. The authors speculated that migration of the anesthetic solution followed the path of least resistance and this was determined by fascial planes and structures encountered in the pterygomandibular space. These studies provide an important clinical lesson – the lack of pulpal anesthesia is not necessarily due to an inaccurate injection.

Why don't patients achieve anesthesia with the inferior alveolar nerve block?

The central core theory (64, 65) may be our best explanation. The theory states that nerves on the outside of the nerve bundle supply molar teeth while nerves on the inside supply anterior teeth. The anesthetic solution may not diffuse into the nerve trunk to reach all nerves to produce an adequate block, even if deposited at the correct site.

Mannitol

Recently, we have studied the use of mannitol to increase the efficacy of nerve blocks. Mannitol (a hyperosmotic sugar solution) temporarily disrupts the protective covering (perineurium) of sensory nerves allowing the local anesthetic agent to gain entry to the innermost part of the nerve. Without the mannitol, the perineurium is a barrier to the diffusion of the local anesthetic into the nerve. We have found mannitol in combination with lidocaine increases anesthetic success in patients with irreversible pulpitis

about 15–20%. The drug combination is undergoing trials for commercial introduction.

Failure in patients with pain

As we are aware, endodontic patients who are in pain and have pulpal pathosis have additional anesthetic problems. There are a number of explanations for failure. One explanation, as discussed previously, is that conventional techniques do not always provide profound pulpal anesthesia. Another explanation relates to the theory that the lowered pH of inflamed tissue reduces the amount of the base form of anesthetic to penetrate the nerve membrane. Consequently, there is less of the ionized form within the nerve to achieve anesthesia. However, this explanation of local influences on the anesthetic solution does not explain the mandibular molar with pulpitis, which is not readily blocked by an inferior alveolar injection. That is, the local anesthetic is administered at some distance from the area of inflammation. Therefore, it would be difficult to blame local influences on failure with the inferior alveolar nerve block. Another explanation for failure is that nerves arising from inflamed tissue have altered resting potentials and decreased excitability thresholds (4, 66). Wallace et al. (4) demonstrated that local anesthetic agents were not sufficient to prevent impulse transmission due to these lowered excitability thresholds. Another factor would be the tetrodotoxin-resistant (TTXr) class of sodium channels that have been shown to be resistant to the action of local anesthetics (67). And finally, patients in pain are often apprehensive, which lowers the pain threshold. Therefore, practitioners should consider supplemental techniques – such as intraosseous (68–71) or periodontal ligament injections (23) when an inferior alveolar nerve block fails to provide pulpal anesthesia for patients with irreversible pulpitis.

Supplemental injections

Supplemental injections are essential when, as frequently occurs, anesthesia from conventional injections is inadequate and the pain is too severe for the endodontist to proceed. There are three such supplemental techniques – the periodontal ligament injection, the intraosseous injection and the intrapulpal injection.

If the patient has *profound lip numbness and experiences pain upon access*, repeating the inferior alveolar

nerve block does not help the problem. Clinicians may think that another injection is helpful because the patient sometimes achieves pulpal anesthesia after the second injection. However, the patient may just be experiencing slow onset of pulpal anesthesia. That is, the second injection does not provide additional anesthesia – the first injection is just ‘catching up’ due to the slow onset of pulpal anesthesia.

Periodontal ligament injection

Historically, the periodontal ligament injection has been shown to be successful in restorative and endodontic procedures (23, 72, 73). Several reviews (23, 72–75) and textbooks are available for clinicians interested in procedural details on the periodontal ligament injection.

New technology for periodontal ligament injection

Recently, a computer assisted local anesthetic delivery system has been introduced. The Wand (CompuDent) local anesthesia computer-controlled injection system (Fig. 2) accommodates a standard local anesthetic cartridge that is linked by sterile micro tubing to a disposable, pen-like handpiece with a Leur-Lok needle attached to the end. The device is activated by a foot control, which automates the infusion of local anesthetic solution at a controlled rate. Two flow rates, slow or fast, may be initiated and maintained by



Fig. 2. A picture of the Wand (CompuDent) computer-assisted local anesthetic delivery unit. The Wand handpiece assembly and micro tubing are also seen.

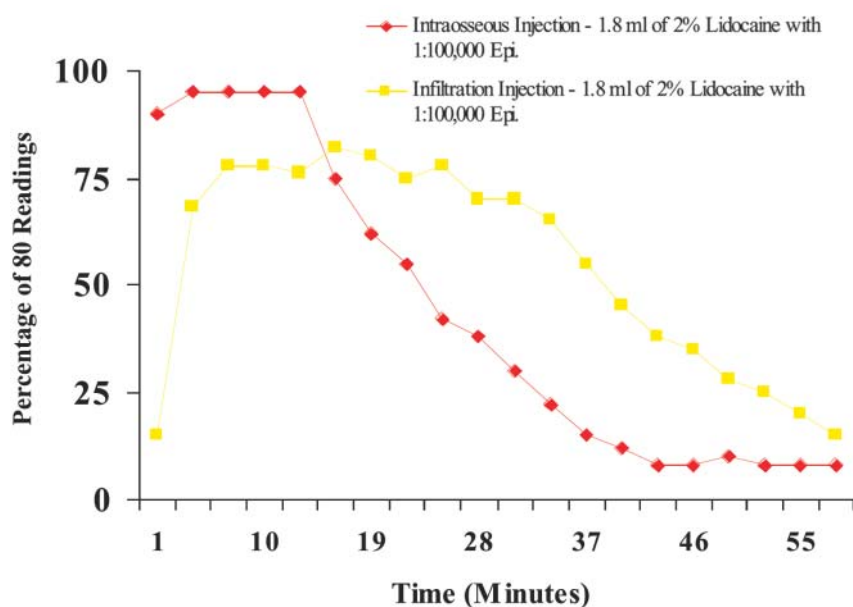


Fig. 3. Incidence of anesthesia for intraosseous and infiltration injections as determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 min. The intraosseous injection had a quicker onset and a shorter duration of anesthesia.

the foot pedal control. The fast rate delivers 1.4 mL of solution in one minute. The slow rate delivers 1.4 mL of solution in approximately 4 min 45 s. The slow rate is used for the periodontal ligament injection.

The periodontal ligament injection with the Wand (CompuDent, Livingston, NJ, USA) system may be successful because potentially 1.4 mL of solution can be delivered intraosseously. The amount differs significantly from the periodontal ligament injection with a conventional syringe or pressure syringe.

Intraosseous anesthesia with Stabident and X-Tip Systems

The intraosseous injection allows placement of a local anesthetic solution directly into the cancellous bone adjacent to the tooth to be anesthetized. Because infiltration injections are not effective for anesthesia of the mandibular molar teeth due to the thickness of the cortical plate, dentists do not attempt infiltration anesthesia in the posterior mandible. The intraosseous injection overcomes this problem by allowing direct access to the cancellous bone. How similar is an infiltration and intraosseous injection? Wood (76) compared these two injection techniques, using 1.8 mL of 2% lidocaine with 1:100,000 epinephrine, in the maxillary lateral incisor. The two techniques were similar except the intraosseous technique had a quicker onset and a shorter duration of anesthesia (Fig. 3).

There are two intraosseous systems that have been

studied clinically—the Stabident™ system (Fairfax Dental Inc., Miami, FL, USA) and the X-tip™ system (X-tip Technologies, Lakewood, NJ, USA). Recently, another intraosseous system has been introduced—the IntraFlow™ (IntraVantage, Plymouth, MN, USA). The system combines a slow-speed handpiece with an anesthetic cartridge dispenser system and a rotating needle/drill. The anesthetic solution is delivered simultaneously as the cortical bone is perforated. No published studies have evaluated this recently introduced system in clinical dentistry.

The Stabident system comprises a slow-speed handpiece driven perforator, a solid 27-gauge wire with a beveled end, that, when activated, drills a small hole through the cortical plate (Fig. 4). The anesthetic solution is delivered to cancellous bone through the 27-gauge ultra-short injector needle placed into the hole made by the perforator. Two needles are available with this system—a pointed needle and a modified (flattened tip) beveled needle. Clinically, we would recommend the modified needle because it allows for an easier negotiation of the perforation hole. Recently, the Alternative Stabident™ system has been introduced. This system utilizes a funnel shaped guide-sleeve that is manually placed into the perforation site, after the perforation is performed, allowing the needle to be placed easily into the perforation site.

The X-tip anesthesia delivery system consists of an X-tip that separates into two parts: the drill and guide sleeve component (Fig. 5). The drill (a special hollow



Fig. 4. The Stabident perforator, a solid 27-gauge wire with a beveled end, which is placed in a slow-speed handpiece.

needle) leads the guide sleeve through the cortical plate, whereupon it is separated and withdrawn. The remaining guide sleeve is designed to accept a 27-gauge needle to inject the anesthetic solution. The guide sleeve is removed after the intraosseous injection is complete.

The technique of intraosseous anesthesia, using the Stabident or X-tip system, can be reviewed in their respective instruction manuals and/or published papers (77–85).

Pain of perforation and solution deposition in patients with irreversible pulpitis

Generally, the incidence of moderate pain due to perforation and solution deposition is low when using the Stabident system, as a primary or supplemental technique, in asymptomatic patients (77–80, 85). In mandibular posterior teeth with irreversible pulpitis, Nusstein et al. (69) and Reisman et al. (68) found 0% and 9% of patients, respectively, reported a transient, moderate to severe pain with the Stabident perforator; 5% and 31%, respectively, reported moderate to severe pain during anesthetic solution deposition. For the X-tip system in patients with irreversible pulpitis, Nusstein et al. (71) reported a 48% incidence of moderate to severe pain with perforation; solution deposition resulted in a 27% incidence of moderate pain. Generally, the clinician should be aware that a transient, but moderate to severe pain, may be experienced when using the Stabident or X-tip system for perfor-

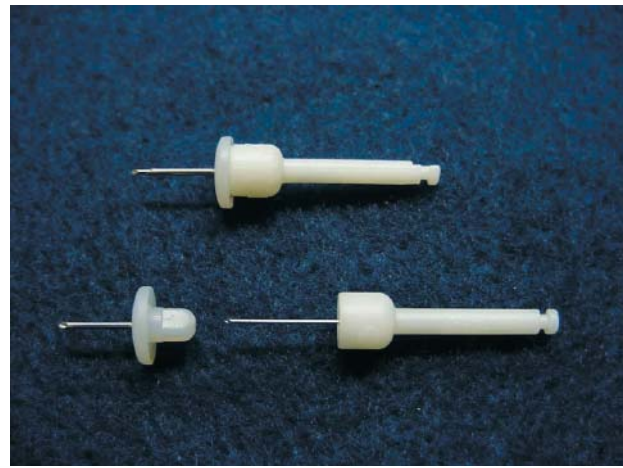


Fig. 5. The X-tip anesthesia delivery system consists of an X-tip (top) that separates into two parts: the drill (a special hollow needle) and guide sleeve component (bottom).

ation and solution deposition in patients with irreversible pulpitis. The higher pain ratings, compared to asymptomatic teeth, are related to the patients being in pain and probably being anxious.

Perforator breakage with Stabident and X-tip systems

About 1% of perforators ‘separate’ during use (70, 77–82, 85). That is, the metal perforator separates from the plastic shank. Each is easily removed with a hemostat. The ‘separation’ usually occurs during a difficult perforation (e.g. dense cortical bone) and it is likely the metal is heated excessively, causing the plastic hub to melt. No perforator ‘breakage’ (metal perforator breaking into parts) has been reported in numerous studies (70, 77–82, 85).

Optimal injection site location

It is important to remember that a site DISTAL to the tooth to be anesthetized will result in the best anesthesia (77–85). An *exception* to this rule would be in maxillary and mandibular second molars – a MESIAL site should be selected (69, 77–85).

Although no study has explored this option, in some mandibular molars where a mesial or distal Stabident injection hasn’t been successful or can’t be used, the authors have used a lingual approach with success.

Onset of anesthesia

Basically, the onset of anesthesia is immediate (77–85). Therefore, there is no ‘waiting period’ for onset of anesthesia.

Site selection

Both the Stabident and X-tip intraosseous systems instruct the user to locate the perforation site in attached gingiva. The gingival site allows the perforation to be made through a minimal thickness of cortical bone and is generally equidistant between adjacent root structures. However, because the guide sleeve remains in place with the X-tip system, we have successfully used it in alveolar mucosa at a more apical location (71, 85). The X-tip system has a definite clinical advantage over the Stabident system because the X-tip perforation may be made at an apical location in unattached gingiva. That is, if the Stabident system is used apically in alveolar mucosa, it is almost impossible to find the hole to deliver the anesthetic solution. Therefore, the clinician may want to consider using the X-tip in an apical location in specific clinical situations. For example, when periodontal pocketing does not allow perforation into cancellous bone through the more coronal attached gingiva or there is a lack of interproximal space (roots are too close together), the X-tip system can be used to achieve pulpal anesthesia. Furthermore, if the Stabident system fails, the clinician may want to consider using the X-tip apically to achieve pulpal anesthesia.

Failure with inferior alveolar nerve block in patients with irreversible pulpitis

Clinical studies in endodontics (68–71), in patients with irreversible pulpitis, have found failure (pain or positive pulp tests) with the inferior alveolar nerve block occurring between 44% and 81% of the time. These studies would indicate that anesthesia is often difficult to achieve in irreversible pulpitis with only the inferior alveolar nerve block.

Success of intraosseous anesthesia in patients with irreversible pulpitis

Stabident success

Nusstein et al. (69), in a clinical study, found a supplemental mandibular intraosseous injection of 1.8 mL

of 2% lidocaine with 1 : 100,000 epinephrine was 91% successful in gaining total pulpal anesthesia for posterior teeth diagnosed with irreversible pulpitis. Parente et al. (70) used the Stabident intraosseous injection in patients with irreversible pulpitis when conventional local anesthetic techniques failed. They found an initial supplemental intraosseous injection, using 0.45–0.9 mL of 2% lidocaine with 1 : 100,000 epinephrine, was successful in 79% of posterior mandibular teeth. A second intraosseous injection increased success to 91%. Reisman et al. (68) reported the supplemental intraosseous injection of 1.8 mL of 3% mepivacaine (Carbocaine) increased success in mandibular teeth diagnosed with irreversible pulpitis to 80% when compared to the inferior alveolar nerve block alone (25% success). A repeated intraosseous injection of 3% mepivacaine increased success to 98%. Therefore, one cartridge of 3% mepivacaine plain is not as efficacious as one cartridge of 2% lidocaine with 1 : 100,000 epinephrine. But 3% mepivacaine does not have the heart rate increase seen with epinephrine-containing solutions.

X-Tip success

Nusstein et al. (71) used an X-tip supplemental intraosseous injection in patients with irreversible pulpitis when a conventional inferior alveolar nerve block failed. The X-tip injection site was 3–7 mm apical to the mucogingival junction of the mandibular molar or premolar tooth and 1.8 mL of 2% lidocaine with 1 : 100,000 epinephrine was administered. They found that six of the 33 (18%) X-tip injections resulted in backflow of the anesthetic solution into the oral cavity – none was successful in obtaining anesthesia. Twenty-seven of the remaining 33 X-tip injections (82%) were successful. They concluded that when the inferior alveolar nerve block fails to provide profound pulpal anesthesia, the X-Tip system, when used in an apical location and when there is no backflow of the anesthetic solution into the oral cavity, is successful in achieving pulpal anesthesia in mandibular posterior teeth of patients presenting with irreversible pulpitis.

Key to success with an intraosseous injection

The key to success with the intraosseous injection is flow of the anesthetic into the cancellous space. If anesthetic solution squirts out of the perforation site

into the oral cavity—naturally, no anesthetic effect will be realized. Reperforation or choosing another perforation site would be a good choice to gain access to the cancellous bone.

In less than 10% of intraosseous injections, constricted cancellous spaces may limit the distribution of the anesthetic solution around the apices of the teeth (68, 69, 71, 77–85). Therefore, failure may result even when the anesthetic solution is delivered intraosseously.

Duration

In patients with irreversible pulpitis, the supplemental intraosseous injection, using the Stabident or X-tip systems, provided anesthesia for the entire debridement appointment (68, 69, 71).

When should intraosseous injection be given?

Considering the high failure rate of the initial inferior alveolar nerve block and our own research, we now give all patients with irreversible pulpitis a supplemental intraosseous injection following an inferior alveolar nerve block. That is, once we have signs of lip numbness, we administer an intraosseous injection. This procedure has significantly decreased patients' pain and allowed a quicker onset of treatment.

Why don't more clinicians use this regimen? Basically, many clinicians do what we were taught during our initial clinical training and sometimes it is hard to change. For example, a 1998 study in the *Journal of the American Medical Association* (86) urges the use of anesthesia during circumcision. Currently, up to 96% of babies don't receive anesthesia. The physicians were taught in their residencies not to administer anesthesia and consequently it will probably be a slow process to change them over. This is a common problem in many health care disciplines and is the rationale for journals such as *Endodontic Topics*.

Success in painful teeth with totally necrotic pulps and radioluncent areas

No study has investigated the success rate in these teeth. We feel that anesthetic solution deposition would be painful and profound anesthesia may not be provided, or if obtained, it may be of short duration.

Success in partially vital teeth

The intraosseous injection should work in teeth where the chamber is necrotic, the canals are vital, and there is a widening of the periodontal ligament radiographically. A recent history of hot and cold sensitivity should differentiate this condition from one of a necrotic tooth experiencing an acute exacerbation (Phoenix abscess).

Use in periradicular surgery

Currently, in the mandible, we give an intraosseous injection into the area of the surgical site after we have given our standard injections. We feel this reduces bleeding and increases surgical anesthesia.

Systemic effects with intraosseous injection

Heart rate effects of intraosseous anesthesia

Various authors (69, 71, 77–85) have reported a transient increase in heart rate (46% to 93% of the time) with the Stabident or X-tip intraosseous injection of epinephrine- and levonordefrin-containing solutions. Replogle et al. (87) reported 67% of their subjects objectively (electrocardiogram recordings) had an increased heart rate with the Stabident intraosseous injection of 1.8 mL of 2% lidocaine with 1:100,000 epinephrine. The mean increase was 28 beats per minute. Chamberlain et al. (88) found the Stabident intraosseous injection of 2% lidocaine with 1:100,000 epinephrine resulted in a mean heart rate increase of 12 beats per minute. Guglielmo et al. (81) reported that the supplemental Stabident intraosseous injection of 1.8 mL of either 2% lidocaine with 1:100,000 epinephrine or 2% mepivacaine with 1:20,000 levonordefrin resulted in a mean increase in heart rate of 23–24 beats per minute (measured with a pulse oximeter) in 80% of the subjects. Stabile et al. (84) found the supplemental intraosseous injection of 1.8 mL of 1.5% etidocaine with 1:200,000 epinephrine resulted in a mean increase in heart rate of 32 beats per minute (measured with a pulse oximeter) in 90% of the subjects. Generally, all these studies showed that the heart rate returned to baseline readings within four minutes in most patients. Therefore, injection of anesthetic solutions containing vasoconstrictors, using either the Stabident or X-tip systems, would result in a transient heart rate increase. No significant change in diastolic, systolic or mean arterial blood pressure will be ob-

served with the intraosseous injection of 2% lidocaine with 1:100,000 epinephrine (87, 88).

Clinical significance of heart rate increase

While the heart rate increase with the Stabident or X-tip intraosseous injection of 2% lidocaine with 1:100,000 epinephrine would likely be noticed by the patient, it would not be clinically significant in most healthy patients (87). Replogle et al. (87) discussed the clinical significance, cardiovascular effects and contraindications to the use of vasoconstrictors in intraosseous injections. The reader is referred to this article for review.

Heart rate effect of other anesthetic solutions for intraosseous anesthesia

There will be no significant increase in heart rate when 3% mepivacaine is used for intraosseous anesthesia (83, 87). Importantly, in those patients whose medical condition or drug therapies suggest caution in administering epinephrine- or levonordefrin-containing solutions, 3% mepivacaine represents an alternative for intraosseous injections (87).

In an attempt to increase the duration of pulpal anesthesia with intraosseous injections, some clinicians may use long-acting anesthetic agents. Bupivacaine (Marcaine) and etidocaine (Duranest) are long-acting anesthetic agents but only for inferior alveolar nerve blocks. These agents are not long-acting when injected by the intraosseous or maxillary infiltration routes (84, 89–91). It is important to realize that bupivacaine and etidocaine have cardiotoxic effects (92) and are equivalent to 2% lidocaine with epinephrine in terms of efficacy, duration, and heart rate effects for intraosseous anesthesia. Therefore, bupivacaine and etidocaine offer no advantage clinically and should not be used for intraosseous anesthesia.

Clinical significance of the intraosseous injection of lidocaine

Some authors (93) have cautioned that administration of an overly large volume of local anesthetic with an intraosseous injection could lead to overdose reactions. Wood et al. (94), using human subjects and 1.8 mL of 2% lidocaine with 1:100,000 epinephrine, found that the venous plasma levels of lidocaine were

the same for an intraosseous injection as for an infiltration injection. While there is a short-lived effect on the heart rate due to the vasoconstrictor, the plasma concentration of lidocaine delivered with the intraosseous injection is no more than that delivered with an infiltration. Therefore, the intraosseous technique should not be considered an intravascular injection. Additionally, if it were an intravascular injection, little or no anesthetic effect would be demonstrated. In conclusion, the same precautions for the maximum amount of lidocaine given for an infiltration injection would also apply to an intraosseous injection.

Postoperative discomfort

As a *primary and supplemental* technique with the Stabident system, the majority of patients report no pain or mild pain (77–82, 95). Approximately 2% to 15% will report a transient moderate pain postoperative (77–82, 95). Postoperative discomfort with the Stabident intraosseous injection is less than reported for the periodontal ligament injection (96).

Gallatin et al. (95) found significantly more males experienced postoperative pain with the X-tip system than with the Stabident system. They felt this was related to denser and more mineralized bone in the posterior mandible in males and the fact that the X-tip perforating system diameter is larger than the Stabident perforator resulting in generation of more frictional heat during perforation.

In patients with irreversible pulpitis, the postoperative pain of the endodontic procedure would likely mask any postoperative pain of the intraosseous injection.

Postoperative problems

For the Stabident system, less than 5% of patients will develop swelling and/or exudate at the site of perforations (77–82, 95). Gallatin et al. (95) found that the X-tip system may have a higher incidence of postoperative swelling clinically. With both systems, the swelling/exudate may be present for weeks after the injection but all resolve with time (77–82, 95). These slow healing perforation sites may be due to overheating of the bone caused by pressure during perforation.

With both the Stabident and X-tip systems, approximately 4–15% of patients will report that their

tooth 'feels high' when chewing for a few days (77–82, 95). This feeling is most likely an increased awareness to biting that results from soreness in the area caused by damage from perforation or inflammation of the bone. The incidence with the intraosseous injection is lower than reported with the periodontal ligament injection (36–49%) (96, 97).

Intrapulpal injection

In about 5–10% of mandibular posterior teeth with irreversible pulpitis, supplemental injections, even when repeated, do not produce profound anesthesia; pain persists when the pulp is entered. This is an indication for an intrapulpal injection.

Historically, this was a popular approach. The major drawback of the technique is that needle placement and injection are directly into a vital and very sensitive pulp; the injection may be moderately to severely painful (69). In the *Journal of Endodontics* (98), Miles, a dentally trained neurophysiologist needing endodontic treatment, reported intense pain when the intrapulpal injection was administered. While he reported it was successful, success was achieved at a price. Miles stated that there was decreased confidence in the endodontist and increased apprehension. Because we currently have more successful methods of supplemental anesthesia, the intrapulpal injection should only be given after all other supplemental techniques have failed. Another disadvantage of the technique is the duration of pulpal anesthesia may be short (15–20 min). Therefore, the bulk of the pulp must be removed quickly, at the correct working length, to prevent reoccurrence of pain during instrumentation. Another disadvantage is that, obviously, the pulp must be exposed to permit direct injection; frequently anesthetic problems occur prior to exposure while still in dentin.

The advantage of the intrapulpal injection is that it is quite predictable for profound anesthesia if given under back-pressure (99, 100). Onset will be immediate and no special syringes or needles are required. The methods for this technique can be found in many excellent endodontic textbooks. Strong-back pressure has been shown to be a major factor in producing anesthesia (99, 100). Depositing anesthetic passively into the chamber is not adequate; the solution will not diffuse throughout the pulp.

Clinical management of endodontic anesthesia

Irreversible pulpitis

The teeth most difficult to anesthetize (with irreversible pulpitis) are the mandibular molars followed by mandibular premolars, then maxillary molars and premolars, and then mandibular anteriors. The least problems are with maxillary anterior teeth.

In some teeth, irreversible pulpitis is the condition in the apical portion of the canals; the tissue in the chamber is necrotic and does not respond to pulp testing. Obviously, the pulp chamber is entered with no problem, but when attempting to place a file to length, severe pain results. Intraosseous injections will be helpful and an intrapulpal injection may be used. However, this condition of irreversible pulpitis must be differentiated from a symptomatic necrotic tooth with apical pathosis since, in this condition, intraosseous and intrapulpal injections may not be effective and there exists the possibility of forcing bacteria into the periradicular tissues. There are no clinical trials with symptomatic necrotic teeth.

Considerations for mandibular teeth with irreversible pulpitis

In the old days (1970–1980s), before supplemental injections (periodontal ligament and intraosseous injections), we would administer conventional anesthesia. After signs of soft tissue anesthesia were evident, the pain abated and the patient relaxed. Local anesthesia produced the classic soft tissue signs and relieved the painful symptoms. However, frequently when the access opening was begun or the pulp was entered, pain resulted. Currently, with supplemental techniques we have significantly reduced this pain during endodontic treatment.

Now after administering conventional anesthesia and observing signs of soft tissue anesthesia (soft tissue anesthesia is required for success of the supplemental injections), we will administer an intraosseous injection. Inform the patient that their tooth is not as numb as desired and therefore, a little extra anesthetic will be used to ensure their comfort. We will then inform the patient that this extra anesthetic is placed next to the tooth and that they may feel some discomfort during the injection.

We would recommend that the intraosseous injection

tion be administered with 1.8 mL of 3% mepivacaine plain (e.g. 3% Carbocaine). This recommendation is not based on the cardiovascular risks associated with a vasoconstricting-containing anesthetic solution, but is based on clinical research that 3% mepivacaine is reasonably effective and there is no clinical side-effects of an increased heart rate (68, 87). That is, a few patients may overreact to the heart rate increase with epinephrine-containing solutions, making treatment difficult or time consuming because the patient has to be calmed before endodontic treatment can begin. However, many endodontists also use 2% lidocaine with 1:100,000 epinephrine for intraosseous anesthesia. Each practitioner may want to experiment to see which anesthetic solution (3% mepivacaine or 2% lidocaine with epinephrine) works best in their hands.

Apply the rubber dam and slowly begin the access preparation. Inform the patient that the procedure will be discontinued if pain is experienced.

If the initial pain occurs in dentin, remove the rubber dam and administer another cartridge of 3% mepivacaine – this should be successful (68). Again, the clinician should ensure that the anesthetic solution is being deposited into medullary bone.

If the initial pain occurs when the *pulp is entered*, remove the rubber dam and administer another cartridge of 3% mepivacaine. If further pain is experienced, then give an intrapulpal injection.

Considerations for maxillary molar and premolar teeth with irreversible pulpitis

The initial anesthetic dose of 2% lidocaine with 1:100,000 epinephrine is doubled (3.6 mL) for the buccal infiltration (101). The injection site may also be a posterior superior alveolar block (PSA) for molars. A small amount may be administered palatally for the rubber dam retainer. Although anesthetic problems occur less frequently with maxillary molars and premolars, when compared to mandibular posterior teeth, the clinician should be aware that they do occur (69). Therefore, administering an intraosseous injection, before proceeding with access, may prove helpful in anesthetizing these teeth. An alternative approach would be to administer anesthesia, then pulp test the tooth with an electric pulp tester or cold refrigerant. If there is a negative response – proceed with access. If there is a positive response, administer

an intraosseous injection. Remember, in teeth with irreversible pulpitis, pulp testing (electric or cold) may not guarantee pulpal anesthesia (9, 23, 68, 69). Therefore, if a patient experiences pain after negative pulp testing, administer an intraosseous injection.

Duration of maxillary infiltration anesthesia is not as long as in the mandible (76, 90, 91, 101–103). Therefore, if pain is experienced during the later stages of instrumentation, an additional infiltration injection is necessary. Occasionally, pain is experienced with the palatal canal of molars. Infiltration over the palatal apex of 0.5 mL of anesthetic solution enhances pulpal anesthesia (104) and may prove helpful.

Considerations for maxillary anterior teeth with irreversible pulpitis

Anesthetic is administered initially as a labial infiltration. Palatal anesthesia may be necessary for the rubber dam retainer. Although supplemental anesthesia is not often necessary, when given, the intraosseous injection should be successful.

Duration of anesthesia may be less than 1 h (76, 90, 91, 101–103). An additional infiltration may be necessary if the patient experiences pain during the later stages of instrumentation.

Considerations for symptomatic teeth with total pulp necrosis and periradicular radiolucencies

This condition indicates pain of periradicular tissue. These teeth may be painful to manipulation and movement during treatment; therefore, extra care must be taken.

For the mandible, administer the inferior alveolar nerve block (and long buccal injection) in all situations. For maxillary teeth, with no swelling, administer anesthesia with conventional infiltration or block. If soft tissue swelling is present (cellulitis or abscess), infiltrate on either side of the swelling or administer a block (second division nerve block or infraorbital nerve block). Basically, these will provide some degree of bone and soft tissue anesthesia. After achieving signs of anesthesia, place the rubber dam and SLOWLY begin the access. Usually, the pulp chamber can be entered without discomfort, if the tooth is not torqued excessively. File placement and debridement

also can be performed without much pain if instruments are 'finessed'.

Occasionally, the conventional injections do not provide profound anesthesia—particularly in the maxillary teeth. Do not use intraosseous, periodontal ligament injections, or intrapulpal injections. While effective for teeth presenting with irreversible pulpitis, these injections would likely be painful and ineffective for symptomatic necrotic teeth with apical pathosis. Rather, explain to the patient that they do not have profound anesthesia due to the inflammation in the bone surrounding their tooth and utilize gentle file manipulation.

Considerations for asymptomatic teeth with total pulp necrosis and periradicular radiolucencies

Asymptomatic teeth with pulp necrosis are the easiest to anesthetize; patient comfort is usually attained without difficulty. Although, it may be tempting to proceed without anesthesia, pain may be experienced during instrumentation if anesthesia is not administered.

Administer the conventional injections: inferior alveolar nerve block and long buccal injection for mandibular teeth, and infiltration (or PSA block) injections in maxillary teeth. Proceed with access and file placement. Usually, the patient is comfortable. On rare occasions, there may be some discomfort during canal preparation requiring an intraosseous injection. Do not inject intrapulpally since bacteria and debris may be forced from the canal into the periradicular tissue. In the maxilla, an additional infiltration may be necessary if anesthesia begins to wear off.

References

1. American Dental Association. *ADA News* 1998; Nov: 4.
2. Weinstein P, Milgrom P, Kaufman E, Fiset L, Ramsay D. Patient perceptions of failure to achieve optimal local anesthesia. *Gen Dent* 1985; **3**: 218–220.
3. Kaufman E, Weinstein P, Milgrom P. Difficulties in achieving local anesthesia. *J Am Dent Assoc* 1984; **108**: 205–208.
4. Wallace J, Michanowicz A, Mundell R, Wilson E. A pilot study of the clinical problem of regionally anesthetizing the pulp of an acutely inflamed mandibular molar. *Oral Surg Oral Med Oral Pathol* 1985; **59**: 517–521.
5. Vreeland D, Reader A, Beck M, Meyers W, Weaver J. An evaluation of volumes and concentrations of lidocaine in human inferior alveolar nerve block. *J Endod* 1989; **15**: 6–12.
6. McLean C, Reader A, Beck M, Meyers WJ. An evaluation of 4% prilocaine and 3% mepivacaine compared with 2% lidocaine (1:100,000 epinephrine) for inferior alveolar nerve block. *J Endod* 1993; **19**: 146–150.
7. Chaney M, Kerby R, Reader A, Beck M, Meyers W, Weaver J. An evaluation of lidocaine hydrocarbonate compared with lidocaine hydrochloride for inferior alveolar nerve block. *Anesth Prog* 1992; **38**: 212–216.
8. Hinkley S, Reader A, Beck M, Meyers W. An evaluation of 4% prilocaine with 1:200,000 epinephrine and 2% mepivacaine with 1:20,000 levonordefrin compared with 2% lidocaine with 1:100,000 epinephrine for inferior alveolar nerve block. *Anesth Prog* 1991; **38**: 84–89.
9. Dreven L, Reader A, Beck M, Meyers W, Weaver J. An evaluation of an electric pulp tester as a measure of analgesia in human vital teeth. *J Endod* 1987; **13**: 233–238.
10. Certosimo A, Archer R. A clinical evaluation of the electric pulp tester as an indicator of local anesthesia. *Oper Dent* 1996; **21**: 25–30.
11. Hannan L, Reader A, Nist R, Beck M, Meyers WJ. The use of ultrasound for guiding needle placement for inferior alveolar nerve blocks. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; **87**: 658–665.
12. Wali M, Reader A, Beck M, Meyers W. Anesthetic efficacy of lidocaine and epinephrine in human inferior alveolar nerve blocks. *J Endod* 1988; **14**: 193 (Abstract).
13. Simon F, Reader A, Meyers W, Beck M, Nist R. Evaluation of a peripheral nerve stimulator in human mandibular anesthesia. *J Dent Res* 1990; **69**: 278 (Abstract).
14. Fernandez C, Reader A, Nist R, Beck M, Meyers W. Evaluation of bupivacaine in human mandibular anesthesia. *J Dent Res* 1991; **70**: 444 (Abstract).
15. Nusstein J, Reader A, Beck FM. Anesthetic efficacy of different volumes of lidocaine with epinephrine for inferior alveolar nerve blocks. *Gen Dent* 2002; **50**: 372–375.
16. Agren E, Danielsson K. Conduction block analgesia in the mandible. *Swed Dent J* 1981; **5**: 81–89.
17. Yared GM, Dagher BF. Evaluation of lidocaine in human inferior alveolar nerve block. *J Endod* 1997; **23**: 575–578.
18. Nist R, Reader A, Beck M, Meyers W. An evaluation of the incisive nerve block and combination inferior alveolar and incisive nerve blocks in mandibular anesthesia. *J Endod* 1992; **18**: 455–459.
19. Clark S, Reader A, Beck M, Meyers W. Anesthetic efficacy of the mylohyoid nerve block and combination inferior alveolar nerve block/mylohyoid nerve block. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; **87**: 557–563.
20. Goldberg S, Reader A, Beck M, Meyers W. Comparison of Gow-Gates and Akinosi techniques in human mandibular anesthesia. *J Endod* 1989; **15**: 173 (Abstract).
21. Yonchak T, Reader A, Beck M, Meyers WJ. Anesthetic efficacy of unilateral and bilateral inferior alveolar nerve blocks to determine cross innervation in anterior teeth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001; **92**: 132–135.
22. Dagher FB, Yared GM, Machtou P. An evaluation of 2% lidocaine with different concentrations of epinephrine for inferior alveolar nerve block. *J Endod* 1997; **23**: 178–180.
23. Cohen HP, Cha BY, Spangberg LSW. Endodontic anesthesia in mandibular molars: a clinical study. *J Endod* 1993; **19**: 370–373.

24. Weaver JM. Articaine, a new local anesthetic for American dentists: will it supersede lidocaine? *Anesth Prog* 1999; **46**: 111–112.
25. Malamed SF, Gagnon S, LeBlanc D. Articaine hydrochloride: a study of the safety of a new amide local anesthetic. *J Am Dent Assoc* 2001; **132**: 177–185.
26. Simon MA, Gielen MJ, Alberink N, Vree TB, van Eggmond J. Intravenous regional anesthesia with 0.5% articaine, 0.5% lidocaine, or 0.5% prilocaine. A double-blind randomized clinical study. *Reg Anesth* 1997; **76**: 29–34.
27. Hidding J, Khoury F. General complications in dental local anesthesia. *Zahnärztl Z* 1991; **46**: 834–836.
28. Malamed SF, Gagnon S, LeBlanc D. A comparison between articaine HCl and lidocaine HCl in pediatric dental patients. *Pediatr Dent* 2000; **22**: 307–311.
29. Haas DA, Harper DG, Saso MA, Young ER. Lack of differential effect by Ultracaine (articaine) and Citanest (prilocaine) in infiltration anesthesia. *J Can Dent Assoc* 1991; **57**: 217–223.
30. 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**: 230–237.
31. Vahatalo K, Antila H, Lehtinen R. Articaine and lidocaine for maxillary infiltration anesthesia. *Anesth Prog* 1993; **40**: 114–116.
32. 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**: 38–42.
33. Malamed SF, Gagnon S, Leblanc D. Efficacy of articaine: a new amide local anesthetic. *J Am Dent Assoc* 2000; **131**: 635–642.
34. Wyeth. *Wydate lyophilized hyaluronidase 150 units package insert*. Philadelphia: Wyeth Laboratories Inc., 2000.
35. Looby J, Kirby C. Use of hyaluronidase with local anesthetic agents in dentistry. *J Am Dent Assoc* 1949; **38**: 1–4.
36. Kirby C, Eckenhoff J, Looby J. The use of hyaluronidase with local anesthetic agents in nerve block and infiltration anesthesia. *Surgery* 1949; **25**: 101–103.
37. Ridenour S, Reader A, Beck M, Weaver J. Anesthetic efficacy of a combination of hyaluronidase and lidocaine with epinephrine in inferior alveolar nerve blocks. *Anesth Prog* 2001; **48**: 9–15.
38. Davis W, Oakley J, Smith E. Comparison of the effectiveness of etidocaine and lidocaine as local anesthetic agents during oral surgery. *Anesth Prog* 1984; **31**: 159–164.
39. Rosenquist J, Rosenquist K, Lee P. Comparison between lidocaine and bupivacaine as local anesthetics with diflunisal for postoperative pain control after lower third molar surgery. *Anesth Prog* 1988; **35**: 1–4.
40. Moore P, Dunsky J. Bupivacaine anesthesia – a clinical trial for endodontic therapy. *Oral Surg Oral Med Oral Pathol* 1983; **55**: 176–179.
41. Dunsky J, Moore P. Long-acting local anesthetics. A comparison of bupivacaine and etidocaine hydrochloride in endodontics. *J Endod* 1984; **10**: 457–460.
42. Linden E, Abrams H, Matheny J, Kaplan A, Kopczyk R, Jasper S. A comparison of postoperative pain experience following periodontal surgery using two local anesthetic agents. *J Periodontol* 1986; **57**: 637–642.
43. Crout R, Koraido G, Moore P. A clinical trial of long-acting local anesthetics for periodontal surgery. *Anesth Prog* 1990; **37**: 194–198.
44. Kennedy M, Reader A, Beck M, Weaver J. Anesthetic efficacy of ropivacaine in maxillary anterior infiltration. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001; **91**: 406–412.
45. Yonchak T, Reader A, Beck M, Clark K, Meyers WJ. Anesthetic efficacy of infiltrations in mandibular anterior teeth. *Anesth Prog* 2001; **48**: 55–60.
46. Clark K, Reader A, Beck M, Meyers WJ. Anesthetic efficacy of an infiltration in mandibular anterior teeth following an inferior alveolar nerve block. *Anesth Prog* 2002; **49**: 49–55.
47. Foster W, Reader A, Beck M. *Anesthetic efficacy of an additional labial or lingual infiltration after the inferior alveolar nerve block*. Ohio: The Ohio State University, 1992.
48. Gow-Gates GAE. Mandibular conduction anesthesia: a new technique using extra-oral landmarks. *Oral Surg Oral Med Oral Pathol* 1973; **36**: 321–330.
49. Akinosi J. A new approach to the mandibular nerve block. *Br J Oral Surg* 1977; **15**: 83–87.
50. Montagnese T, Reader A, Melfi R. A comparative study of the Gow-Gates technique and a standard technique for mandibular anesthesia. *J Endod* 1984; **10**: 158–163.
51. Joyce AP, Donnelly JC. Evaluation of the effectiveness and comfort of incisive nerve anesthesia given inside or outside the mental foramen. *J Endod* 1993; **19**: 409–411.
52. Rood JP. The nerve supply of the mandibular incisor region. *Br Dent J* 1977; **143**: 227–230.
53. Cooley R, Robison S. Comparative evaluation of the 30-gauge dental needle. *Oral Surg Oral Med Oral Pathol* 1979; **48**: 400–404.
54. Davidson M. Bevel-oriented mandibular injections: needle deflection can be beneficial. *Gen Dent* 1989; **37**: 410–412.
55. Hochman MN, Friedman MJ. *In vitro* study of needle deflection: a linear insertion technique versus a bidirectional rotation insertion technique. *Quintessence Int* 2000; **31**: 33–38.
56. Aldous J. Needle deflection. a factor in the administration of local anesthetics. *J Am Dent Assoc* 1968; **77**: 602–604.
57. Robison SF, Mayhew RB, Cowan RD, Hawley RJ. Comparative study of deflection characteristics and fragility of 25-, 27-, and 30-gauge short dental needles. *J Am Dent Assoc* 1984; **109**: 920–924.
58. Jeske AH, Boshart BF. Deflection of conventional versus nondeflecting dental needles in vitro. *Anesth Prog* 1985; **32**: 62–64.
59. Kennedy S, Reader A, Nusstein J, Beck M, Weaver J. The significance of needle deflection in success of the inferior alveolar nerve block in patients with irreversible pulpitis. *J Endod* 2002, in press.
60. Frommer J, Mele FA, Monroe CW. The possible role of the mylohyoid nerve in mandibular posterior tooth sensation. *J Am Dent Assoc* 1972; **85**: 113–117.
61. Wilson S, Johns P, Fuller P. The inferior alveolar and mylohyoid nerves: An anatomic study and relationship to local anesthesia of the anterior mandibular teeth. *J Am Dent Assoc* 1984; **108**: 350–352.
62. Berns JM, Sadove MS. Mandibular block injection: a method of study using an injected radiopaque material. *J Am Dent Assoc* 1962; **65**: 736–745.

63. Galbreath JC, Eklund MK. Tracing the course of the mandibular block injection. *Oral Surg Oral Med Oral Pathol* 1970; **30**: 571–582.
64. DeJong RH. Neural blockade by local anesthetics. *J Am Dent Assoc* 1997; **238**: 1383–1385.
65. Strichartz G. Molecular mechanisms of nerve block by local anesthetics. *Anesthesiology* 1967; **45**: 421–444.
66. Byers M, Taylor P, Khayat B, Kimberly C. Effects of injury and inflammation on pulpal and periapical nerves. *J Endod* 1990; **16**: 78–84.
67. Roy ML, Narahashi T. Differential properties of tetrodotoxin-sensitive and tetrodotoxin-resistant sodium channels in rat dorsal root ganglion neurons. *J Neurosci* 1992; **12**: 2104–2111.
68. Reisman D, Reader A, Nist R, Beck M, Weaver J. Anesthetic efficacy of the supplemental intraosseous injection of 3% mepivacaine in irreversible pulpitis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997; **84**: 676–682.
69. Nusstein J, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of the supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in irreversible pulpitis. *J Endod* 1998; **24**: 487–491.
70. Parente SA, Anderson RW, Herman WW, Kimbrough WF, Weller RN. Anesthetic efficacy of the supplemental intraosseous injection for teeth with irreversible pulpitis. *J Endod* 1998; **24**: 826–828.
71. Nusstein J, Kennedy S, Reader A, Beck M, Weaver J. Anesthetic efficacy of the X-tip intraosseous injection in patients with irreversible pulpitis. *J Endod* 2002; **28**: 238 (Abstract).
72. Walton R, Abbott B. Periodontal ligament injection: a clinical evaluation. *J Am Dent Assoc* 1981; **103**: 571–575.
73. Smith G, Walton R, Abbott B. Clinical evaluation of periodontal ligament anesthesia using a pressure syringe. *J Am Dent Assoc* 1983; **107**: 953–956.
74. White J, Reader A, Beck M, Meyers W. The periodontal ligament injection: a comparison of the efficacy in human maxillary and mandibular teeth. *J Endod* 1988; **14**: 508–514.
75. Childers M, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of the periodontal ligament injection after an inferior alveolar nerve block. *J Endod* 1996; **22**: 317–320.
76. Wood M. A comparison of the anesthetic efficacy of intraosseous and infiltration anesthesia. Master Thesis, 2001. The Ohio State University.
77. Coggins R, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of the intraosseous injection in maxillary and mandibular teeth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996; **81**: 634–641.
78. Dunbar D, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of the intraosseous injection after an inferior alveolar nerve block. *J Endod* 1996; **22**: 481–486.
79. Replogle K, Reader A, Nist R, Beck M, Weaver J, Meyers W. Anesthetic efficacy of the intraosseous injection of 2% lidocaine (1:100,000 epinephrine) and 3% mepivacaine in mandibular first molars. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997; **83**: 30–37.
80. Reitz J, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of the intraosseous injection of 0.9 ml of 2% lidocaine (1:100,000 epinephrine) to augment an inferior alveolar nerve block. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998; **86**: 516–523.
81. Guglielmo A, Reader A, Nist R, Beck M, Weaver J. Anesthetic efficacy and heart rate effects of the supplemental intraosseous injection of 2% mepivacaine with 1:20,000 levonordefrin. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; **87**: 284–293.
82. Reitz J, Reader A, Nist R, Beck M, Meyers W. Anesthetic efficacy of a repeated intraosseous injection given 30 min following an inferior alveolar nerve block/intraosseous injection. *Anesth Prog* 1999; **45**: 143–149.
83. Gallatin E, Stabile P, Reader A, Nist R, Beck M. Anesthetic efficacy and heart rate effects of the intraosseous injection of 3% mepivacaine after an inferior alveolar nerve block. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; **89**: 83–87.
84. Stabile P, Reader A, Gallatin E, Beck M, Weaver J. Anesthetic efficacy and heart rate effects of the intraosseous injection of 1.5% etidocaine (1:200,000 epinephrine) after an inferior alveolar nerve block. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; **89**: 407–411.
85. Gallatin J, Reader A, Nusstein J, Beck M, Weaver J. A comparison of two intraosseous anesthetic techniques in mandibular posterior teeth. *J Am Dent Assoc* 2003: in press.
86. Andersson C. Local anesthesia for infants undergoing circumcision. *JAMA* 1998; **279**: 1170–1171.
87. Replogle K, Reader A, Nist R, Beck M, Weaver J, Meyers W. Cardiovascular effects of intraosseous injections of 2 percent lidocaine with 1:100,000 epinephrine and 3 percent mepivacaine. *J Am Dent Assoc* 1999; **130**: 649–657.
88. Chamberlain TM, Davis RD, Murchison DF, Hansen SR, Richardson BW. Systemic effects of an intraosseous injection of 2% lidocaine with 1:100,000 epinephrine. *Gen Dent* 2000; **48**: 299–302.
89. Hull TE, Rothwell BR. Intraosseous anesthesia comparing lidocaine and etidocaine. *J Dent Res* 1998; **77**: 197 (Abstract).
90. Danielsson K, Evers H, Nordenram A. Long-acting local anesthetics in oral surgery: an experimental evaluation of bupivacaine and etidocaine for oral infiltration anesthesia. *Anesth Prog* 1985; **32**: 65–68.
91. Gross R, Reader A, Beck M, Meyers W. Anesthetic efficacy of lidocaine and bupivacaine in human maxillary infiltrations. *J Endod* 1988; **14**: 193 (Abstract).
92. Bacsik CJ, Swift JQ, Hargreaves KM. Toxic systemic reactions of bupivacaine and etidocaine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995; **79**: 18–23.
93. Ingle J, Bakland L. *Endodontics*, 5th edn, Hamilton, Ontario: BC Decker. 2002: 391.
94. Wood M, Reader A, Nusstein JM, Beck M, Padgett D, Weaver J. Venous blood concentrations of lidocaine after maxillary infiltration and intraosseous injection. *J Endod* 2002; **28**: 237 (Abstract).
95. Gallatin J, Nusstein J, Reader A, Beck M, Weaver J. A comparison of injection pain and postoperative pain of two intraosseous anesthetic techniques. *Anesth Prog* 2003: in press.
96. Schleder J, Reader A, Beck M, Meyers W. The periodontal ligament injection. A comparison of 2% lidocaine, 3% mepivacaine, and 1:100,000 epinephrine to 2% lidocaine

- with 1:100,000 epinephrine in human mandibular premolars. *J Endod* 1988; **14**: 397–404.
97. D'Souza J, Walton R, Peterson L. Periodontal ligament injection. An evaluation of extent of anesthesia and postinjection discomfort. *J Am Dent Assoc* 1987; **114**: 341–344.
98. Miles TS. Dental pain: self-observations by a neurophysiologist. *J Endod* 1993; **19**: 613–615.
99. Birchfield J, Rosenberg P. Role of the anesthetic solution in intrapulpal anesthesia. *J Endod* 1975; **1**: 26–27.
100. VanGheluwe J, Walton R. Intrapulpal injection – factors related to effectiveness. *Oral Surg Oral Med Oral Pathol* 1997; **19**: 38–40.
101. Mikesell A, Reader A, Beck M, Meyers W. Analgesic efficacy of volumes of lidocaine in human maxillary infiltration. *J Endod* 1987; **13**: 128 (Abstract).
102. Mason R, Reader A, Beck M, Meyers W. Comparison of epinephrine concentrations and mepivacaine in human maxillary anesthesia. *J Endod* 1989; **15**: 173 (Abstract).
103. Katz S, Reader A, Beck M, Meyers W. Anesthetic comparison of prilocaine and lidocaine in human maxillary infiltrations. *J Endod* 1989; **15**: 173 (Abstract).
104. Guglielmo A, Nist R, Reader A. Palatal and buccal infiltrations in maxillary first molar anesthesia. *J Dent Res* 1993; **72**: 274 (Abstract).