CHAPTER 2

Review of the literature

The review is divided into eight parts as follows:

2.1 Mechanisms of action of local anesthetics

2.2 Success rate of inferior alveolar nerve block

2.3 Causes of the local anesthetic failure

2.4 Pulpal anesthesia in the inflamed teeth

2.5 The ways to improve success rate of pulpal anesthesia in the inflamed teeth

2.6 Differences of pulp between the young and aged permanent teeth

2.7 Sensibility test

2.8 Anxiety and pain assessment in children

2.1 Mechanisms of action of local anesthetics

Local anesthetic works by inhibiting the passage of sodium ion in the nerve cell. There are two mechanisms that explain the blocking of sodium channel (34). First is the effect of a non-specific expansion of the nerve cell membrane, which cause physical obstruction of sodium channel. Second is the reversible binding of local anesthetic to the specific receptors in the sodium channel. This causes conformational change of sodium channel, then sodium ion is blocked.

When local anesthetic is in the solution form, it consists of charged and uncharged molecules. Only the uncharged molecules can penetrate the lipid nerve cell membrane into the cell because the uncharged molecules of anesthetic are fat-soluble. In the cell, these uncharged molecules re-equilibrate to the mixture of charged and uncharged molecules again. Only the charged molecules, which is important for anesthesia achievement, bind to the specific anesthetic binding sites in the cell (Figure 2.1).

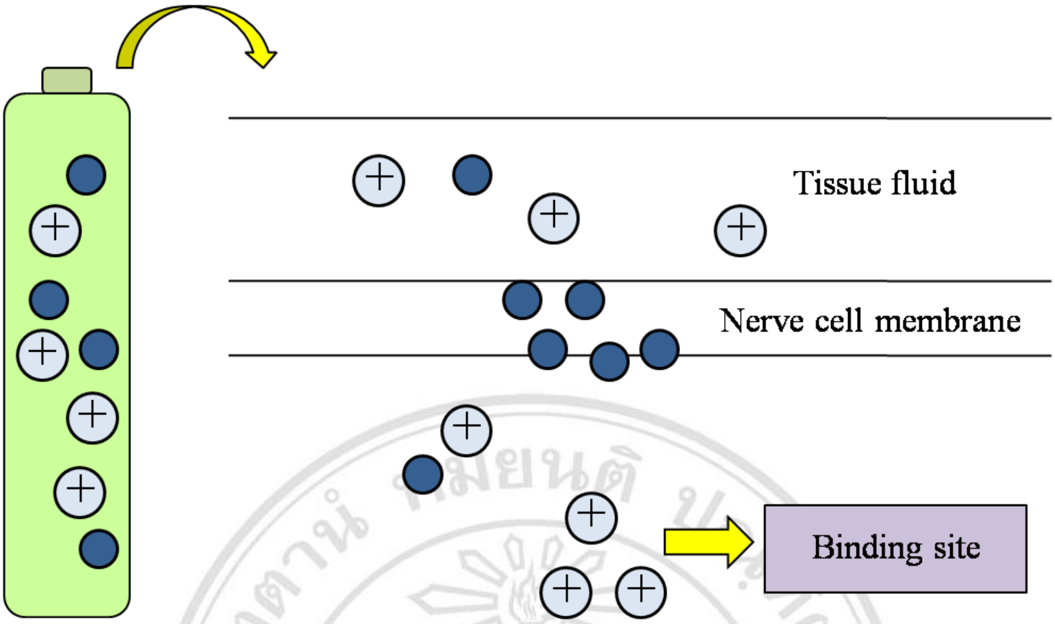

Figure 2.1 Mechanism of action of local anesthetics: Local anesthetics molecules are present in both charged and uncharged forms in solution. Only the uncharged form can cross the cell membrane. Then re-equilibrates to charged and uncharged form again. Only the charged form bind to the specific binding site. (Modified from Meechan(34))

2.2 Success rate of inferior alveolar nerve block

The success of inferior alveolar nerve block (IANB) involves two evaluations, including soft tissue and pulpal anesthetic testing. Soft tissue anesthesia is usually confirmed by asking the patient or using a sharp explorer to stick the soft tissue when pulpal anesthesia can be confirmed by using the sensibility test. Profound pulpal anesthesia is mandatory in operative or endodontic procedures and several studies confirmed that soft tissue anesthesia does not always indicate pulpal anesthesia (5-7).

Success of local anesthetic has been previously reported; however, its percentages varied. In their textbook, Reader and colleagues (35) have thoroughly reviewed the success of pulpal anesthesia and reported that anesthetic success ranged between 87-92% in maxillary teeth with infiltration technique and between 10-65% in mandibular teeth with IANB. These success rates are variable, depending on different factors, such as region of teeth (anterior or posterior teeth), anesthetic agent, concentration of vasoconstrictor, method of measurement of anesthetic success, and status of the pulp. Since the anesthetic success rate in mandibular teeth has been reported to be lower than that of the maxillary teeth, this review will focus on mandibular teeth, especially in posterior teeth.

The status of the pulp is one of major factors that can influence the anesthetic success. In teeth with normal pulp, the success rates of pulpal anesthesia in molar area following IANB have been reported to be between 32-90% (1-4). However, there are several researchers that were interested in anesthetic success of IANB in the teeth diagnosed as irreversible pulpitis of the patients older than 18 years old and their success rates have been reported to range from 10-75% (5-12) (Table 2.1). Therefore, it can be concluded that the success rate of pulpal anesthesia of the inflamed teeth tends to be lower than that of the normal teeth.

Table 2.1 Success rates of pulpal anesthesia by IANB in teeth with irreversible pulpitis

Years	Authors	Age	Success rates of pulpal anesthesia	Measure-ment
2004	Claffey et al. (5)	20-53	4% articaine (epi 1:100,000) = 24% 2% lidocaine (epi 1:100,000) = 23%	VAS
2009	Tortamano et al. (6)	18-50	4% articaine (epi 1:100,000) = 65% 2% lidocaine (epi 1:100,000) = 70%	EPT
2009	Matthews et al. (7)	18-71	2% lidocaine (epi 1:100,000) = 33%	VAS
2010	Parirokh et al. (9)	>18	2% lidocaine (epi 1:80,000) 1.8 ml success = 14.8% 3.6 ml success = 39.3%	VAS

Table 2.1 (Continued)

Years	Authors	Age	Success rates of pulpal anesthesia	Measurement
2011	Poorni et al. (8)	18-30	4% articaine (epi 1:100,000) = 75% 2% lidocaine (epi 1:100,000) = 69.2%	VAS
2012	Kanaa et al. (10)	18-66	2% lidocaine (epi 1:80,000) = 67%	EPT
2012	Khademi et al. (11)	18-50	2% lidocaine (epi 1:100,000) = 40%	VAS
2014	Monteiro et al. (12)	>18	2% lidocaine (epi 1:100,000) = 10%	EPT

2.3 Causes of the local anesthetic failure

Understanding the mechanism and causes of anesthetic failure is beneficial for the improvement of anesthetic success rate. There are two major factors associated with the local anesthetic failure, which are operator dependent and patient dependent factors.

The operator dependent factor includes a choice of anesthetic solution, the technique of local anesthesia administration, and an inadequate mouth opening. First discussion here will be on the choice of anesthetic solution. Nowadays, there are several types of anesthetic solution including short-acting and long-acting anesthetic solutions with or without vasoconstrictors. In 1999, Meechan (36) recommended that lidocaine with epinephrine is the gold standard anesthetic solution for majority of cases. Likewise, the technique of local anesthesia administration is also important. Poor technique, such as improper needle placement, can also cause anesthetic failure. Direct technique, which is also known as the Halstead approach, is the best way to achieve success with IANB. Direct technique is the technique which the operator's thumb is placed intra-orally at the deepest curve of the anterior ascending ramus and the index finger at the same height extra-orally on the posterior border of the ramus. The inserted point is mid-way between the thumb nail and the pterygomandibular raphe. Then, the needle is further inserted through this point being paralleled to the occlusal plane from the premolars of the contralateral side. The appropriate end point is reached between 15 and 25 mm of penetration (36). The inserted needle contacting bone too soon is the common cause of failure. To improve the success, syringe is swung across the mandibular teeth on the same side, then advanced 1 cm and returned to the original angle. Moreover, injecting more inferior to the mandibular foramen is another cause of failure from the needle placement. Injecting at a higher level may improve the success (36). Inadequate mouth opening is another cause of operator dependent failure. The target area for IANB is the mandibular sulcus which is at the level of coronoid notch and above the mandibular foramen. When the mouth opening is inadequate, the inferior alveolar nerve is relaxed and away from medial wall of the ramus which is far from the target area. Hence, inadequate anesthesia may occur (37).

Second factor relating to anesthetic failure is the patient dependent factor. It is important to have knowledge of anatomy in the injected area. Anatomic variation may be less problematic in maxillary teeth where local infiltration technique is mainly responsible for local anesthesia in this area. However, concern should be emphasized over the variation of anatomy in mandibular teeth anesthesia. There are two anatomical variations which often mentioned in literatures. First concern is the position of the mandibular foramen. Because inferior alveolar nerve enters mandible through the mandibular foramen, this foramen is the target site for the deposition of anesthetic solution in the standard IANB. However, position of mandibular foramen is highly variable especially in children because of their continuing craniofacial growth. There are several studies that demonstrated changes and differences in reference position of a mandibular foramen in children so the position of needle insertion for IANB should be concerned. Ashkenazi et al. (38) studied mandibular foramen position in the anteroposterior dimension of dry mandibles in primary, mixed, and permanent dentitions. They found that the mandibular foramen moves anteriorly and the gonial angle decreases with age. Furthermore, Kanno et al. (39) studied changing in the position of mandibular lingula, a reliable reference for IANB in 7-10 years old children.

They found that the distance between mandibular lingula and the occlusal plane increased in the older group; however, it was statistically significant only in the male group. From the result of their study, they suggested that the inferior alveolar anesthetic technique should be applied at least 6 mm above the occlusal plane in 7-8 years old children and 10 mm in 9-10 years old children. In conclusion, the mandibular foramen is located both anteriorly and inferiorly on the child mandible and undergoes a gradual dislocation until the adult stage. To date, controversies exist among researchers regarding the needle insertion position for the IANB in children; however, general recommendation is to perform the needle puncture as high as 10 mm above the occlusal plane in all age groups to achieve anesthesia (39).

Another anatomical variation related to IANB failure is accessory innervation of mandibular teeth. In general, the pulp of mandibular teeth is anesthetized by blocking inferior alveolar nerve. However, there are accessory innervations from several sources that can cause inadequate anesthesia. Aps (40) found that most of the subjects in his study had between 1-11 accessory canals and only 5.4% of them had none. He also assumed that these canals may contain several nerves such as mylohyoid nerve, lingual nerve and extra inferior alveolar nerve. Mylohyoid nerve, the nerve branch from the inferior alveolar nerve, is one of the most frequently mentioned in literatures to be the cause of IANB failure (13, 41). Wilson and colleagues (42) found that mylohyoid nerve branches from inferior alveolar nerve at the point approximately 14.7 mm. above the mandibular foramen. Likewise, Bennett and Townsend (43) also reported this distance in their study to be 13.4 mm. These distances may be adequately prevent the mylohyoid nerve from being blocked when the standard technique is used. There are several options to solve the failure caused by mylohyoid nerve innervation. First, block technique that deposits in higher position such as Gow-Gates technique is recommended. Second, infiltration technique on lingual surface of the operated tooth has also been suggested. Another option is to use the technique that can deposit anesthetic solution in space around the targeted tooth such as intraligamentary or intraosseous injection (13).

Moreover, position of the teeth can also affect the success rate of local anesthesia. Vreeland et al. (44) reported that failure rates of pulpal anesthesia of molars, canines and lateral incisors were 43-57%, 43-60%, and 57-80%, respectively. These results related with the study of Mikesell and colleagues (1) who reported that the failure rates of pulpal anesthesia of molars, premolars and incisors were 7-18%, 19-20% and 44-72%, respectively. Hence, it can be concluded that anterior teeth generally have lower success rate of pulpal anesthesia than the posterior teeth do. This may be explained by the central core theory. Vreeland et al. (44) referred to de Jong and Strichartz, who described the central core theory that the nerve fibers at the center of the nerve trunk supply the most remote targets and they are usually the finals to be anesthetized. Although the central core theory may elucidate why onset of anesthesia happens earlier in molars than in anterior teeth, it can not completely explain the causes of IANB failure.

Another important cause of patient dependent anesthetic failure is a pathological factor or known well as an inflammation condition. To emphasize this factor, it is separately described in the next topic.

Apart from anatomy and inflammation, psychological factors such as anxiety and fear are also important causes of local anesthetic failure. There are differences between anxiety and fear. Fear is defined as natural emotion based on the perception of a real threat, while anxiety is associated with fear-reactions towards a situation of an anticipated, but not realistic threat (45).

Feck and Goodchild (22) referred to Milgrom who stated that fear and the effectiveness of local anesthesia have a reciprocal relationship meaning that fear can cause inadequate anesthesia; vice versa, inadequate anesthesia can cause fear. Anxious patients have lower pain threshold compared to the patients without anxiety. van Wijk and Makkes (46) found that the highly anxious dental patients indicated more pain during dental injection than the normal patients did. Similarly, Kuscu and Akyuz (47) and Nakai et al. (48) confirmed that anxiety plays an important role in the pain perception of children. Children who have higher anxiety levels reported more severe pain during local anesthetic administration than children with lower anxiety levels did. Moreover, Okawa et al. (49) reported that patients felt stronger pain if anxiety in the treatment environment was high. They recommended that the operators should reduce anxiety of patients during treatment to reduce pain. Furthermore, Eli and Svensson (50) described that apprehensive patients, who learn the pain response from past experience, can create an expectation of pain after effective local anesthesia although they experience only pressure or touch.

2.4 Pulpal anesthesia in the inflamed teeth

Bacteria in dental caries is the major cause of dental pulp injury. To respond to bacteria and their products penetrating via dentinal tubules into the pulp, inflammatory and immunologic reactions occur. Bruno and colleagues (51) reviewed and concluded that the inflammatory reaction composes of non-specific and immediate defense mechanism. They involve vascular-exudative phenomena including vasodilatation and increased permeability, as well as infiltration of inflammatory cells such as mast cells, neutrophils, and macrophages. Additionally, the teeth diagnosed as irreversible pulpitis have more inflammatory cells such as T helper lymphocyte, memory lymphocyte, macrophage and B lymphocyte than the healthy teeth do.

Gibbs and Hargreaves (52) concluded that teeth with symptomatic pulpitis has an acute inflammation and usually results in three unique characteristics. First is allodynia, a decreased threshold of pain allowing an innocuous stimulus to stimulate and produce pain. Second is hyperalgesia, an enhanced response to a frankly noxious stimulus. The last characteristic is spontaneous pain. Nusstein et al. (53) called a pulp that has been diagnosed with irreversible pulpitis, with spontaneous, moderate-to-severe pain as “hot tooth”.

There are many studies reporting variable successes of pulpal anesthesia provided by IANB in patients with irreversible pulpitis. The success rates in those studies ranged from 10-75% (5-12) (Table 2.1). Tortamano et al. (6) used EPT to test pulpal anesthesia in patients with irreversible pulpitis after lip anesthesia was reported and demonstrated that only 65% of the articaine group and 70% of the lidocaine group exhibited pulpal anesthesia by having two consecutive negative responses to the pulp stimulus with EPT. However, 35% of the patients in the articaine group and 55% in the lidocaine group still reported pain during treatment. Moreover, Modaresi et al. (54) reported that the inflamed pulp has more resistance to local anesthesia than the normal pulp does. Dreven et al. (55) studied the success rate of pulpal anesthesia in both maxillary and mandibular teeth. They found that patients with normal or asymptomatic teeth did not experience pain but 27% of patients with irreversible pulpitis still experienced pain during endodontic therapy although they did not respond to EPT pre-operatively. These results showed that the negative response to sensibility test can not guarantee the complete pulpal anesthesia during the treatment.

There are several explanations of why it is more difficult to achieve profound anesthesia in the teeth with inflamed pulp tissue compared to the teeth with normal pulp. One is the effect of inflammation on nociceptors. Hargreaves and Keiser (13) described in their review that in normal pulp, the nociceptors are in quiescence state until there are stimuli which is strong enough to damage the tissue; then, the nociceptors will be activated. Whilst, nociceptors of inflamed pulp are activated by inflammatory mediators such as bradykinin and prostaglandin E_2 which reduce the threshold for firing to the point that gentle stimuli can now activate these neurons. Additionally, inflammatory mediators including certain growth factors alter the structural properties of these neurons. Byers et al. (56) found the terminal of peripheral nerves sprout in the areas of inflammation in dental pulp and periradicular tissue, consequently the size of their receptive field is increased and pain neurons are more easily activated by stimuli. Moreover, tissue injury may alter the composition, distribution or activity of sodium channels expressed on nociceptors. Sodium channels have nine subtypes of voltage-gated sodium channels (VGSCs). Some VGSCs are blocked by tetrodotoxin (TTX) but some VGSCs are resistant to the toxin (TTX-R). Nav1.8 and Nav1.9 are the only two subtypes of VGSCs which are TTX-R. Because TTX-R is expressed on nociceptors under normal conditions and their activities are more than double after being exposed to prostaglandin E_2, local anesthetic failures may occur in inflamed condition (52).

Secondly, because an inflammation induces tissue acidosis, local anesthetic distribution to uncharged form is poor. Hence charged form has a greater proportion. This situation is called ion trapping. Uncharged or base form of local anesthesia, which can cross cell membrane, is reduced. This also affects the local anesthetic distribution to acid or charged form inside the cell. The charged form blocking sodium channel to achieve anesthesia is also reduced resulting in local anesthetic failure. Because of decrease in tissue pH in localized tissue inflammation, this lower pH in the area may explain the inefficient anesthesia by infiltration technique but may not be able to explain local anesthetic failures by nerve block technique (13). Another explanation of anesthetic failure in inflamed tooth is an effect of inflammation on blood flow. Hargreaves and Keiser (13) referred to Vandermeulen, who concluded that inflammatory mediators induce peripheral vasodilation thus increasing the rate of systemic absorption leading to reduction in the concentration of local anesthesia.

The last explanation for anesthetic failure in inflamed tooth is an effect of inflammation on central sensitization. Inflammation alters the central nervous system's pain processing system. Central sensitization is the enhanced excitability of central neurons and is believed to be a main central mechanism of hyperalgesia and allodynia (57). Under the central sensitization condition, an intensified CNS respond to even only slight peripheral stimuli. Central sensitization can explain not only endodontic pain mechanism but also local anesthetic failures. Under normal conditions, most of the nerve fibers (approximately 90%) are blocked by local anesthesia and may result in clinical success. While under central sensitization condition, there is an overresponse to peripheral stimuli and, under these conditions, the same 90% block may allow the signaling to occur, leading to the perception of pain. Thus, central sensitization may be another factor that contributes to local anesthetic failures.

Success rates of local anesthesia in the inflamed pulp were mostly studied in the teeth diagnosed as irreversible pulpitis (Table 2.1), despite the teeth which have deep caries with normal pulp or reversible pulpitis may also have pulp inflammation. Hahn and Liewehr (58) reviewed and concluded that caries bacteria are major cause of pulpal inflammation and infection because bacteria by product can diffuse through the dentinal tubules and then activate immune response in the pulp. Khabbaz et al. (27) found that endotoxins, which are bacterial by product, can be found not only in the teeth with symptomatic irreversible pulpitis but also asymptomatic teeth with deep caries that have at least 0.5 mm of remaining dentin thickness. Moreover, Hahn and Liewehr (58) referred to Reeves and Izumi who reported that inflammatory cells in pulps can be found in the teeth with deep caries which have less than 1.5 mm of the remaining dentin thickness. Therefore, besides irreversible pulpitis, inflammation may also alter success rates of local anesthesia in the teeth with deep caries which diagnosed as normal pulp or reversible pulpitis.

2.5 The ways to improve success rate of pulpal anesthesia in the inflamed teeth

Several studies have been carried out to improve pulpal anesthetic success of inflamed teeth in many different ways, including changing the local anesthetic agents, increasing the volume of the solution, using the supplemental injections, and using the adjuvant drugs.

2.5.1 Changing the local anesthetic agents

There have been several studies that were interested in finding the most effective local anesthetic agent for pulpal anesthesia. Lidocaine has been used as the gold standard anesthetic agent for comparison of other agents. Its anesthetic successes in the teeth with irreversible pulpitis were quite low and reported to be between 10-70% (5-12). Thus, many studies have tried to use other anesthetic agents to enhance anesthetic success particularly in the teeth with irreversible pulpitis. One of them was 4% articaine with 1:100,000 epinephrine, which is often compared to 2% lidocaine with 1:100,000 epinephrine in literatures. However, different researchers have reported conflicting results.

In normal teeth, Mikesell et al. (1) and Haase et al. (59) found no significant difference between the efficacy of 4% articaine with 1:100,000 epinephrine and 2% lidocaine with 1:100,000 epinephrine. In contrast, the studies of Kanaa et al. (60) and Robertson et al. (61) showed that the success rates of 4% articaine with 1:100,000 epinephrine were significant higher than 2% lidocaine with 1:100,000 epinephrine. The success of 4% articaine with 1:100,000 epinephrine and 2% lidocaine with 1:100,000 epinephrine were 64% versus 39% in the study of Kanaa et al. (60), and were 87% versus 57% in the study of Robertson et al. (61).

The conflicting results not only occur in the normal teeth but also in the inflamed teeth. Srinivasan and colleagues (14) used the Visual Analogue Scale (VAS) to measure the pulpal anesthetic success of maxillary buccal infiltration in premolars and molars with irreversible pulpitis and reported that the pulpal anesthetic successes of 4% articaine with 1:100,000 epinephrine were 100% in both premolars or molars and the successes of 2% lidocaine with 1:100,000 epinephrine were 80% in premolars, but only 31% in molars. They also concluded that 4% articaine with 1:100,000 epinephrine had the higher success rates than that of 2% lidocaine with 1:100,000 epinephrine. On the other hand, Claffey et al. (5) and Tortamano et al. (6) reported that there was no significant difference between 4% articaine with 1:100,000 epinephrine and 2% lidocaine with 1:100,000 epinephrine in the teeth diagnosed as irreversible pulpitis. In the meta-analysis, Brandt et al. (62) found that articaine was superior to lidocaine when administered in healthy teeth but no significance was found in symptomatic teeth.

Although some studies reported that 4% articaine with 1:100,000 epinephrine and 2% lidocaine with 1:100,000 epinephrine had no significant difference in pulpal anesthetic success, 4% articaine with 1:100,000 epinephrine tended to have higher success rates than 2% lidocaine with 1:100,000 epinephrine in both the normal and inflamed teeth (1, 5, 6, 8, 59).

Yapp et al. (63) concluded in their review that articaine has two unique properties relating to its molecular structure that makes it an attractive local anesthetic for clinical use. Firstly, it contains a thiophene group when other amide local anesthetics contain the benzene ring. This property makes it more potent, more lipid-soluble, and more easily diffuses through soft tissue and bone compared to other local anesthetics. Therefore, articaine may increase success rate of local anesthesia. Secondly, articaine is the only amide anesthetic containing an ester group, which allows it to be rapidly broken down into its inactive state; thus, articaine may decrease risk of systemic toxicity. Because of its excellent properties, articaine has become a good option for the anesthesia in both healthy and inflamed teeth.

Because of its excellent diffusion through soft tissue and bone, articaine is often chosen for both primary and supplemental buccal infiltrations with high success rates of pulpal anesthesia reported. Monteiro et al. (12) compared success rates of pulpal anesthesia with primary injection between using buccal infiltration with 4% articaine with 1:100,000 epinephrine and IANB with 2% lidocaine with 1:100,000 epinephrine in mandibular molar diagnosed as irreversible pulpitis. They found that buccal infiltration with 4% articaine with 1:100,000 epinephrine had higher success rate of pulpal anesthesia compared to IANB with 2% lidocaine with 1:100,000 epinephrine. The successes were 40% versus 10%, respectively. Moreover, buccal infiltration with 4% articaine can be used as a supplemental anesthetic technique after IANB failure and this will be further described in the topic 2.5.3.

Although articaine has become increasingly popular for adult dentistry, concerns of its use in children should be kept in mind. The manufacturer does not recommend the use of articaine in children younger than 4 years old; however, Wright and colleagues (64) showed the results of their retrospective study that articaine can be used in children younger than 4 years old without any adverse effects. Moreover, Leith et al. (65) gathered results from several studies that had used articaine in children. Although the most frequent adverse event was prolonged numbness that may cause anxiety in children, the serious adverse reactions have never been reported. As a result of the good anesthetic properties and safety of articaine, it was preferred in this study.

2.5.2 Increasing the volume of the anesthetic solution

Increasing the volume of anesthetic solution has been proposed to solve the problems of anesthetic failures. Aggarwal et al. (15) recommended that increasing the volume of 2% lidocaine with 1:200,000 epinephrine to 3.6 ml can improve the success rate of pulpal anesthesia as compared with that of 1.8 ml. They showed that 1.8 ml and 3.6 ml gave IANB success rates of 26% and 54%, respectively. On the other hand, Parirokh et al. (9) compared anesthetic volume of 2% lidocaine with 1:80,000 epinephrine between 1.8 ml and 3.6 ml in the teeth with irreversible pulpitis and found no significant difference between these groups. The success rates of pulpal anesthesia in their study by using 1.8 ml and 3.6 ml were 14.8% and 39.3% respectively. Similarly, Fowler and Reader (16) also found that there was no significant difference of anesthetic success rates between 1.8 ml and 3.6 ml of 2% lidocaine with 1:100,000 epinephrine. Although several studies have shown no significant differences of success rates between different volume of anesthetic use, a trend of higher pulpal anesthesia exists when the volume was increased.

2.5.3 Using the supplemental injections

After local anesthetic failure occurs, supplemental injection techniques, including intraosseous injection, intraligamentary injection, intrapulpal, and buccal infiltration with 4% articaine, have been recommended in literatures.

Intraosseous injection

Intraosseous injection is a technique that local anesthetic solution is directly deposited into the cancellous bone surrounding the tooth (53). In this technique, the bony perforation is required for the penetration of the needle into the cancellous bone. The point of bony perforation should lie in the attached gingiva distal to the treated tooth, 2 mm apical to the gingival margin. Then, the short (8 mm) 27 gauge needle is advanced through the perforation into the cancellous bone and approximately 1 ml of anesthetic solution is administered slowly (over a 2 minutes period) (19). This technique anesthetizes the target teeth and will also anesthetize the adjacent teeth in most of the cases (66). Nowadays, there are several specialized equipments, such as Stabident (Fairfax Dental Inc., Miami, NA, USA), X-Tip (Dentsply Inc., York, PA, USA) or Quicksleeper S4 (Dental HiTec, France) (67, 68), for the use of this technique.

The onset of anesthesia after the intraosseous injection is rapid, ranging from 10 to 120 seconds (34). Moreover, the duration of this technique is 60 minutes when used with a local anesthetic with a vasoconstrictor and approximately 15 to 30 minutes when used with a local anesthetic without a vasoconstrictor (66).

Although intraosseous injection technique effectively enhances the anesthetic success of the irreversible pulpitis teeth following the failure of IANB (10, 67), this supplemental technique has several disadvantages. Firstly, it can create pain during the perforation as well as after the procedure. Reisman and Reader (69) showed that 27% of patients reported moderate pain and 6% reported severe pain during administration of the intraosseous injection. Moreover, they found swelling, bruising or purulence that healed within two weeks. In contrast, Dunbar and colleagues (3) showed that intraosseous injection resulted in low pain rating during needle insertion, perforation, and solution deposition. Another disadvantages of intraosseous injection is that patients may report that their teeth feel “high” for a few days after this type of injection (3). Additionally, intraosseous injection is not recommended to use in patients with primary and mixed dentition due to potential for damage of developing permanent teeth (70).

Intraligamentary injection

Intraligamentary (IL) injection or periodontal ligament injection is one of the supplemental technique which the anesthetic solution is injected via the periodontal ligament. Although the solution is deposited into the coronal segment of the periodontal ligament, the anesthetic is not forced down the periodontal ligament space to the tooth apex but instead is redirected into the surrounding cancellous bone through the fenestrations in the dental socket (19). Therefore, this technique is considered to be one form of the intraosseous anesthesia.

In this technique, Meechan (34) suggested that the needle is inserted at the mesiobuccal and distobuccal aspects of the root at 30 degrees to the long axis of the tooth. The needle is then advanced until it is wedged between the tooth and the alveolar crest. Then, 0.2 ml of the anesthetic solution is deposited. The injection time is approximately 20 seconds for 0.2 ml of solution, which means that the injection is very slow (71). To ensure that the solution is being forced into the tissue, Walton and Abbott (72) recommended that the strong back-pressure to the injection should be felt. They defined that the strong back-pressure occurs when the rubber stopper moves slightly in the cartridge of the syringe when the operator is pushing on the syringe handle with maximum force. Moreover, they showed that the injection was significantly more effective when the back-pressure is present. Thus, back-pressure is an important factor for this technique. Smith and Walton (73) reported that the solution injected is distributed into the adjacent soft and hard tissue structures next to the injected tooth. The distribution was consistently more wide spread when the injection was administered using moderate to strong pressure. Since it may be difficult in applying pressure using the conventional syringe, there are special syringes for IL injection, such as Ergoject syringe (Anthogyr, USA), SOPIRA Citoject (Heraeus Kulzer, Germany), which give adequate pressure to force the anesthetic solution into the tissue. Moreover, the computer controlled local anesthesia delivery (C-CLAD) for IL injection, such as Wand, Wand Plus, and CompuDent, could also be found in the market (74). However, several studies (75, 76) found no difference of anesthetic success rates of IL injection between the special and conventional syringes. When using the specialized syringe, Meechan (19) referred to Roberts & Rosenbaum who suggested that it is important that the needle should be maintained in the sulcus for 5-10 seconds after activation of the lever to prevent the leakage of anesthetic solution into the oral environment.

The other two factors that also affect the effectiveness of IL injection are diameter and orientation of the needle. Because the sulcus between tooth and alveolar bone is extremely small, Endo and colleagues (71) recommended that the injection needle used for IL injection must have an external diameter no larger than 0.3 mm or 30-gauge. On the other hand, Malamed (75) observed that many of the 30-gauge needles were bended upon insertion into the gingival sulcus while there were no incidences of needle bending with 25- and 27- gauge short needles. Thus, he suggested the 25- and 27- gauge short needles, a length between 12 and 16 mm, for this technique. Moreover, some authors agreed that the success of pulpal anesthesia is independent from the needle gauge (73). Another controversy regarding the IL injection is the bevel orientation of the needle. Walton and Abbott (72) suggested that the bevel of the needle should be directed away from the tooth and toward the crestal bone. Nevertheless, Malamed (77) suggested that the bevel orientation is not significant to the success of this technique and further recommended that the bevel of needle should be oriented toward the root surface to permit easy advancement of the needle in the apical direction.

IL injection technique is often used after the failure of the standard technique because of its several advantages. Firstly, the IL injection has immediate to rapid onset. Walton and Abbott (72) studied the onset of IL injection in 120 patients. They divided the onset of the injection in to three groups; immediate onset which occured in less than 5 seconds, rapid onset which occured within 5 to 15 seconds, and long onset which occured in more than 15 seconds. They found that 73% of the patients had the immediate onset, 20% of them had the rapid onset, and only 7% of them had the long onset. This study showed that the onset of IL injection generally takes off within 30 seconds conforming with other recommendations (19, 77). Secondly, IL injection can effectively increase success of pulpal anesthesia. The success rates of supplemental IL injection were between 48-70% in the teeth diagnosed as irreversible pulpitis (10, 67). Another advantage of IL injection is that it could be administered under rubber dam isolation making it convenient as well as decreasing contamination during the pulp treatment (71).

Nonetheless, there are several disadvantages of the IL injection. The first disadvantage is its relatively short duration of pulpal anesthesia which only lasts for 30-45 minutes (75). Secondly, it can produce peri and post injection discomfort, including pain during administration of the injection, tenderness at the injection site after treatment and a subjective sensation that the tooth is elevated in the occlusion or “high” after treatment (19, 75). Nusstein and colleagues (78) reported that IL injection produced moderate to severe postoperative pain in 31% of subjects using 4% articaine with 1:100,000 epinephrine and 20% of subjects using 2% lidocaine with 1:100,000 epinephrine. However, Endo et al. (71) stated that this technique had less injection pain. They referred to Dirnbacher who compared three anesthetic techniques; IL injection, infiltration and nerve block anesthesia and found only 6.4% of injection pain in the IL injection group, the lowest percentages in these three groups. Thirdly, IL injection in primary dentition may associate with enamel hypoplasia in permanent teeth. Brannstrom et al. (79) studied IL injection in 16 primary teeth in monkeys and found that 15 permanent teeth had enamel hypoplasia. Additionally, they suggested that IL injection should be carefully used on primary teeth close to developing permanent teeth. However, such effects have never been reported in humans. Moreover, producing bacteraemia and damaging the injection equipment are other disadvantages of the IL injection (19).

Intrapulpal injection

Intrapulpal injection is the anesthetic technique that anesthetic solution is directly deposited into the pulp tissue. Around 0.2 ml of solution is used for this technique. The key to success of the intrapulpal injection is that it must be delivered under pressure. Attempting the tight fit of the needle at the exposure site is highly recommended before administering the anesthetic solution (34). Nusstein et al. (53) reviewed and found that onset of anesthesia with this technique is immediate and the duration was only 15-20 minutes. Moreover, they claimed that supplemental injections, including the intraosseous or IL, do not produce profound anesthesia in 5% to 10% of mandibular teeth with irreversible pulpitis. Hence, intrapulpal injection technique is suggested for supplemental injection in this regard. However, it can not be used in the teeth without pulp exposure.

Mandibular buccal infiltration injection

Using the buccal infiltration as a supplemental technique has been reported in several studies. Because the use of articaine was found to be superior to lidocaine in asymptomatic patients (88% versus 71%) (59), 4% articaine with 1:100,000 epinephrine is often selected for this supplemental technique in literatures.

Matthews and colleagues (7) showed the success rates of supplemental buccal infitration with 4% articaine with epinephrine 1:100,000 after failing from IANB to be 58%. Furthermore, Kanaa and colleagues (18) found that when buccal infiltration with 4% articaine with 1:100,000 epinephrine was added following the IANB, pulpal anesthetic success increased from 55.6% to 91.7%. However, they did not study in the inflamed teeth in their study. Moreover, Fan and colleagues (17) showed pulpal anesthetic success rates of 81.48 when adding 4% articaine 1:100,000 epinephrine buccal infiltration to IANB. In that same study, they also reported 83.33% success rates of pulpal anesthesia by IANB plus IL injection and also concluded that there was no significant difference of successes between these two supplemental techniques.

There are several studies comparing anesthetic successes between different supplemental techniques in the teeth diagnosed as irreversible pulpitis. Zarei and colleagues (67) compared the efficacies of supplemental anesthesia using IL and intraosseous injections after IANB failure. They found that pulpal anesthetic success was obtained in 100% of intraosseous injections and 70% of IL group in the first added injection. Furthermore, Kanaa et al. (10) compared four different supplemental techniques including 4% articaine buccal infiltration (ABI); repeat lidocaine IANB (rIANB); intraligamentary injection (IL); and intraosseous injection (IO). They found that ABI and IO allowed more pain-free treatment (84% and 68% of pulpal anesthetic success, respectively) compared to rIANB or IL techniques (32% and 48% of pulpal anesthetic success, respectively). Obviously, all of these pulpal anesthetic success rates were entirely performed in patients who were older than 18 years of age. Theoretically, children who have lower condense cortical bone (80) allowing easier penetration of anesthetic solution into the cancellous bone may have higher pulpal anesthetic success rate compared to that of adult patients. However, there have been no studies that confirms this hypothesis.

2.5.4 Using the adjuvant drugs

Many researchers have been searching for the method to increase the pulpal anesthetic success of teeth diagnosed as irreversible pulpitis. Using pre-emptive drug is another interesting method that may possibly improve the anesthetic success. The analgesic drugs, such as acetaminophen, ibuprofen, and indomethacin, were used in the previous studies (23-25). Parirokh and colleagues (24) found that patients with inflamed pulp, who received the premedication with ibuprofen or indomethacin, had significantly higher success rates than that of the control group. On the other hand, Simpson et al. (25) and Ianiro et al. (23) showed that there was no significant difference of pulpal anesthetic successes between the premedication of ibuprofen combined with acetaminophen and the placebo control groups. However, they concluded that there was a trend toward higher success in the premedication groups.

Because psychological factors can reduce local anesthesia efficacy as previously mentioned, anxiolytic drugs, such as benzodiazepine, have been used to improve the anesthetic success in several studies (11, 22). Khademi and colleagues (11) showed that preoperative oral administration of 0.5 mg of alprazolam did not significantly improve the success of IANB in mandibular molars in patients with irreversible pulpitis.

Besides preemptive drugs, using nitrous oxide (N_2O) inhalation sedation during the operation can be found in the recent literature. Stanley and colleagues (26) found that using N_2O/O_2 inhalation sedation can significantly increase the success of the IANB in patients with irreversible pulpitis.

2.6 Differences of pulp between the young and aged permanent teeth

From literature reviews, there is no clear definition of young permanent teeth. However, the differences of pulp between the young and aged permanent teeth have been reported. In their studies, Bernick (28) and Bernick and Nedelman (28, 29) defined aged pulp to be the pulp of individuals who were older than 40 years old and young pulp to be the pulp of individuals who were younger than 40 years old. They also reported the difference of histological characteristics between the aged and young pulps. In young pulp of permanent teeth, it consists of loose connective tissue, rich blood vessels and nerves, which form an extensive network in the pulp. Moreover, blood vessels and nerves branch toward occlusal surface and reach the pulpal horn, where a rich subodontoblastic plexus is formed. Unlike individuals who are older than 40 years old, the number of blood vessels supplying the coronal pulp decreases. Moreover, they exhibited 90% of calcification concomitant with decreasing number of demonstrable nerve fibers, especially in the odontoblastic zone and pulpal horn. So decrease in sensitivity of teeth may occur in the aged pulp group. In contrast, there was no histologic evidence of pulpal calcification in the root or crown but richness of nerve fibers in young permanent teeth. Furthermore, Tranasi et al. (81) confirmed that the vitality of the pulp dentinal complex decreased with aging as shown by the low expression of genes encoding for transcription regulators and the high expression of genes involving in apoptotic processes. Likewise, Ikawa et al. (30) reported that pulpal blood flow is decreased in aged pulp. Moreover, aged pulp has a smaller pulp chamber than the young pulp does. Morse et al. (31) described that decrease in size of pulp chamber is caused by the physiological dentinogenesis throughout life of odontoblasts. In addition, increasing in the apical deposition of secondary dentin and cementum causes the constriction of the originally wide-open root apex of aged teeth, compromising the pulpal circulation and innervation. Johnsen et al. (32) found that the pulps in older teeth are less heavily innervated than the younger teeth are. Michaelson and Holland (33) assumed that young teeth with heavily innervation would be extremely sensitive and only minor injury and inflammation would affect their responses.

Because there are many differences between young and aged teeth, pulpal responses of these teeth may also be different. Most studies regarding pulpal anesthetic success were studied mostly in permanent teeth of subjects who are older than 18 years of age (Table 2.1). Currently, there is only one study regarding anesthetic success rate in young permanent teeth. Sixou and Barbosa-Rogier (82) studied anesthetic success of intraosseous injection as a primary technique in permanent teeth of patients who are younger than 16 years old. They showed that the success rates were 92.3% for endodontic and 89.9% for restorative procedures.

Nakai and colleagues (48) demonstrated the factors that affect the effectiveness of local anesthesia in 26 to 155 months of age children. They suggested that anxious children, children with symptomatic teeth, and children experienced more invasive procedures were more likely to face inadequate pain control. However, this study did not clearly identify the difference in local anesthetic success between the group of primary and permanent teeth.

The stage of root development may be another factor that associates with pulpal anesthetic success in young permanent teeth. The anesthetic solution from buccal infiltration, intraosseous injection and IL injection, may be easier to enter through the wide-open root apex than through the narrow-apex of the complete root formation. However, there have not yet been the studies that support this hypothesis.

2.7 Sensibility test

In the area of pulp testing, there are two of the most confusing terms, vitality and sensibility tests, that are sometimes used interchangeably. Understanding the exact meaning of both terminologies leads to the correct interpretation of the tests. Vitality is referred to the blood supply presenting in the pulp. To date, there are several types of the pulp vitality tests (83). Each pulp vitality test has different mechanism of action. Laser doppler flowmetry measures the velocity of red blood cell moving in the pulp by laser. Pulse oximetry and dual-wavelength spectrophotometry are the other pulp vitality tests, that also measure oxygen saturation of artery in the pulp. Additionally, thermography measures the surface temperature of the tooth based on the principle that the vital and non-vital teeth have different surface temperatures. In vital teeth, heat is produced from external environment and pulpal circulation while in non-vital teeth, heat derives from only external source. Although these tests are designed to test the vascular supply which directly indicates the vitality of the tested tooth, several limitations make them mostly currently employed in research environment. The routine use in clinical practice is under the ongoing developing process.

On the other hand, sensibility is referred to the test of function of nerve fiber in the pulp. The methods for pulp sensibility testing include thermal test and electrical stimulation. Because of the limitations of vitality test in clinical practice, the vitality is usually assumed when there is a nerve response and the sensibility test is often used to indirectly determine the pulp vitality. Moreover, the sensibility test can also be used to determine the pulpal anesthesia after local anesthetic administration (84).

To truly understand the sensibility test, nerve fibers in dental pulp will be briefly reviewed. There are two types of nerve fibers in dental pulp. Myelinated A fibers predominantly innervate the dentin and unmyelinated C fibers innervate the body of the pulp. Because approximately 90% of A fibers are Aδ fibers which have lower electrical thresholds than C fibers do, they respond to a more number of stimuli that C fibers do not (85). To assess the function of Aδ fibers in the dentin-pulp complex, stimulus is applied to the outer surface of the tooth. If the Aδ nerve fibers are successfully stimulated, the patient will respond by reporting a short, sharp sensation/tingling from the tooth. A positive response indicates that the nerve fibers are functioning (86).

Sensibility test is the assessment that examines the ability of nerve fibers in dental pulp in responding to a stimulus applied to the tooth (84). Sensibility test has two major clinical applications in dentistry. First, it is used to test the vitality of the tooth aiding in diagnosis of the pulp status. Second, it is used to test pulpal anesthesia. Following routine local anesthesia in dentistry, both soft tissue and pulpal anesthesia are usually anticipated. To verify soft tissue anesthesia, pricking soft tissue with sharp instrument or asking patient directly of how they feel have been recommended (35). On the other hand, pulpal anesthesia has to be confirmed by the sensibility test. Pulpal sensibility tests include thermal tests (heat and cold stimuli) and electric pulp tests (EPT).

2.7.1 Thermal testing

Thermal testing consists of cold and heat tests. Cold or heat stimuli are used to determine sensitivity to thermal change.

In cold test, cold stimuli are applied on the tooth and causes rapid contraction of the dentinal fluid within the dentinal tubules. This accelerated movement of dentinal fluid results in hydrodynamic pressure affecting on $A\delta$ fibers within the dental pulp. If $A\delta$ fibers still function, cold tests will lead to a sharp sensation remaining for the duration of the test (87). Moreover, cold test can be used to distinguish reversible from irreversible pulpitis. If the patient feels a persisting pain although the cold stimulus is removed, a condition of irreversible pulpitis may be diagnosed. Conversely, if the pain relieves immediately after stimulus is removed, a condition of reversible pulpitis is confirmed (86).

There are currently many types of cold tests available. First is an ice-sticks which is a simple mean of applying a cold stimuli. It is a freezing water in the plastic mold that produces a temperature of 0°C, which is usually not cold enough to stimulate the pulp. Second is a refrigerant spray which is the most convenient and easiest cold test available. The material is sprayed onto a cotton pellet which is then applied to the middle third of the facial/labial surface of the crown. Jones (88) suggested that the refrigerant spray should be kept in contact with the surface for 10 seconds or until the patient begins to feel pain. However, Jones et al. (89) found that most of the pulp can respond to 1,1,1,2-tetrafluoroethane, one form of refrigerant spray, within only 5 seconds. Different refrigerant sprays are currently available in the market. Dichlorodifluoromethane (DDM) produces a temperature of -50 °C and is commercially packed for dental use as a compressed spray (Endo-Ice®; Coltene/Whaledent, Switzerland). Because of the concern in its effect on the ozone layer of the atmosphere, DDM has been prohibited by the Clean Air Act in the United States since January 1996 (84). However, 1,1,1,2-tetrafluoroethane (TFE) has been produced to replace DDM. It is a haloalkane refrigerant without ozone-depletion potential and has thermodynamic characteristics similar to that of the DDM. TFE produces a temperature of -26.2 °C and is commercially available as Green Endo-Ice® (Coltene/Whaledent, Switzerland). Another refrigerant spray available in the market is propane–butane mixture (PBM), which is commercially available as Endo-Frost (Coltene/Whaledent, Germany), produces a temperature of -50 °C.

Another effective cold stimulus is carbon dioxide (CO_2) snow or dry ice which produces temperature of -78 °C. When dry ice is applied on the tooth, pulp will rapidly responds in 2 seconds (90). However, this low temperature does not jeopardize the tooth tested. In addition, ethyl chloride which produces temperature of -12.3°C is commonly used in medicine as a skin refrigerant. It was also previously used as a cold stimulus in the cold test of pulp tissue. However, the use of ethyl chloride in pulp testing is no longer recommended because it has been found to be less effective than CO_2 snow or DDM (91).

Because these cold stimuli provide different temperatures, they may result in different reliabilities. Fuss et al. (90) found that DDM and CO_2 snow were more reliable than ethyl chloride and ice-stick. Furthermore, Chen and Abbott (92) showed that the accuracy of CO_2 snow, Endo-Frost, and ice-stick were 97%, 90.7%, and 84.8% respectively. They summarized that CO_2 snow was significantly more accurate than Endo-Frost and ice-stick were. From these results, it may be summarized that the cold test with lower temperature tends to be more accurate than that with the higher temperature. In contrast, Weisleder et al. (93) reported that the sensitivity of CO_2 snow and TFE are equal, which are 76%, although CO_2 snow produces lower temperature than TFE does. Moreover, Jones et al. (89) found that TFE can produce more responses, both in frequency and intensity of pulpal responses. Moreover, TFE also produced shorter onset of response compared to that of CO_2 snow. Additionally, they suggested that TFE is more convenient than CO_2 snow is because TFE can be available at chairside when CO_2 snow requires a pressurized CO_2 tank. Because of these good properties, TFE was preferred in this study.

In heat tests, heat stimuli such as heated gutta-percha, hot water, warmed hand instruments or rotating rubber cup without prophylactic paste are applied on the tooth. Aδ fibers stimulated by heat result in expansion of fluid in dentinal tubule. Therefore, when heat is applied to the inflamed or necrotic pulp, which are a bacterial reservoir that produce gases, it can increase pulpal pressure, then stimulate C fibers resulting in long lasting pain (94). However, heat tests are not popular because of the difficulties relating to tooth isolation and consistency of heat produced (95). Additionally, this test may not be practical to use on posterior teeth because of limiting access and excessive heat may also damage the dental pulp (96).

2.7.2 Electric pulp test

Electric pulp test (EPT) functions by using low-grade current applied on the tooth and causes ionic shift in the dentinal fluid. When EPT is applied to a tooth, peripheral myelinated Aδ fibers are stimulated (97) and the patient will respond by demonstrating a brief sharp sensation or a tingling from the tooth. However, C fibers do not react in this situation because their firing threshold is higher and a much stronger electrical current is required to stimulate them (98).

Reader et al. (35) suggested to use EPT to assess the pulpal anesthesia. They defined the pulpal anesthetic success when patient have no response to two consecutive 80 EPT readings within 15 minutes after injection and continuously sustain the 80 reading for 60 minutes.

In young permanent teeth, there are several limitations regarding the use of sensibility test. Sensibility test, especially the EPT, has limitations resulting in both false negative and positive responses in teeth with immature root formation. Fuss et al. (90) found that EPT is less reliable than DDM and CO_2 snow in the group of young patients with immature root formation although its reliability is equal to DDM and CO_2 in the adult group with mature root formation. Moreover, Klein (99) also concluded that the stage of root development affects the response to EPT, the number of positive responses increased following the more advanced stages of root maturation. The immature teeth with opened apex have higher threshold to EPT because of their incomplete innervation of the odontoblast layer (100) and fewer myelinated axons within their pulps (32). Hence, DDM and CO_2 snow are more reliable than EPT in the immature permanent teeth (90, 101, 102).

Furthermore, mental and emotional status of the patient can affect the pain perception because anxious and nervous patients may have a lower response threshold resulting in more false positive responses (103). Consequently, psychological state should be concerned when using the pulp sensibility testing, particularly in young patients who have high anxiety in dental practice. Because the result of pulp sensibility tests depend on the patient’s response, Cooley and Robison (104) found that false positive response may occur in anxious or young patient.

EPT was used in several researches that studied the success rates of local anesthesia. Harris (105) found that EPT gave an accurate result and is an appropriate objective measurement in determining profound pulpal anesthesia. Moreover, Modaresi (54) suggested that EPT is an accurate device in evaluating pulpal anesthesia for both symptomatic and asymptomatic teeth. Additionally, Certosimo and Archer (106) demonstrated that asymptomatic teeth that still responded to EPT after local anesthetic administration almost always resulted in pain during the operative treatment in their study. However, intra-operatively complete pulpal anesthesia may not be absolutely achieved in teeth with irreversible pulpitis and teeth with negative responses to both sensibility tests (9, 69).

Controversies exist regarding the accuracies of EPT and cold test when used as a pulpal anesthetic tests. Petersson et al. (107) reported that the accuracy of EPT, which was 81%, was lower than that of ethyl chloride cold test, which was 86%. Conversely, Chen and Abbott (92) showed that accuracy of EPT was slightly higher than that of CO_2 snow cold test, that were 97.7% and 97.0%, respectively. Additionally, Weisleder et al. (93) found that the sensitivity of EPT was higher than that of cold tests with CO_2 and TFE, that were 92%, 76% and 76%, respectively. Moreover, they suggested that combined use of EPT and cold test can get the more accurate result.

2.8 Anxiety and pain assessment in children

There are several scales to assess dental anxiety in children. These scales are grouped into dental anxiety scales which recorded by the observer, (such as Frankl Category Rating Scale (FCRS) and Global Rating Scale (GRS)) or self-reported by the child, (such as Facial Image Scale (FIS) and Venham Picture Test (VPT)) (108). The Facial Image Scale (FIS) (Figure 2.2) consists of a row of five faces ranging from very happy to very unhappy faces. The children are asked to finger on the face that matches with their feeling at that moment. The score one means the most positive emotion and score five means the most negative emotion (109). Because the Facial Image Scale (FIS) has a set of discrete number of faces, not a continuous line, for the children to select from; thus making it easier to score in a clinical situation and easier for very young children as young as 3 years old to understand. Moreover, Facial Image Scale (FIS) takes a very short time (less than 1 min) to complete (109). Buchanan and Niven (109) reported that the validity of FIS was 0.7 showing the strong correlation with the VPT. They further concluded that FIS was valid to assess children dental anxiety in clinical practice.

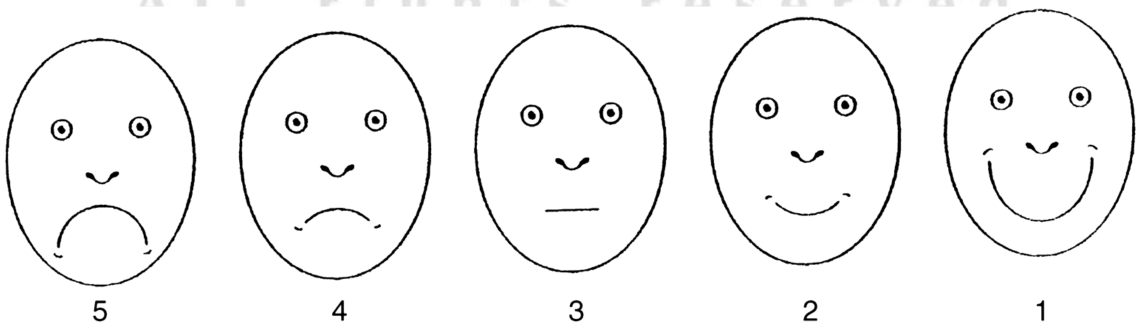

Figure 2.2 Facial Image Scale, score 1–5 (109)

Pain measurement during and after the dental procedure are also necessary for evaluating the effectiveness of pain management. Tomlinson et al. (110) concluded that there are three approaches that have been established to measure pain in children including self-report, observational/behavioral indicators which provided by the observers, and physiological parameters such as heart rate.

Self-reported measurement tools (such as visual analog scales (VASs), numerical rating scales, faces scales, color analog scales (CASs), and the pieces-of-hurt (poker chip) scale). However, faces scales are generally preferred by children more than other self-report measurement (110).

Several faces scales, such as the Faces Pain Scale (FPS), the Faces Pain Scale–Revised (FPS-R), the Oucher pain scale, and the Wong-Baker Faces Pain Rating Scale (WBFPS) can be regularly seen in literatures. The WBFPS (Figure 2.3) is the most common self-reported scales that has been used in children. Moreover, Tomlinson et al. (110) reported that most investigators preferred this scale over other scales.

The WBFPS is a horizontal scale of 6 faces, ranging from score 0 to score 10. Score 0 is a smiling face that means "no hurt", when score 10 is a crying face that means "hurt worst" (110).

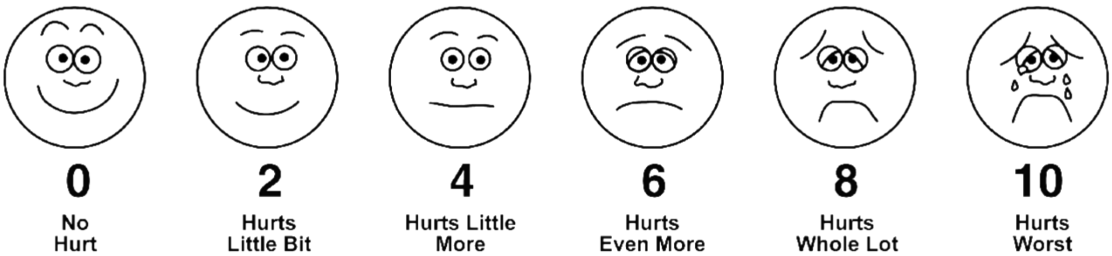

Figure 2.3 The Wong-Baker Faces Pain Rating Scale (WBFPS), score 0-10 (110)

The advantages of this scale are not only it is easy and quick to use but also preferred by children and practitioners when compared with other faces pain scales (111-113). However, the WBFPS has some limitations because smiling and crying anchor faces in this scale can confound pain intensity, leading to misinterpreted result (114, 115).

Tomlinson et al. (110) concluded that the measurement of pain intensity by self-report is not absolutely reliable and valid. To date, there is no gold standard of self-report pain scale for use with all children. However, von Baeyer (116) found that most 5 years old children and older, and many of children age 3- and 4-years old are able to understand self-report of pain if age-appropriate devices are utilized.