Current Concepts in Local Anaesthesis

And their application to the nerve block techniques

for the mandibular and maxillary divisions of the

trigeminal nerve

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Synopsis

Traditionally, techniques for cranial and peripheral nerve blocks have been based upon the use of superficial anatomical landmarks and an understanding of the deeper anatomical relations to target the selected nerve trunk. Recent advances in regional anaesthesia have demonstrated the limitations of the traditional techniques and raised other issues, which are as pertinent to the nerve block techniques employed in dental local anaesthesia as they are to general medicine and surgery.

This thesis first presents a review of the published local anaesthetic nerve block techniques for the mandibular and maxillary divisions of the trigeminal nerve. It then presents a review of recent research in three fields

- the structure and function of the sodium channel
- the pharmacology of local anaesthetic agents
- advances in the techniques for the administration of local anaesthetics for peripheral nerve blocks.

The thesis presents a review of research into the anatomy of the trigeminal nerve and the anatomical structures associated with it, which includes studies over a period of almost sixty years. Then, a recent statistical study, conducted by the author, of certain anatomical structures
pertinent to the anatomy of the nerve pathways of the maxillary and mandibular divisions of the trigeminal nerve is presented.

A discussion on the implications of the recent research, including the clinical application of the anatomical study, for nerve block techniques for the mandibular and maxillary divisions of the trigeminal nerve is then presented.
What men want is not knowledge but certainty

*Bertrand Russell*

Think not that I am come to send peace on earth:

I came not to send peace, but a sword

*St Matthew, 10:34*
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1. Introduction

Local anaesthetics are the most important and most commonly utilised pharmaceuticals in the dental profession today (Malamed, 2004). However, in the field of medicine, the use of peripheral nerve blocks to achieve anaesthesia for surgical procedures has been far more limited (Hadzic, 2007). The reason for the different degrees of utilisation in the two professions lies in the traditional paradigm that underpins most techniques of nerve block anaesthesia (Eriksson, 1969; Hadzic, 2007). This paradigm employs superficial anatomical landmarks and the clinician’s knowledge of the deeper anatomical structural relations to achieve success (Eriksson, 1969; Hadzic, 2007). The techniques that have been taught under these principles have, for the most part, made little provision for anatomical variability, so that peripheral nerve blocks using the traditional approaches have not often enjoyed a high rate of successful outcomes (Urmey, 2007).

In recent years, however, techniques to improve nerve targeting for peripheral nerve blocks have advanced the use of local anaesthesia in medical practice and made it far more popular (Hadzic et al, 2008).

Like their medical counterparts, nerve block anaesthesia in dentistry has not been without its problems. Despite the ease of administration and the general predictability of the action of local anaesthetic, practitioners are often confronted with the problem of clinically inadequate, or even failed, local anaesthesia. Most clinicians have at least one anecdote about a
patient on whom local anaesthesia was, despite many attempts, unsuccessful. This is most notable in mandibular nerve block injections. Studies have shown that the success rates of the standard inferior alveolar nerve block technique can be as low as 70% in optimal circumstances and even lower in the presence of inflammation (Budenz, 2007; Hargraves and Keiser, 2002). Much has been written on this subject over many years. Many researchers and authors have directed their attention towards perfecting anaesthetic delivery techniques (Sargenti, 1966; Milles, 1984; Malamed, 2004). For others the main focus has been to develop alternative delivery techniques that, hopefully, provide improved reliability and predictability of anaesthesia (Vazirani, 1960; Gow-Gates, 1973 and 1983; Morishita, 2007). These alternative techniques have, for the most part, been focussed on the mandibular division of the trigeminal nerve. Despite the many articles and textbooks that have been written, most of the underlying precepts for maxillary and mandibular nerve blocks have remained little changed for decades (Bremer, 1952; Malamed, 2004; Baart and Brand, 2009). The classic anatomical concept of the structure and pathways of the mandibular nerve and its branches (fig 1) remains firmly fixed as both normative and largely invariable (Sargenti, 1966; Madan et al, 2002; Malamed, 2004).
Another aspect of local anaesthesia, the pharmacological principles of the action of local anaesthetic, has remained little changed in the clinical textbooks for over a decade (Malamed, 2004; Frankhuijzen, 2009). Clinical pharmacology has focussed on the problems of achieving anaesthesia and the adverse local and systemic effects of these drugs. Issues such as the effect of tissue pH on the dissociation and diffusion of local anaesthetic, the problems of dosage and allergy tend to form the major part of any discussion on local anaesthetic pharmacology. Yet knowledge of the action of the local anaesthetic agents on the cell membrane and ion channels, which is fundamental to the understanding of these drugs, has remained very generalised and simplistic, often stating only that local
anaesthetic prevents the entry of sodium ions into the cell (Malamed, 2004; Frankhuijzen, 2009).

In the past decade researchers in the fields of cell biology and biochemistry have made significant advances in the understanding of the physiology of nerve cells, their cell membranes and ion channels (Hille, 2001; McNulty et al, 2007). This work has often been achieved through the use of local anaesthetic agents as research tools. Hence, while local anaesthetics have helped unravel the intricacies of the ion channel, the research has also revealed much about the pharmacology and the pharmacodynamics of local anaesthetics in respect of their interactions with the nerve cell and the sodium ion channel (Lipkind and Fozzard, 2005). Unfortunately, this information has tended to remain within the confines of the research literature and has yet to reach the clinical domain.

Clinically there have been significant advances in the field of peripheral nerve block anaesthesia. The use of nerve stimulation to target nerves has latterly been surpassed by the use of ultrasound guided regional anaesthetic techniques (Casati and Putzu, 2007; Gray, 2007; Urmey, 2007). These new techniques have proved hugely popular in medical anaesthetic circles and they have provided new information and insights into local anesthetic techniques (Chin et al, 2008; Chan, 2009 [a, b, c]).
In the field of dentistry research into the anatomy of the mandibular nerve and the structures that surround it has been conducted over several decades. In the past decade several studies have investigated the variability of the branches of the mandibular nerve (Roy et al, 2002; Kim et al, 2003; Shimokawa et al, 2004; Stein et al 2007). The author of this thesis has also conducted a statistical study of certain anatomical features that have significance for the administration of nerve block anaesthesia to the mandibular and maxillary nerves and this research is presented here.

This thesis seeks to integrate the new research in pharmacology and anatomy, along with the clinical evidence emerging from the use of ultrasound, with the existing precepts that underlie the administration of local anaesthetic to the mandibular and maxillary nerves. To achieve this it considers the following:

- First, the principles and the various published nerve block techniques for the mandibular and maxillary divisions of the trigeminal nerve are reviewed. Some of these techniques have been popularised, while others have been forgotten. All have some significance, for they provide insights into the perceived problems and principles of anaesthesia that guided the development of so many different approaches.

- Second, there is a review of recent research concerning the nerve cell membrane, the sodium ion channels and the subsequent developments in the understanding of the interaction of local
anaesthetic agents with these structures. As well, other recent pharmacologic knowledge is discussed.

- Third, the recent developments in peripheral nerve block techniques through the use of ultrasound guidance are reviewed. The results of recent studies in ultrasonography and their implications for nerve block anaesthesia are presented.

- Fourth, there is a review of anatomical studies concerning the anatomy of the region of the maxillary and mandibular divisions of the trigeminal nerve. This review includes both older studies and more recent investigations.

- Fifth, a statistical anatomical study, conducted by the author, is presented. This study considers the variability of certain structures that are pertinent to the successful delivery of local anaesthetic to the trigeminal nerve.

- Finally, the pharmacological, clinical and anatomical data that have been presented are combined to develop a new set of precepts for mandibular and maxillary nerve anaesthesia. Some concepts for improving the efficacy and safety of certain local anaesthetic techniques are also introduced.
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- Fourth, there is a review of anatomical studies concerning the anatomy of the region of the maxillary and mandibular divisions of the trigeminal nerve. This review includes both older studies and more recent investigations.

- Fifth, a statistical anatomical study, conducted by the author, is presented. This study considers the variability of certain structures that are pertinent to the successful delivery of local anaesthetic to the trigeminal nerve.

- Finally, the pharmacological, clinical and anatomical data that have been presented are combined to develop a new set of precepts for mandibular and maxillary nerve anaesthesia. Some concepts for improving the efficacy and safety of certain local anaesthetic techniques are also introduced.
6. The Clinical Implications of the Research for Nerve Block Anaesthesia of the Mandibular and Maxillary Nerves

All the techniques of nerve block anaesthesia for the mandibular and maxillary divisions of the trigeminal nerve that have been developed are based upon the principles of the traditional paradigm (Eriksson, 1969; Hadzic, 2007). These principles are:

- the identification of the superficial anatomical landmarks
- a thorough knowledge of the deeper anatomy
- the perfection of the technique being employed to deposit the local anaesthetic solution at a precise location.

In respect of the intraoral techniques for the inferior alveolar nerve block, it is notable that the many different techniques all seek to deposit the anaesthetic solution at different locations yet the majority attain approximately the same rate of successful nerve block. The reasons for this have been debated for years, but there has been little tangible evidence to provide an explanation. For the extraoral techniques of both mandibular and maxillary nerve block, it may be noted that most are ‘blind’, meaning that the target site must be probed even when a particular insertion point is identified and geometrically precise directions followed (Stajcic and Todorovic, 1997; Stajcic et al, 2002). Despite the reported
shortcomings, clinically all the techniques that have been described have enjoyed a high level of success over many decades, even the often maligned standard inferior alveolar nerve block technique. How then can the recent advances in knowledge in pharmacology, anatomy and regional nerve block anaesthesia using ultrasound imaging improve the understanding of mandibular and maxillary nerve blocks?

6.1 The contribution of the research

The contribution of the anatomy studies

The overall contribution of the anatomical studies relating to the mandibular nerve and its branches is to disprove the notion of anatomical consistency. Bremer (1952) demonstrated the high degree of positional variability of both the lingula and the mandibular foramen, both of which are the presumed targets in several injection techniques. Further, extrapolation of Bremer’s results show that the mandibular foramen must lie below the level of the occlusal plane of the mandibular teeth in over 50% of cases (Bremer, 1952). This finding is in sharp contrast to the prevailing notion that the reason for the failure of the standard inferior alveolar nerve block is the deposition of the anaesthetic solution below the level of the mandibular foramen. Other studies have shown the highly variable pathways and branching patterns of the mandibular nerve (Jablonski et al, 1985; Roy et al, 2002; Kim et al, 2003; Shimokawa et al, 2004).
The contribution of the present study

The model developed in the present study suggests that the nerve pathway may lie away from the ramus of the mandible for some considerable distance and also be screened by the lateral pterygoid muscle and plate for much of its length. This model is reflected clinically in the examination of coronal-section, computerised tomographs. Figure 151 shows the pathway that the mandibular nerve must take through the connective tissue of the pterygomandibular space (seen as a narrow, dark band on the radiograph), between the lateral and medial pterygoid muscles after it emerges through foramen ovale.
Fig 151: Coronal CT at the level of foramen ovale. The path of the mandibular nerve and its branches lies between the lateral pterygoid and medial pterygoid muscles

- FO with orange arrow = foramen ovale
- LP = lateral pterygoid muscle
- SP with blue arrow = spinous process of lateral pterygoid plate
- MP = medial pterygoid muscle

Figure 152 is another coronal section from the same series, but several millimetres anterior to the previous image at the level of the mandibular foramen. This image shows the relationship of the lateral pterygoid muscle to the mandibular foramen and demonstrates the path of the inferior alveolar nerve to the mandibular foramen after it has passed beneath the lateral pterygoid muscle.
Fig 152: Coronal CT at the level of the mandibular foramen. The path of the inferior alveolar nerve branch from the lower border of the lateral pterygoid muscle to the mandibular foramen is indicated by the red line.

LP = lateral pterygoid muscle
SP with blue arrow = spinous process of lateral pterygoid plate
MP = medial pterygoid muscle.
MF with yellow arrow = mandibular foramen

These images demonstrate two of the features of the anatomical model; the effect of a wide angular relationship between foramen ovale and the mandibular foramen and the influence the lateral pterygoid muscle and plate has on the path of the mandibular and inferior alveolar nerves. Of these two factors, it can be seen that the size and position of the lateral pterygoid muscle is the most influential.

The model developed from the study also demonstrates the importance of the anatomical variability of the lateral pterygoid plate and its relationship...
to the mandibular foramen and the influence this may have on the effective delivery of local anaesthesia.

The third part of the study, on the relationship of the pterygomaxillary fissure to other landmarks, provides significant information for maxillary nerve blocks that are delivered by an extraoral approach.

The contribution of the ultrasound studies

The use of ultrasound imaging techniques for nerve blocks has provided valuable information on the administration of local anaesthesia. The first findings were that nerve trunks could show considerable variability in both their positions and structure, which confirmed the anatomical studies (Chin et al, 2008; Chan, 2009 [b]). The second findings were that precise targeting of the nerve trunk was not essential and that deposition within the correct tissue plane was just as effective, in terms of onset of anaesthesia, depth of anaesthesia and duration of anaesthesia, as deposition of the anaesthetic solution immediately adjacent to the nerve (Casati and Putzu, 2007; Chan et al, 2007; Chan, 2009 [c]). These findings provide an explanation for the success of the various inferior alveolar nerve block techniques.

The finding that the volume of anaesthetic solution deposited is a significant factor in achieving nerve block (Ifeld et al, 2008; Taboada et al, 2008) provides confirmation of the recommendations of several authors for
increasing the volume of local anaesthetic solution used in some of the inferior alveolar nerve block techniques (Sargenti, 1966; Levy, 1981; Morishita, 2007; Kohler et al, 2008).

The finding by Abrahams et al (2008) that structures within the tissue plane can impede or even prevent the diffusion of the local anaesthetic solution provides support for the assertion by Clarke and Holmes (1959) that the sphenomandibular ligament may be an impediment to the diffusion of local anaesthetic to the inferior alveolar nerve. Further indirect evidence comes from Wolfe (1992). His closed-mouth block, which deposited the anaesthetic solution against the ramus in the proximity to the sphenomandibular ligament, had a longer time to onset of anaesthesia than the techniques of Vazirani (1960) or Akinosi (1977).

Perhaps the most important finding of the use of ultrasound guidance for regional anaesthesia is that a 100% success rate for nerve block has still not been obtained. Even when the nerve trunk has been visualised and the local anaesthetic seen to diffuse to the nerve, the reported rate of successful surgical anaesthesia is still only 90-95% (Chan, 2009 [c]).

The contribution of the pharmacology studies

The recent studies in the structure and function of the nerve cell membrane and the sodium ion channel help to provide a clearer and more
comprehensive understanding of how local anaesthetics achieve nerve block. The interaction of local anaesthetic agents with the docking site in the inner pore of the sodium channel is now revealed to be both complex and transient (Hille, 2001; Lipkind and Fozzard, 2005; McNulty et al, 2007). The clinical effectiveness of local anaesthetic agents in achieving nerve block is a function not only of the local anaesthetic agent but also the nerve cell’s intrinsic activity, including factors such as impulse frequency, cytoplasmic pH, ion concentrations, and membrane polarisation (Hille, 2001; Mulroy, 2002).

Hille’s (2001) finding that local anaesthetic molecules can only dock with the sodium channels when they are open helps to explain patients’ perceptions of sensation when tissues are stimulated for the first time following the administration of nerve block anaesthesia. The finding that repeated, or even continuous, sensory receptor stimulation is required to maintain effective nerve block (Hille, 2001) also has clinical significance if treatment is intermittent. This effect, called use-dependent block, may also help to explain the apparently poor test results in trials of local anaesthetic agents or techniques. Standard testing involves the use of electric dental-pulp testers, which are applied intermittently to selected teeth (Vreeland et al, 1989). The periods between tests, in which no stimulation is given to the receptors, may be long enough for the sodium channel block to be lost. This must be considered as a potential confounding factor in interpreting the results of such studies.
The low therapeutic index of local anaesthetics is explained through Hille’s (2001) work on the nerve cell membrane and his discovery of the high concentration of sodium channels at the nodes of Ranvier. This, in turn, explains Raymond et al’s (1989) finding that, over short exposure lengths, only very high concentrations of anaesthetic will successfully block nerve impulses and if lower concentrations of local anaesthetic are used they must act on much longer sections of the nerve trunk to achieve effective blockade. These findings are in accord with the clinical findings that increasing the volume of local anaesthetic solutions results in improved success rates for nerve block (Ifeld et al, 2008; Taboada et al, 2008). The anatomical finding that the lateral pterygoid plate and muscle may screen much of the mandibular and inferior alveolar nerves may then prove to be a complicating factor in the achievement of effective nerve block.

The underlying assumption on the efficacy of local anaesthetic agents should now be reconsidered. Local anaesthetics are expected to deliver profound anaesthesia at low concentrations for only a relatively short period of time in the clinical setting. Even with the highly accurate deposition of anaesthetic adjacent to the nerve bundle through the use of ultrasonic location (Hannan et al, 1999), profound anaesthesia cannot be guaranteed. Even higher volumes or concentrations may not guarantee anaesthesia. Vreeland et al (1989) found that neither doubling the volume
of anaesthetic (from 1.8 ml to 3.6 ml) nor doubling the concentration (from 2% to 4%) guaranteed anaesthesia.

The neurotoxic effects of local anaesthetics have been recognised for many years (Myers et al, 1986; Kalichman et al, 1993; Bainton and Strichartz, 1994). However, it is only now that the adverse outcomes that occasionally follow the administration of local anaesthetic, such as prolonged paraesthesia and nerve damage, can be attributed to the pharmacology of the agents rather than physical causes (Hogan, 2008).

The new understanding of the pharmacological limitations of local anaesthetic can combine with the ultrasound clinical studies on the value of using increased volumes of local anaesthetic to improve clinical outcomes. The prevailing perception that only minimal amounts of the agents should be administered (Rood, 1977; Foot, 2006) should now be reconsidered.

6.2 The application of the research to nerve block techniques

Open-mouth inferior alveolar nerve blocks

The open-mouth inferior alveolar nerve blocks – the standard technique, the standard indirect technique, the Clarke-Holmes technique, the Sargenti technique, the Gow-Gates technique and the Morishita technique – all
utilise superficial anatomical landmarks to locate their target site and all seek to deposit the local anaesthetic solution adjacent to the mandible. Although these techniques target quite different sites to achieve nerve block, they all achieve a relatively high rate of success. The standard techniques (direct and indirect) and the Morishita technique have a similar reported success rate, which is lower than the reported success rates of the other techniques. The Gow-Gates technique has the highest reported success rate of this group, yet it deposits the local anaesthetic solution at (apparently) the greatest distance from the nerve trunk.

**The purpose of superficial landmarks**

Bremer’s (1952) study remains the most potent argument against the reliability of targeting the inferior alveolar nerve through the use of superficial landmarks. The findings from anatomical studies and ultrasound studies provide confirmation that a high degree of anatomical variability is normal and common. The rationale for the use of superficial landmarks should therefore be reconsidered as a guide to locating the correct tissue plane for the deposition of the anaesthetic solution rather than being the means to target the nerve trunk at a specific site.

**The need to target the nerve trunk**
Ultrasound studies now confirm that precise targeting of nerve trunks is unnecessary to achieve successful nerve block and that deposition within the correct tissue plane is as effective as peri-neural deposition (Hannan et al, 1999; Casati and Putzu, 2007; Chan et al, 2007). Therefore the aim of any inferior alveolar nerve block technique should be amended to achieving the deposition of the local anaesthetic solution within the pterygomandibular space. This rationale provides the explanation for the success of all the intraoral inferior alveolar nerve block techniques, despite their various target sites for the deposition of the anaesthetic solution.

The purpose of peri-mandibular anaesthetic deposition

The current anatomical study, combined with radiographic evidence, shows that the path of the mandibular nerve and its branches need not lie close to the medial aspect of the mandible. This is primarily due to the influence of the lateral pterygoid muscle and plate. Figure 153 shows the connective tissue plane through which the mandibular nerve and its branches pass. In this individual the large lateral pterygoid muscle will cause the inferior alveolar nerve to approach the mandibular foramen from a wide angle and deposition of the local anaesthetic solution will be unlikely to offer any advantage over deposition more medially away from the ramus.
Fig 153: Coronal CT, indicating the tissue plane for the nerve trunk

LP = Lateral pterygoid muscle
Orange line = connective tissue plane

The aim of deposition of the local anaesthetic against the medial aspect of the ramus may now be viewed from a different perspective. By contacting the medial surface of the bone with the needle tip, the clinician gains certainty that the local anaesthetic will be deposited within the connective tissue plane between the ramus and the pterygoid muscles (fig 154), from whence it will be able to diffuse to the nerve trunk.
The high nerve block

Attempts to overcome the perceived lack of success of the standard inferior alveolar nerve block have, for the most part, focussed on the deposition of the local anaesthetic solution at higher levels on the medial aspect of the ramus. Gow-Gates (1973) targeted the fovea of the neck of the mandible as the preferred site for anaesthetic deposition. Gow-Gates and Watson (1973) argued that the anaesthetic would diffuse medially to block the nerve trunk at a higher level than any other technique. However, Coleman and Smith (1982) argued that the lateral pterygoid muscle prevented the spread of the local anaesthetic in the manner described by both Gow-Gates and Watson. Rather, Coleman and Smith stated that the anaesthetic must spread along the tissue plane, in this
case inferiorly to below the lower border of the lateral pterygoid muscle. The current study confirms Coleman and Smith’s position. Fig 155 shows the site of local anaesthetic deposition for the Gow-Gates technique at the fovea. In this individual the lateral pterygoid muscle would prevent the diffusion of the local anaesthetic medially. Instead, the solution would diffuse inferiorly until it reached the nerve passing between the lateral and medial pterygoid muscles. This raises the question of why the Gow-Gates technique has such a high rate of clinical success in achieving nerve block.

Fig 155: Coronal CT, at the level of the condyles

X = the site of deposition of local anaesthetic for the Gow-gates technique
LP = lateral pterygoid muscle
MP = medial pterygoid muscle
**Impediments to local anaesthetic diffusion**

In 1959 Clarke and Holmes opined that the sphenomandibular ligament might prevent the diffusion of local anaesthetic to the inferior alveolar nerve trunk. That structures within the tissue plane could impede the diffusion of local anaesthetic was demonstrated by Abrahams et al (2008). The sphenomandibular ligament is described as being a flat, thin band which passes from the spine of the sphenoid bone to the lingula (Davies, 1967). At the lower end of the ligament, the inferior alveolar vessels and nerve and a lobule of the parotid gland are considered to lie between it and the ramus of the mandible and, in this circumstance, the sphenomandibular ligament should help to contain the local anaesthetic solution deposited between the ramus and the ligament. However, as noted by Bremer (1952), the mandibular foramen need not lie adjacent to the lingula but could be up to 14 mm distant with a mean distance of over 8 mm from the lingula. In individuals where the nerve path is distant from the medial aspect of the ramus and the mandibular foramen is distant from the lingula, diffusion of local anaesthetic that was deposited between the ramus and the sphenomandibular ligament would likely be impeded or even prevented.

This may provide the explanation for the success of the Gow-Gates block, for by depositing the local anaesthetic against the fovea the solution
would be able to diffuse through the tissue plane unimpeded by the (distant) sphenomandibular ligament. Combined with the higher volume of solution administered, the free diffusion of the local anaesthetic would result in the high success rate of this technique.

**Volumes of local anaesthetic**

The recommended volume of local anaesthetic for the inferior alveolar nerve block technique is ‘one cartridge’, which may be either 1.8 ml or 2.2 ml (Rood, 1977; Foot, 2006). However, as already noted, increasing the volume of local anaesthetic will result in improved rates of successful nerve block (Brunetto et al, 2008; Taboada et al, 2006; Ilfeld et al, 2008). Kohler et al (2008) noted that the volume of the pterygomandibular space was reported to be only ‘approximately 2 ml’ and that deposition of the contents of a single anaesthetic cartridge would ‘completely fill in the space’. If this were so, it would be reasonable to expect that all injections within the pterygomandibular space would achieve equal rates of onset times for anaesthesia, equality of depth and duration of anaesthesia, and a high degree of equivalence of the success rates for the different techniques (Kohler et al, 2008). However, as Kohler et al’s (2008) reported, there are sufficient examples of the use of increased volumes of local anaesthetic within the pterygomandibular space to disprove this assertion. As early as 1966, Sargenti (1966) had recommended additional volumes of local anaesthetic for his block in the event of failure. Gow-Gates came to
recommend a higher dose of 3.3 ml for his block (Levy, 1981), and it has recently been shown that the administration of a higher volume of anaesthetic (3.6 ml) is associated with a greater degree of success for the Gow-Gates technique (Kohler et al, 2008). Morishita (2007) also recommends 3.6 ml (two cartridges) for his technique.

The effect of the lateral pterygoid on nerve block

Another aspect to the issue of local anaesthetic volumes is the variability, in size and shape, of the lateral pterygoid muscle and plate. The current anatomical study has suggested that much of the nerve trunk may be screened by the lateral pterygoid and only a relatively short section may be available between the lower border of the muscle and the mandibular foramen (fig 156).

Fig 156: Coronal CT, at the level of the mandibular foramen

The arrows indicate the distance between the lower border of the lateral pterygoid muscle (LP) and the mandibular foramen (MF)
In a case such as this, the deposition of a small volume of local anaesthetic against the ramus may not bathe sufficient length of the nerve trunk to gain nerve block. Administering a greater volume of local anaesthetic may permit the spread of the anaesthetic into the medial arm of the pterygomandibular space and over a longer section of the nerve trunk, thereby achieving satisfactory anaesthesia.

Fig 157: Coronal CT, showing the potential spread of local anaesthetic along the tissue plane

X = the site of deposition
Arrows = path of diffusion

It would therefore seem more appropriate that clinicians seek to administer volumes of local anaesthetic that are appropriate to the individual case, rather than relying on the concept of the single cartridge for all nerve blocks.
Closed-mouth inferior alveolar nerve blocks

There have been three published closed-mouth techniques: Vazirani (1960), Akinosi (1977) and Wolfe (1992). The insertion point for each is almost identical, being in the posterior buccal vestibular fold in close approximation to the hamular notch. However, the target sites for the three techniques differ. Vazirani’s (1960) technique inserts the needle 15 mm parallel to the sagittal plane. Akinosi (1977) recommended using the line of the maxillary teeth to angle the needle toward the ramus and advancing the needle 25-30 mm. Wolfe (1992) recommended bending the needle so that it would curve on insertion to contact the medial aspect of the ramus at a depth of 20 mm.

The site of local anaesthetic deposition

The Vazirani and Akinosi techniques both sought to deposit the local anaesthetic in the centre of the pterygomandibular space (fig 158). Wolfe’s technique sought to deposit the local anaesthetic against the ramus, as for the open-mouth techniques. The notable feature of these differences is the time to onset of anaesthesia. Both Vazirani and Akinosi’s techniques have a relatively rapid onset time – Akinosi claimed times to onset of as little as 90 seconds (Akinosi, 1977). In contrast, the onset time for the Wolfe block was 5-7 minutes (Wolfe, 1992). This lends further indirect support for the proposition of Clarke and Holmes (1959)
that the sphenomandibular ligament is a barrier to the diffusion of local anaesthetic within the tissue plane.

Fig 158: Coronal CT of the pterygomandibular space

X = the site of deposition of local anaesthetic for Vazirani and Akinosi techniques

LP = Lateral pterygoid muscle
MP = Medial pterygoid muscle

The depth of needle penetration

As noted, another difference between these techniques is the recommended depth of needle penetration. The model developed in the present study suggests that the distance from the hamular notch to the path of the inferior alveolar nerve lies in a range of approximately 15-25 mm. This means that all three techniques would deposit the anaesthetic solution in reasonable proximity to the nerve trunk.
The influence of the lateral pterygoid muscle and plate

The potential influence of the lateral pterygoid muscle and plate on the administration of the closed-mouth techniques has not been considered to date. However the current study suggests that a large lateral pterygoid may intrude into the recommended paths of insertion of the needle (figs 159, 160). Clinical experience confirms that the lateral pterygoid muscle may be penetrated on occasions and that even the lateral pterygoid plate may be contacted. This potential complication should be incorporated into future discussion of closed-mouth techniques.

Fig 159: Coronal CT, showing lateral pterygoid plates

LP = lateral pterygoid
O = needle insertion into connective tissue plane
X = needle insertion into muscle
Foramen ovale blocks

The lateral extraoral mandibular nerve block, described by Roberts and Sowray in 1979 (fig 186) and the anterior foramen ovale block described by Eriksson (1969) both target an area with significant variability. The data from the current study indicate that the lateral approach must locate a point which lies within a vertical range of up to nearly 25 mm depending on the depth of penetration to the foramen. More importantly, the depth of penetration has a variability of up to almost 30 mm with no landmarks to assist in the determination of accuracy.

Notwithstanding these variables, there is the additional complication of the variability of the lateral pterygoid plate. The lateral extraoral approach relies on contact with the lateral pterygoid plate to assist in the redirection
of the needle towards foramen ovale. Having contacted the lateral pterygoid plate, the needle is redirected posteriorly until it passes behind the posterior margin of the bone. However, as noted by Koepsell (2006), the lateral pterygoid plate may extend to the spinous process of the sphenoid bone and actually obscure foramen ovale (fig 161). In such a case it may not be possible to accurately estimate the correct deposition site and the anaesthetic may be deposited too far posteriorly toward the carotid sheath.

Fig 161: Inferior-lateral view of an extended lateral pterygoid plate

- Blue arrow = an incomplete pterygospinous foramen
- Green arrow = the posterior end of the lateral pterygoid plate
- FO = foramen ovale

(Note: the end of the plate lies posterior to foramen ovale)
A calculation derived from the study shows that an average angular difference of 17 degrees exists between foramen ovale and the carotid canal from the perspective of the lateral extraoral approach. This is sufficiently large to provide a measure of safety, particularly if the general position of the carotid canal (posterior to the coronal plane of the mandibular condyles in when viewed from norma lateralis) is understood. However, where the lateral pterygoid plate is extended by the ossification of the pterygospinous ligament, there may be an increased risk of the needle penetrating the carotid sheath if it is directed too far posteriorly in an attempt to pass behind the lateral pterygoid plate.

For the anterior approach, the data from the study indicate that, for a depth of penetration of 80 mm, the vertical angular range to target is 16 degrees and the horizontal range is 20 degrees. Again, this must be achieved without the benefit of reference points. As with the lateral approach, the problems of an extended lateral pterygoid plate potentially complicate access to foramen ovale and risk deviation of the needle towards the carotid sheath.

**Intra-oral Foramen Ovale block**

Despite Rosenberg and Phero’s (2003) assertion that extraoral techniques are easier than intraoral approaches, the current study suggests that an intraoral approach to foramen ovale should be both simple to perform and
relatively safe for the patient. The current study shows that the distance of foramen ovale from the hamular notch is relatively close to the oral mucosa and is readily accessible by the passage of a needle through the lateral pterygoid muscle, as occurs in the lateral and anterior extraoral approaches. The insertion of a needle to the mean depth of penetration (30 mm) along the mean angles of 41 degrees superiorly from the occlusal plane and parallel to the sagittal plane would place the tip of the needle in good proximity to foramen ovale. The ability to accurately target the foramen is no better than for the extraoral approaches and the potential problem of interference by an extended lateral pterygoid plate is the same. However, the risk of perforation of the carotid sheath is less, as the relative difference in the distances to foramen ovale and the carotid canal is much greater with an intraoral approach (fig 162).
Extraoral maxillary blocks

Current extraoral techniques utilise no landmarks to locate the pterygomaxillary fissure. With the exception of Stajcic and Todorovic (1997), even the insertion point of the needle is approximate. Both the lateral and anterior techniques rely on blind palpation of deep bony structures (the maxilla, greater wing of sphenoid, or lateral pterygoid plate) and may require multiple insertions of the needle until the target (the pterygomaxillary fissure) is located.
The technique of Stajcic and Todorovic (1997) needs special mention, because they provided precise angular directions to overcome the ‘blindness’ of the approach to the pterygomaxillary fissure. The directions were based on the outcome of a statistical study, but the authors only reported the means and did not consider the ranges. Using the statistical means, the authors claimed that the direction of the needle, from the insertion point at the frontozygomatic angle, was to be at an angle of 60 degrees posteriorly and 10 degrees superiorly. The utilisation of the mean score without knowledge of the range may prove problematic, as seen in the case seen in figs 163 and 164 in which the approach to the fissure is by a posterior angulation of 10 degrees and an inferior angulation of 10 degrees from the point of insertion.

Fig 163: Superior view of the supra-zygomatic approach to the pterygomaxillary fissure

The angle of approach has a posterior angulation of 10 degrees
Therefore, in this case at least, a clinician who was relying solely on Stajcic and Todorovic’s (1997) figures, and without further landmarks for guidance, would fail to locate the pterygomaxillary fissure. The other factor not considered by the authors, but found in the current study, was the possible complicating factor of the coronoid process or the tendon of the temporalis muscle lying in the path of insertion of the needle.

**Targeting the pterygomaxillary fissure**

The present anatomical study has shown that there is a moderately wide range of variation in the position of the pterygomaxillary fissure relative to a specific landmark, the intersection of the coronal plane of the hamular notches and the arch of the zygoma. The angular range was 30 degrees in both the horizontal and vertical planes, which means that precise targeting of the fissure is not possible even if landmarks are identified.
The anterior approach to the maxillary nerve block

The anterior approach, described by Eriksson (1969), passes the needle below the zygomatic arch anterior to the coronoid process of the mandible. This approach is safer and more comfortable for the patient than the lateral extraoral approach (Roberts and Sowray, 1979; Rosenberg and Phero, 2003), the main advantages being that there are no major structures to pass through and that trapping the maxillary artery is far less likely. It is difficult to agree with Rosenberg and Phero (2003), who regard this approach as providing less consistent anaesthesia than the lateral approach, for it is no less accurate. The one significant anatomical feature overlooked in the discussions of this approach is the coronoid process of the mandible, which has been shown to block the path of insertion of the needle in 30% of cases in the study.

The reference point used in the study (the intersection of the coronal plane of the hamular notches with the arch of the zygoma) has been used clinically as a superficial landmark for this technique. The landmark is created by first measuring the distance to the hamular notch from the commissure of the lips (fig 165) then transferring this measurement onto the patient’s face (fig 166). The point where this line crosses the lower border of the arch of the zygoma becomes the insertion point (fig 167) and the mean angulations of 15-16 degrees superiorly and posteriorly are used for the initial insertion (fig 168).
Fig 165: Intraoral measurement of the hamular notch

Fig 166: Transfer of the intraoral measurement onto the cheek
Fig 167: The insertion point lies vertically above the distance mark for the hamular notch

Fig 168: The insertion of the needle into the pterygomaxillary fissure

Although it slightly increases the complexity of the injection technique, the major benefits in utilising the landmark lie in the aid it gives in targeting the pterygomaxillary fissure and in increasing confidence for the clinician.
6.3 Future directions

The present study provides evidence of a high degree of anatomic variability in the structures of the facial skeleton that has been shown in other areas by recent ultrasound studies and further research into this variability should be undertaken. However, the study also reveals the difficulties and limitations that occur in such classic anatomical studies.

For future research in the area of the facial skeleton, the use of ultrasonography may be of value as the technology continues to evolve. At present, ultrasonography provides a high degree of detail of the superficial soft tissue layers. However, the current technology requires the use of large transducers which have limited application for the facial skeleton and, more particularly, within the oral cavity. Further, complex osseous structures currently impose limitations on the effectiveness of this approach.

A more immediate potential for further research may be found in the use of radiographic images generated by computerised tomography and cone-beam volumetric tomography. Images of both technologies can be seen in this thesis. Although it is not suggested that subjects be exposed to ionising radiation for research purposes, there exists a wealth of imagery that might provide a large amount of useful and statistically significant data. Computerised tomography has the advantage of providing good soft
tissue definition. Its disadvantage lies in the sectional nature of the imagery – only discrete radiographic sections are recorded. In contrast, cone-beam volumetric tomography records three-dimensional data that can be reconstructed in any manner required. Currently, the quality of this data is insufficient to provide soft tissue detail, but the osseous imagery is of a higher quality than is often seen in computerised tomography. The applicability of these types of radiographic images to an anatomical study should be investigated.
7. Conclusion

Recent advances in the fields of pharmacology, anatomy and nerve block techniques have provided a wealth of new information that is of direct benefit to the understanding of the principles of local anaesthesia. As a result, the traditional precepts that have underpinned the various techniques of nerve block anaesthesia should now be revised.

The traditional paradigm for nerve block is that the target nerve can be achieved through the use of superficial anatomical landmarks and a thorough knowledge of the underlying anatomy. Anatomical studies, including the present research, have demonstrated the high degree of variability of nerve trunks and the inability of superficial anatomical landmarks to provide a means to determine the position of the deeper anatomical structures.

The traditional paradigm holds that the local anaesthetic solution must be deposited immediately adjacent to the nerve trunk to ensure a successful nerve block. Ultrasound studies have now demonstrated that targeting the nerve trunk does not improve success rates over the deposition of the local anaesthetic within the correct tissue plane.

The traditional opinion that only minimal volumes of local anaesthetic solution should be administered has also been superseded by ultrasound
research that shows that increasing the volume of the local anaesthetic is directly proportional to increasing the rate of successful nerve block.

Anatomical structures associated with the nerve trunks, or simply lying within the tissue plane, have been shown to have an influence on the diffusion of local anaesthetic and the successful outcome of nerve block anaesthesia. These features and their potential effects should feature more prominently in future discussions on nerve block techniques.

The pharmacology of the local anaesthetic interaction with the sodium channel has now been shown to be a complex and highly dynamic state. The need to bathe a significant length of the nerve fibre in order to improve clinically successful anaesthesia and the need for the administration of larger volumes of local anaesthetic than previously supposed has been demonstrated both in vitro and in clinical studies. The understanding of the neurotoxic effects of local anaesthetic agents has been also advanced, with potential benefits for clinical practice.

These advances in no way repudiate any of the techniques that have been advanced over the decades. These have proven their worth clinically time and time again. Instead, the benefit of this work lies in developing a new paradigm for the principles of nerve block technique. In this paradigm:
- the aim of any nerve block technique is the deposition of local anaesthetic within the correct tissue plane
- superficial landmarks can be used to assist in locating the correct tissue plane for local anaesthetic deposition
- for the inferior alveolar nerve block, the aim of the peri-mandibular deposition of local anaesthetic is to place the solution within the connective tissue plane (the pterygomandibular space)
- the volume of local anaesthetic solution is an important factor in the successful outcome of nerve block. The concept of using only minimal amounts of local anaesthetic should be replaced with the concept of titration to achieve effective nerve block for individual patients.

Perhaps the most important contribution of all of the current research is that it makes clear that, no matter how accurate the technique or how much local anaesthetic is administered, the achievement of an effective nerve block cannot be guaranteed. Therefore, the notion of the perfectibility of any nerve block technique and its corollary, that the failure to achieve a successful nerve block is primarily due to poor technique, should now be eliminated from the teaching of local anaesthesia.
5. A Statistical Anatomical Study of Certain Osseous Structures Pertinent to the Mandibular and Maxillary Nerves

Introduction

The teaching of nerve block techniques for the mandibular and maxillary nerves are still based on the traditional concepts in which superficial anatomical landmarks are used to target the deeper tissue injection sites (Malamed, 2004; Baart, 2009). However, anatomical studies undertaken over many years have demonstrated the variability of the anatomical pathways and structure of the mandibular nerve (Zoud and Doran, 1993; Roy et al, 2002; Kim et al, 2003; Shimokawa et al, 2004). Other anatomical studies have shown the variability of structures that both relate to and influence the nerve pathways (Bremer, 1952; Coleman and Smith, 1982). These reported variations prompted the attempt to conduct a statistical study of certain anatomical structures to ascertain the degree of consistency or variability of these structures with respect to traditional localisation techniques.

Aim

The aim of this study was to develop statistical data to ascertain the degree of consistency, or variation, of several anatomic structures that
have significance with regard to the various techniques of local anaesthetic delivery to the trigeminal nerve. The following individual structures were studied:

- foramen ovale
- carotid canal
- lateral pterygoid plate
- pterygomaxillary fissure.

Foramen ovale is an important structure because it is the aperture through which the mandibular nerve exits the middle cranial fossa and it is also the target of most extraoral mandibular nerve block techniques. The carotid canal is also important as it lies in close proximity to foramen ovale and the perforation of the carotid sheath is a recognised complication in foramen ovale nerve blocks. The lateral pterygoid plate provides the origin of both the lower head of the lateral pterygoid muscle and the medial pterygoid muscle. Both of these muscles have significance for mandibular nerve block techniques, for they in part define the boundaries of the pterygomandibular space. The pterygomaxillary fissure is important as it is the pathway to the maxillary nerve and the site of the deposition of local anaesthetic to achieve blockade of that nerve trunk.

The following structural relationships were examined:

- the relationship between foramen ovale and the carotid canal
- the linear relationship between foramen ovale and the mandibular foramen
- the linear relationship between the foramen ovale-mandibular foramen ‘line’ and the lower border of the lateral pterygoid plate.

The relationship between foramen ovale and the carotid canal is significant for techniques that target foramen ovale (Eriksson, 1969; Roberts and Sowray, 1979; Stajcic and Todorovic, 1997), due to the potential risk of perforation of the carotid sheath and deposition of local anaesthetic around the internal carotid, internal jugular vein and the vagus nerve (Rosenberg and Phero, 2003; Rathmell and Pollack, 2007). The relationship between foramen ovale and the mandibular foramen, as well as the relationship between these two structures and the lateral pterygoid plate, was studied in an attempt to develop a simplified anatomical model to assist in the clinical understanding of inferior alveolar nerve block techniques.

An underlying principle of the study was to examine the dried skull specimens from a clinical perspective. This meant that all measurements of the relevant structures were considered from the perspective of a clinician looking at a patient’s face (norma frontalis or norma lateralis) or looking into a patient’s mouth.
Materials and Methods

A series of 34 dried-skull specimens were examined. These were selected from specimens held in university collections and in private hands. To be selected for study, the skulls had to:

- be intact (structurally undamaged)
- possess matching mandibles
- possess sufficient, correctly positioned teeth to enable the mandible to be articulated with the maxilla as closely as possible to that in life
- possess no obvious asymmetry or pathology.

One set of measurements, from the right side, was taken from each specimen. The right side was chosen because it was the easier side from which to obtain measurements, due to the nature of the equipment used. Measuring the right side also allowed for greater security of and protection for the specimens – due to right-handed bias in both the equipment and the examiner. Three skulls had additional measurements taken from the left side for comparison to ensure that left and right sides demonstrated a good degree of symmetry, but these measurements were not included in the results.

Due to the intricate contours and structure of the base of the skull and to the delicacy of many of the bony features, measurement taking proved somewhat challenging. Soft, plastic instruments (rulers and protractors)
and soft, wooden sticks had to be employed to obtain both distance and angulation measurements. As a result, there was a small degree of inaccuracy in the measurements. Distances were able to be rounded to the nearest millimetre. However, angles were often only able to be calculated to the nearest 2.5 degrees. This is reflected in the results, which show distances in millimetres and angles rounded to five degree intervals.

The anatomical reference point

As has been noted, superficial landmarks are routinely used in the administration of local anaesthetic, in both medicine and dentistry. These are often a combination of bony landmarks, located by palpation, and soft tissue features (Malamed, 2004; Greyling et al, 2007; Dubash et al, 2007; Rathmell and Pollack, 2007). Because the specimens used in this study were dried and lacked the soft tissue structures normally used by clinicians as landmarks, a bony landmark was required that could be related to the superficial structures in the living subject. The hamular notch was chosen as this reference point. The hamular notch lies between the alveolar tuberosity of the maxilla and the pterygoid hamulus and includes the pyramidal process of the palatine bone (Davies, 1967) (fig 70). It is also readily identifiable in the living subject as a concavity immediately posterior to the maxillary tuberosity (Barker, 1981) (fig 71). The hamular notch lies in close
proximity to the soft tissue landmarks used for all intraoral mandibular nerve block techniques.

Fig 70: The hamular notch (arrow) in a dried specimen

Fig 71: The hamular notch in the living subject (arrow)

The pterygomandibular raphe (dotted line) and nerve block insertion point (x) are also indicated.

Modified from: Malamed, 2004
The measurements

A total of twenty-two parameters were measured, including the measurement of facial height. The facial height of each specimen was measured (from the nasion (the deepest part of the concavity of the nasal bridge) to the lower border of the mandibular symphysis), as it had been suggested that patient size is a factor in the variability of the relationship between superficial landmarks and the target site (Urmey, 2007). To determine if facial length was a factor in the various measurements a chi-square test was performed between these results and each of the anatomical data sets.

The parameters relating to the anatomical structures were grouped into each particular anatomical feature or relationship. The position of the individual structures relative to the hamular notch was studied in respect of their distance, vertical angular relationship and horizontal angular relationship. The vertical angular relationship was measured from the lateral perspective (norma lateralis) using the dental occlusal plane as the baseline. The horizontal angular relationship was measured from the basal perspective (norma basalis) using a line intersecting both hamular notches as the baseline, i.e. the coronal plane (Stajcic et al, 2002). The angular relationship between foramen ovale and the mandibular foramen was studied from the perspective of norma frontalis (for lateral angulation) and norma lateralis (for horizontal angulation). The angular relationship
between the foramen ovale-mandibular foramen line and the lateral pterygoid plate was studied from the perspective of norma lateralis and norma basalis, as previously described for the individual structures (Stajcic et al, 2002).

Data analysis

The collected data was analysed using the SPSS\textsuperscript{TM} (Graduate Pack, Version 16.0) statistical programme. Because the data collected was not experimental, descriptive statistics were developed to provide the essential information of mean, standard deviation and range. Each data set was analysed to determine that it conformed to normal distribution and that the median and mean values were similar. Then each data set was cross-checked using a Q-Q plot to determine the degree of conformity with normal distribution. A high degree of closeness-of-fit between the actual results and the ideal normal distribution confirms both the validity of the obtained data and also reveals any anomalies.

Individual data groups from each anatomical feature were plotted against each other to produce two-dimensional and three-dimensional maps. The purpose of this was to gain a better understanding of the range of variation from the clinical perspective.
Chi-square tests were applied to pairs of data sets to determine if any one variable, such as facial height, had a statistically significant relationship to other variables. Should such a relationship be demonstrated, it might then prove to be a means to improve the predictability of the various techniques of nerve block local anaesthesia.

The SPSS programme was also employed to produce all the tables, graphs, charts and models developed from the data.
The results

The combined results are presented in table form (fig 72). Then, as each group is discussed, the results are also presented in diagrammatic form. The table shows the mean values and standard deviations, as well as the median scores. Also shown are the 25th and 75th percentile ranges and the maxima and minima, along with the overall range.

It is of note that all data sets conformed to normal distribution and the confirmation test, the Q-Q plot of each set, demonstrated a high degree of closeness of fit almost all data sets. For those data sets that showed some variance in the Q-Q plots the divergence was seen at the limits of the range. Chi-square testing was also significant in fact that no data set was found to have any meaningful relationship to any other, even within the data sets for each landmark (Chi-square significantly greater than 0.05 in all cases).

However, from the clinical perspective, it is the range of the scores that has the greatest significance. The range indicates the amount of normal variability an object or structure has. The wider the range the lower the chance of accurately predicting the size, shape or position of a given structure or object in any individual.
Fig 72: Table of statistical results

<table>
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<th>Notes:</th>
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<tr>
<td>1. Angular values are in degrees</td>
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<td>2. For horizontal angles – a negative value represents an angle lateral to the sagittal plane, a positive value represents an angle medial to the sagittal plane</td>
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<tr>
<td>3. For vertical angles – a negative value represents an angle inferior to the horizontal plane, a positive value represents an angle superior to the horizontal plane</td>
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<td>4. For definitions of terms, see page 155</td>
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</table>
Fig 72: Definitions of terms

Facial h’t: a measurement in mm of the distance between the nasion and the lower border of the mandible in the midline

Max block depth: the linear distance from the zygoma to the pterygomaxillary fissure

Max block vert angle: the degree of divergence from the horizontal plane of the line ‘Max block depth’

Max block hor angle: the degree of divergence from the coronal plane of the line ‘Max block depth’

Ovale depth: the linear distance to foramen ovale from the hamular notch

Ovale vert angle: the degree of divergence from the horizontal plane of the line ‘Ovale depth’

Ovale hor angle: the degree of divergence from the sagittal plane of the line ‘Ovale depth’

Carotid depth: the linear distance to the carotid canal from the hamular notch

Carotid vert angle: the degree of divergence from the horizontal plane of the line ‘Carotid depth’

Carotid hor angle: the degree of divergence from the sagittal plane of the line ‘Carotid depth’

Nerve length: the linear distance from foramen ovale to the mandibular foramen when the dentition is articulated

Nerve length antr angle: the degree of divergence from the coronal plane of the line ‘Nerve length’

Nerve length latr angle: the degree of divergence from the sagittal plane of the line ‘Nerve length’

Closed M depth: the linear distance from the hamular notch to the line between foramen ovale and the mandibular foramen at the level of the lower border of the lateral pterygoid plate

Closed M vert angle: the degree of divergence from the horizontal plane of the line ‘Closed M depth’

Closed M hor angle: the degree of divergence from the sagittal plane of the line ‘Closed M depth’

Ovale-LP length: the linear distance along the line ‘Nerve length’ from foramen ovale to the level of the lower border of the lateral pterygoid plate

LP lower border: the distance in the vertical plane of the lower border of the lateral pterygoid plate from the hamular notch, measured in mm

LP horiz length: the linear distance, in the horizontal plane, of the posterior border of the lateral pterygoid plate, at the level of the lower border of the plate, from the hamular notch

Coronoid: the percentage of specimens in which the coronoid process overlies the pterygomaxillary fissure when viewed from norma lateralis

% hidden nerve: the percentage of the length of the line ‘Nerve length’ that is screened by the lateral pterygoid plate

Exp nerve length: the length of the segment of ‘Nerve length’ between the lower border of the lateral pterygoid plate and the mandibular foramen
In the analysis of each individual structure, each anatomical feature has two to three data sets to describe it. In order to bring these sets together meaningfully, two and three-dimensional maps have also been constructed. These show the spatial relationships of the landmarks and the degree of variability.

The effect of facial height

The facial height of each specimen was measured from the nasion to the lower border of the mandible at the symphysis. The minimum is 96 mm and the maximum 128 mm. The mean is 111.3 mm and the median 113 mm. The group was divided into two subsets, the ‘long face’ group ranging from 112 – 128 mm and the ‘short face’ group from 96 – 110 mm. The ‘long face’ group (group 1) contained 19 specimens and the ‘short face’ group (group 2) 15 specimens. Each variable was then reanalysed for each of the individual structures and relationship sets to determine if facial size was a factor. The overall results for the ‘long face’ group are tabled (fig 73), as is the ‘short face’ group (fig 74). The results of this analysis show that many of the variables were almost identical between the two groups. In those data sets that did show variation, the degree of difference was minimal, particularly when the groups of data sets were considered as a whole. Therefore, the results do not support a link between facial height and the positions of the various anatomical structures or their relationships as suggested by Urmey (2007).
Fig 73: ‘Long face’ group results

Group 1 (long face) Descriptive Statistics

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See page 159 for definitions of terms
Fig 74: ‘Short face’ group results

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See page 159 for definitions of terms
Fig 3.73 and 74: Definitions of terms

Facial heightt: a measurement in mm of the distance between the nasion and the lower border of the mandible in the midline

Max n dist: the linear distance in mm from the zygoma to the pterygomaxillary fissure

Max n vert angle: the degree of divergence from the horizontal plane of the line 'Max n dist'

Max n hor angle: the degree of divergence from the coronal plane of the line 'Max n dist'

Ovale dist: the linear distance to foramen ovale from the hamular notch

Ovale vert angle: the degree of divergence from the horizontal plane of the line 'Ovale dist'

Ovale hor angle: the degree of divergence from the sagittal plane of the line 'Ovale dist'

Carotid dist: the linear distance to the carotid canal from the hamular notch

Carotid vert angle: the degree of divergence from the horizontal plane of the line 'Carotid dist'

Carotid hor angle: the degree of divergence from the sagittal plane of the line 'Carotid dist'

Nerve dist: the linear distance from foramen ovale to the mandibular foramen when the dentition is articulated

Nerve ant angle: the degree of divergence from the coronal plane of the line 'Nerve dist'

Nerve lat angle: the degree of divergence from the sagittal plane of the line 'Nerve dist'

Closed dist: the linear distance from the hamular notch to the line between foramen ovale and the mandibular foramen at the level of the lower border of the lateral pterygoid plate

Closed vert angle: the degree of divergence from the horizontal plane of the line 'Closed dist'

Closed hor angle: the degree of divergence from the sagittal plane of the line 'Closed dist'

Ovale-LP dist: the linear distance along the line 'Nerve dist' from foramen ovale to the level of the lower border of the lateral pterygoid plate

LP vert: the distance in the vertical plane of the lower border of the lateral pterygoid plate from the hamular notch, measured in mm

LP hor: the linear distance, in the horizontal plane, of the posterior border of the lateral pterygoid plate, at the level of the lower border of the plate, from the hamular notch

Coronoid: the percentage of specimens in which the coronoid process overlies the pterygomaxillary fissure when viewed from norma lateralis

Hidden n %: the percentage of the length of the line 'Nerve dist' that is screened by the lateral pterygoid plate

Exposed n dist: the length of the segment of 'Nerve dist' between the lower border of the lateral pterygoid plate and the mandibular foramen
5.1 Foramen ovale and the carotid canal

Foramen ovale

Foramen ovale has significance for local anaesthesia as it is the point of entry of the mandibular nerve into the infratemporal fossa and is the target of several anaesthetic techniques. The ability to accurately locate foramen ovale relative to one or more landmarks would greatly improve the reliability and safety of anaesthetic delivery. The relationship of foramen ovale to the hamular notch was as follows:

**Distance**

The minimum distance from the hamular notch to foramen ovale was 25 mm and the maximum distance was 37 mm. The mean distance was 29.9 mm and the median score was almost identical at 30 mm. The standard deviation was 2.7 mm and the middle 50% of measurements were within a 3.3 mm range. The overall range was only 12 mm. The frequency distribution is shown in figure 75 and the normal distribution is shown in figure 76. The Q-Q plot (fig 77) shows that the collected data has a high degree of conformity to optimal normal distribution.
Fig 75: The frequency distribution of the distance measurements to foramen ovale

![Histogram showing frequency distribution]

X-axis values are in millimetres

Fig 76: The normal distribution curve of the distance measurements to foramen ovale

![Normal distribution curve]

X-axis values are in millimetres
Fig 77: The Q-Q plot of the distance measurements to foramen ovale

The graph shows the high conformity of the actual measurements (points) with ideal normal distribution (line)

**Vertical angular relationship**

The vertical angulation from the hamular notch to foramen ovale showed a higher than expected degree of variability. The mean (41.0 degrees) and median (42.5 degrees) showed good conformity, but the standard deviation was high at 8.9 degrees. The middle 50% of measurements covered a 16.2 degree band and the overall angular range was some 35 degrees (20 – 55 degrees). The frequency distribution (fig 78) and normal distribution (fig 79) are shown. The Q-Q plot confirms the closeness of fit of the results with the ideal normal distribution (fig 80).
Fig 78: The frequency distribution of the vertical angulation to foramen ovale

![Histogram showing frequency distribution of vertical angulation to foramen ovale.
X-axis measurements are in degrees.]

Fig 79: The normal distribution curve of the vertical angulation to foramen ovale

![Normal distribution curve showing frequency with mean and standard deviation. X-axis measurements are in degrees.]

Mean = 41.63
Std. Dev. = 8.943
N = 54
Horizontal angular relationship

The horizontal angular relationship between the hamular notch and foramen ovale demonstrated an even wider range than did the vertical angular relationship. The mean (0.6 degrees medial to the sagittal plane) and the median (0 degrees, i.e. parallel to the mid-sagittal plane) were again almost identical. The standard deviation was high at 11.3 degrees. The middle 50% of measurements covered a 15-degree band from 5 degrees laterally to 10 degrees medially, relative to the sagittal plane in the line of the hamular notch, and the overall range was high at 45 degrees of arc – from 30 degrees laterally to 15 degrees medially. The negative values in the graphs of the frequency distribution (fig 81) and normal distribution (fig 82) indicate angles that are lateral to the sagittal plane, whereas positive values indicate angles that are medial to the
sagittal plane. The Q-Q plot (fig 83) shows a small degree of variation at
the most lateral angulations.

Fig 81: The frequency distribution of the horizontal angulation to foramen ovale

![Graph](image)

X-axis measurements are in degrees.

Negative values indicate lateral angulation, positive values indicate medial angulation

Fig 82: The normal distribution curve of the horizontal angulation to foramen ovale

![Graph](image)

X-axis measurements are in degrees.

Negative values indicate lateral angulation, positive values indicate medial angulation
The spatial relationship of foramen ovale relative to the hamular notch

The overall spatial relationship between the hamular notch and foramen ovale can be seen in the three-dimensional construct below (fig 84). Although the Z-axis/V5 plane (representing distance) is fairly narrow, the X and Y planes demonstrate the high variability (scatter) of the angular relationships. The three-dimensional graph demonstrates the wide range of variability in the location of foramen ovale relative to the hamular notch.
To better understand the clinical implications of these relationships, the actual circumferential distances over the angles of arc can be calculated using simple geometry. So that:

- At the minimum depth (distance) from the hamular notch (25 mm), foramen ovale has a vertical positional range of variability of 15 mm and a horizontal positional range of variability of 19.6 mm.

- At the mean depth from the hamular notch (30 mm), foramen ovale has a vertical positional range of variability of 18.3 mm and a horizontal positional range of variability of 23.6 mm.

- At the maximum depth from the hamular notch (37 mm), foramen ovale has a vertical positional range of variability of 22.6 mm and a horizontal positional range of variability of 29 mm.
The high degree of positional variability means that it is not possible to predict or determine the position of foramen ovale from superficial landmarks, even when such landmarks are only a short distance from the foramen.
The carotid canal

In respect of mandibular nerve block techniques, the nearest structure of clinical significance to foramen ovale is the carotid sheath, which contains the internal carotid artery, the internal jugular vein and the vagus nerve. Measurements were taken from the hamular notch to the carotid canal to determine not only this relationship but also the proximity of this structure (and hence the carotid sheath) to foramen ovale. The relationship of the carotid canal to the hamular notch was as follows:

**Distance**

The minimum distance to the carotid canal was 34 mm and the maximum was 45 mm. The mean distance was 40.2 mm, with the median value being almost identical at 40.0 mm. The standard deviation was 3.0 mm and the middle 50% of the measurements were between 38.0 and 42.0 mm, a band width of only 4 mm. The overall range was 11.0 mm. The frequency distribution (fig 85) and normal distribution (fig 86) are shown below. The Q-Q plot (fig 87) shows that the measurements have a high degree of conformity to normal distribution.
Fig 85: The frequency distribution of distance measurements to the carotid canal

Fig 86: The normal distribution curve of distance measurements to the carotid canal
Vertical angular relationship

The vertical angulation from the hamular notch to the carotid canal showed a moderate degree of variability. The minimum angulation was 5 degrees and the maximum was 35 degrees. The mean was 19.85 degrees, almost identical to the median of 20 degrees. The standard deviation was 6.9 degrees and the middle 50% of measurements were in a 10 degree range. The overall range was 30 degrees. The frequency distribution (fig 88) and normal distribution (fig 89) are shown. The Q-Q plot (fig 90) shows the closeness of fit of the data to the normal distribution curve.
Fig 88: The frequency distribution of the vertical angulation to the carotid canal

X-axis values are in degrees

Fig 89: The normal distribution of the vertical angulation to the carotid canal

X-axis values are in degrees
Horizontal angular relationship

The horizontal angulation from the hamular notch to the carotid canal showed a somewhat greater degree of range than the vertical angulation. The maximum lateral angulation was 20 degrees lateral to the hamular notch sagittal plane and the maximum medial angulation was 15 degrees. The mean was 1.9 degrees to the lateral, almost identical to the median of 0 degrees (i.e. lying in the sagittal plane). The standard deviation was 7.8 degrees and the middle 50% of measurements were in a 7.6 degree range. The overall range was 35 degrees of arc. The negative values in the frequency distribution (fig 91) and normal distribution (fig 92) indicate angles lateral to the sagittal plane, whereas the positive values indicate angles medial to the sagittal plane. The Q-Q plot (fig 93) demonstrates the closeness of fit of the data to normal distribution.
Fig 91: The frequency distribution of the horizontal angulation to the carotid canal

X-axis values are in degrees

Fig 92: The normal distribution of the horizontal angulation to the carotid canal

X-axis values are in degrees
**Spatial relationship**

The overall spatial relationship between the hamular notch and the carotid canal can be seen from the three-dimensional construct (fig 94). As with foramen ovale, the carotid canal demonstrates a high degree of positional variability with respect to the hamular notch.
The actual circumferential distances were calculated to be:
- At the minimum depth from the hamular notch (34 mm), the carotid canal has a vertical positional range of variability of 17.8 mm and a horizontal positional range of variability of 20.8 mm
- At the mean distance (40 mm), the carotid canal has a vertical positional range of variability of 20.95 mm and a horizontal positional range of variability of 24.4 mm
- At the maximum distance (45 mm), the carotid canal has a vertical positional range of variability of 23.27 mm and a horizontal positional range of variability of 27.5 mm.

The high degree of positional variability means that (like foramen ovale) it is not possible to predict or determine the position of the carotid canal.
from superficial landmarks, even when such landmarks are only a short
distance away.

Discussion

All the data sets for both foramen ovale and the carotid canal
demonstrated a high degree of conformity with normal distribution,
indicating that the results of the study have relevance for normal
populations. The feature of the study that has the most clinical
significance is the range of the variables. These ranges are large,
particular for the data sets for the vertical and horizontal angulations of
both foramen ovale and the carotid canal. Attempts to find relationships
between variables, were unsuccessful. Therefore it is not possible to
predict any of the variables even if one data set is known.

The high degree of positional variability of foramen ovale relative to the
hamular notch means that locating this foramen (for the purposes of local
anaesthetic delivery) by means of superficial landmarks can only be
approximate. However, based on the calculated circumferential distances,
if the mean/median angulations are used as a guide the potential distance
error at the maximum depth is no more than 11 mm in the vertical plane
and 15 mm in the horizontal plane. From the studies of ultrasound guided
regional anaesthesia, deposition of local anaesthetic solution at these
distances from the nerve trunk is likely to prove effective for nerve block provided that sufficient volumes are administered.

The variability of the carotid canal relative to the hamular notch also means that locating the canal by using superficial landmarks can only be an approximation. Comparison of the results of the foramen ovale and carotid canal studies shows that the vertical angular relationship to the carotid canal is shallower than that of foramen ovale, but this may simply reflect the increased distance to the carotid canal from the hamular notch. Of greater importance clinically, the mean difference in distances from the hamular notch to foramen ovale and the carotid canal is 11 mm (fig 95). This measurement confirms the risk of inadvertent penetration of the carotid sheath when attempting extraoral foramen ovale blocks (Rosenberg and Phero, 2003; Rathmell and Pollack, 2007). However, if an approach to foramen ovale were performed from an intraoral insertion point adjacent to the hamular notch, the carotid canal would be 33% further away from the distance needed to reach foramen ovale, based on the statistical means. Such an approach would therefore have a greater margin for safety.
Fig 95: The relationship of foramen ovale (blue arrow) and the carotid canal (red arrow)
5.2 The lateral pterygoid plate

The lateral pterygoid plate and the lateral pterygoid muscle are important structures influencing the path of the mandibular nerve and its branches (Coleman and Smith 1982, Kim et al 2003, Shimokawa et al 2004). This part of the study considers the size and shape of the lateral pterygoid plate by measuring the position of the lower border of the lateral pterygoid plate, relative to the hamular notch, and then the anterior-posterior length of the lower border of the lateral pterygoid plate.

The lower border of the lateral pterygoid plate

The lower border of the lateral pterygoid plate (LPP), relative to the level of the hamular notch, was found to lie in a range from 7 mm above the horizontal plane of the hamular notch to 8 mm below – an overall range variability of 15 mm. The mean was 0.4 mm below the level of the notch and the median score was 0 mm (i.e. level with the hamular notch in the horizontal plane). The standard deviation was 3.4 mm and the middle 50% of scores lay in a 5 mm range, from 2 mm above to 3 mm below. The frequency distribution (fig 96) and normal distribution (fig 97) demonstrate the data. Negative values indicate that the lower border lies above the level of the hamular notch, whereas positive values indicate a lower border below the level of the hamular notch. The Q-Q plot (fig 98) shows the closeness of fit of the data.
Fig 96: The frequency distribution of the vertical relationship values of the LPP

X-axis values are in millimetres

Negative values indicate a level above that of the hamular notch
Positive values indicate a level below that of the hamular notch

Fig 97: The normal distribution curve of the vertical relationship values of the LPP

X-axis values are in millimetres

Negative values indicate a level above that of the hamular notch
Positive values indicate a level below that of the hamular notch
Anterior-posterior length of the lateral pterygoid plate

The distance to the posterior margin of the lower border of the lateral pterygoid plate (LPP) was measured from the suture line at the hamular notch. The minimum distance (horizontal length) was 4 mm and the maximum distance was 19 mm. The mean length of the plate was 10.3 mm, corresponding to the median score of 10 mm. The standard deviation was 3.7 mm and the middle 50% of scores lay between 7 mm and 13 mm (a 6 mm band). The overall range was 15 mm. The frequency distribution (fig 99) and the normal distribution (fig 100) show the data. The Q-Q plot (fig 101) shows one outlier (at the maximal length measurement), but otherwise demonstrates good closeness of fit.
Fig 99: The frequency distribution of the length measurements of the LPP.

X-axis values in millimetres

Fig 100: The normal distribution curve of the length measurements of the LPP.

X-axis values in millimetres
Discussion

A two-dimensional graph (fig 102) was generated to show the relationships of the posterior-inferior corner of the lateral pterygoid plate relative to the hamular notch. The graph demonstrates the high degree of variability in the spatial relationship. Examples of the high variability of the size and shape of the lateral pterygoid plate are shown in figures 103 and 104. The potential clinical implications of this degree of variability will be discussed in section 5.4, in which a model is developed.
Fig 102: Two-dimensional graph showing the variability of the lower margin of LPP relative to the hamular notch.

Points (circles) indicate the posterior-inferior point of the LPP.

Fig 103: An example of the LPP with the lower border (red arrow) far below the level of the hamular notch (blue line), but with a narrow horizontal width.
Fig 104: An example of the LPP with the lower border extending posteriorly to beyond the level of foramen ovale (in the coronal plane, indicated by the dotted line)
5.3 The pterygomaxillary fissure

As with the study of the other anatomical structures the aim was to examine the pterygomaxillary fissure (PMF) from a clinical perspective. The hamular notch was chosen as the initial reference point. However, for the measurements of the PMF, the base reference point was the intersection between the coronal plane that extended through both left and right hamular notches and the zygomatic arch. This point, on the lower border of the zygomatic arch directly lateral to the hamular notch, may be referred to as the (needle) insertion point (fig 105), for it appears to approximate the insertion point in Eriksson’s description of the anterior extraoral maxillary nerve block (Eriksson, 1969).

Fig 105: Eriksson’s approach to the pterygomaxillary fissure
The wooden stick extends from the insertion point to the fissure
Measurements were taken from the insertion point on the zygomatic arch to the PMF to measure the depth (distance), the vertical angulation from the lower border of the zygomatic arch to the PMF, and the horizontal angulation. During the taking of the measurements it was noted that, in some specimens, the coronoid process overlaid the PMF (from the perspective of norma lateralis). In life, this would prevent the insertion of a needle into the PMF from the insertion point. The presence of this feature was recorded and the percentage of specimens which demonstrated this was calculated.

Measurements were analysed for conformity to normal distribution and cross-analysed for relationships (chi-square test). All measurements displayed a very high degree of fit with normal distribution but were shown to be independent of all other variables.

**Distance**

The minimum distance from the zygomatic arch to the PMF was 31 mm and the maximum distance was 48 mm. The mean distance was 37.9 mm and the median score was 38 mm. The standard deviation was 3.9 mm and the middle 50% of results were in a 4 mm band, from 36 – 40 mm. The overall range was 17 mm. The data is shown in the frequency
distribution (fig 106) and normal distribution curve (fig 107). The Q-Q plot (fig 108) shows minor variations at the lower end of the measurements, but this is not statistically significant.

Fig 106: The frequency distribution of the distance measurements to the PMF

X-axis values in millimetres
Fig 107: The normal distribution curve of the distance measurements to the PMF

Fig 108: The Q-Q plot of the distance measurements to the PMF
**Vertical angular relationship**

The entrance to the pterygomaxillary fissure lies somewhat superiorly to the lower border of the zygomatic arch. The minimum upwards angulation was 0 degrees (i.e. on the same horizontal plane) and the maximum upward angulation was 30 degrees. The mean was 14.9 degrees and the median score was 15 degrees. The standard deviation was 6.2 degrees and the middle 50% of scores was between 10 – 20 degrees. The overall range was 30 degrees. The frequency distribution (fig 109) and the normal distribution (fig 110) present the data. The Q-Q plot (fig 111) demonstrates a high closeness of fit of the data.

**Fig 109: The frequency distribution of the vertical angulation to the PMF**

![Graph showing frequency distribution](image)
Fig 110: The normal distribution curve of the vertical angulation to the PMF

Fig 111: The Q-Q plot of the vertical angulation to the PMF
Horizontal angular relationship

The pterygomaxillary fissure lies slightly posterior to the hamular notch. The minimum posterior angulation from the zygomatic arch was 0 degrees, indicating that the fissure lay directly above the hamular notch, and the maximum posterior angulation was 30 degrees. The mean was 16.6 degrees and the median score was 15 degrees. The standard deviation was 8.4 degrees and the middle 50% of scores lay between 10 – 25 degrees. The overall range was 30 degrees. The frequency distribution (fig 112) and the normal distribution (fig 113) present the data and the Q-Q plot (fig 114) demonstrates the closeness of fit of the data to the normal distribution.

Fig 112: The frequency distribution of the horizontal angulation to the PMF

X-axis values in degrees
Fig 113: The normal distribution curve of the horizontal angulation to the PMF

![Normal Distribution Curve]

X-axis values in degrees

Fig 114: The Q-Q plot of the horizontal angulation to the PMF

![Q-Q Plot]

Observed Value vs. Expected Normal Value
Coronoid Process

The coronoid process of the mandible was found to be a potential complicating factor in the use of landmarks to target the PMF. The study found that, from the perspective of norma lateralis, the coronoid process of the mandible overlies the PMF and, as a consequence, screens the PMF from the insertion point in 30% of cases. Examples of this variability are shown in figs 116, 117, and 118. Figure 116 shows the coronoid process lying posterior to the PMF from the perspective of norma lateralis. Figure 117 shows the coronoid process screening the PMF from the insertion point. Figure 118 shows a short coronoid process; however in this case the PMF would be screened by the tendon of temporalis.

Fig 116: The coronoid process lies posterior to the PMF
Fig 117: The coronoid process screens the PMF

Fig 118: A short coronoid process (normal variant)

The PMF would be screened by the tendon of temporalis

Discussion

The spatial relationship of the pterygomaxillary fissure relative to the insertion point on the zygomatic arch is shown below (fig 119). This map demonstrates that there is a significant variability in the position of the pterygomaxillary fissure relative to the superficial landmark. The degree of angular variability, as well as the incidence of potential interference
from the coronoid process, demonstrates that it is not possible to precisely target the pterygomaxillary fissure even if a landmark or reference point is employed.

Fig 119: Three-dimensional map of the relationship between the landmark on the zygomatic arch and the pterygomaxillary fissure

V2 represents the distance, V3 the vertical angle, V4 the horizontal angle
5.4 A simplified model for the anatomical relations of the mandibular nerve for the techniques of nerve block

As a means to better understand the effects that the variability of the anatomical structures might have on the outcomes of mandibular nerve block techniques, a simplified model was developed. This model was based on the linear relationship between foramen ovale and the mandibular foramen. The line between these two foramina was taken to be an approximation of the path of the mandibular nerve and its inferior alveolar branch. Measurements were then taken against this line to create the model.

5.4.1 The relationship between foramen ovale and the mandibular foramen

The relationship between foramen ovale and the mandibular foramen has potential clinical significance for anaesthetic techniques that postulate that the inferior alveolar nerve lies in close proximity to the medial surface of the ramus. The linear spatial relationship between foramen ovale and the mandibular foramen (fig 120) was examined in terms of the distance and the lateral and anterior angular relationship.
Distance

The distance from foramen ovale (FO) to the mandibular foramen (MF) was measured as a direct line and ranged from a minimum of 28 mm to a maximum of 50 mm. The mean distance was 39.3 mm. This was almost identical to the median score of 39.5 mm. The standard deviation was 5.3 mm and the middle 50% of the measurements were within an 8.3 mm range. The overall range was relatively large at 22 mm. The frequency distribution (fig 121) and normal distribution (fig 122) are shown below. The Q-Q plot (fig 123) shows a high degree of conformity between the data and the normal distribution.
Fig 121: The frequency distribution of the distance FO – MF

X-axis values are in millimetres

Fig 122: The normal distribution curve of the distance FO – MF

Mean = 39.26
Std. Dev. = 0.253
N = 34

Measurements are in millimetres
Anterior angular relationship of foramen ovale and the mandibular foramen

The anterior angular relationship is the degree of divergence from the vertical of the straight line from foramen ovale to the mandibular foramen. This measurement is taken with the skull in the normal, upright position and with the occlusal plane set in the horizontal axis. The perspective for this measurement is from norma lateralis, with a coronal plane through foramen ovale as the vertical.

The minimum anterior angle was 0 degrees (i.e. the mandibular foramen was directly inferior to foramen ovale from the lateral perspective). The maximum anterior angle was 35 degrees. The mean was 20.6 degrees, almost identical to the median, which was 20 degrees. The standard
deviation was 6.7 degrees. This was higher than the middle 50% score, which lay in a band of only 5 degrees (20 – 25 degrees). The overall angular range was 35 degrees. The frequency distribution (fig 124) and normal distribution (fig 125) indicate the data. The Q-Q plot (fig 126) demonstrates a high degree of closeness of fit of the data to normal distribution.

Fig 124: The frequency distribution of the anterior angulation of FO – MF

X-axis values are in degrees
Fig 125: The normal distribution curve of the anterior angulation of FO – MF

X-axis values are in degrees

Fig 126: The Q-Q plot of the anterior angulation of FO – MF
Lateral angular relationship of foramen ovale and the mandibular foramen

The lateral angular relationship is the degree of divergence from the vertical of the line between foramen ovale and the mandibular foramen. The measurements were taken with the skull in the normal upright position and the occlusal plane set in the horizontal axis. The perspective for the measurements is from norma frontalis, with the vertical defined by a sagittal plane passing through foramen ovale.

The minimum lateral angle was 0 degrees (i.e. the mandibular foramen was directly inferior to foramen ovale from the frontal perspective). The maximum lateral angle was 40 degrees. The mean was 16.9 degrees, slightly greater than the median, which was 15 degrees. The standard deviation was 10.4 degrees and the middle 50% score was a range of 11.3 degrees (10 – 21.3 degrees). The overall lateral angular range was 40 degrees. The frequency distribution (fig 127) and normal distribution (fig 128) are shown below. The Q-Q plot (fig 129) shows a small divergence of the data from normal distribution, but this is not statistically significant.
Fig 127: The frequency distribution of the lateral angulation of FO – MF

Fig 128: The normal distribution curve of the lateral angulation of FO – MF

X-axis values are in degrees
Discussion

The overall spatial relationship of the mandibular foramen to foramen ovale is demonstrated below (fig 130). The wide range of all three data sets is reflected in the scatter. The three-dimensional graph serves to demonstrate the high degree of positional variability that exists between these two important foramina. The wide variability in the relationship between foramen ovale and the mandibular foramen can be further demonstrated in another graph (fig 131), which presents the perspective from above.
Fig 130: Three-dimensional map of the relationship of the mandibular foramen to foramen ovale

V11 represents the distance, V12 the anterior angle, V13 the lateral angle

Fig 131: Two-dimensional map of the relationship between the mandibular foramen and foramen ovale, viewed from above

Foramen ovale = 0,0 on X-Y axis, V12 = anterior angulation, V13 = lateral angulation
The inference that may be drawn from the two-dimensional graph (fig 131) is that the nerve trunk may well lie in close proximity to the medial surface of the ramus where the two foramina show good approximation in the vertical perspective. However, where the relationship shows a wide divergence in the vertical perspective, the nerve trunk did not necessarily lie in close approximation with the medial aspect of the ramus prior to entering the mandible, but may approach from a wide angle (fig 132). These results suggest that the deposition of local anaesthetic solutions against the medial surface of the ramus, as recommended by many authors (Clarke and Holmes, 1959; Sargenti, 1966; Gow-Gates, 1973; Wolfe, 1992; Malamed, 2004), may not be the optimal site in a percentage of the population.

Fig 132: An example of a wide angular relationship between the FO – MF line (the wooden stick and green line) and the ramus (red line), from the posterior aspect
5.4.2 The screening effect of the lateral pterygoid plate

This part of the study considers the potential screening effect that the lateral pterygoid plate (and, hence, the inferior head of the lateral pterygoid muscle) has on the mandibular nerve and its branches. The mandibular nerve emerges through foramen ovale and descends behind the lateral pterygoid muscle. Thus the lateral pterygoid plate and muscle screen the mandibular nerve (from the anterior or oral perspective) until it emerges from beneath the lower border of the inferior head of the muscle. It is only that part of the inferior alveolar nerve branch which lies between the lower border of the lateral pterygoid muscle and the mandibular foramen that is able to be bathed in local anaesthetic by standard intraoral local anaesthetic techniques which deposit local anaesthetic solution adjacent to the medial aspect of the ramus. Therefore the size and position of the lateral pterygoid plate may have an impact on access to the nerve for local anaesthesia.

The linear relationship of foramen ovale and the mandibular foramen, discussed in section 5.4.1, described as a line, was divided into an upper, ‘hidden’ segment and a lower, ‘exposed’ segment by measuring the distance from foramen ovale to the intersection point of the lower border of the lateral pterygoid plate on the FO – MF line (fig 133).
The measurements of the foramen ovale-lateral pterygoid distance were then converted into a percentage of the total distance. The measurements of the segment from lateral pterygoid to the mandibular foramen were also recorded.

The upper ‘hidden’ segment

The distance from foramen ovale to the intersection point of the lower border of the LPP (FO – LPP segment) ranged from 18 mm to 35 mm. The total range of measurements was 17 mm. The mean was 23.1 mm and the median score was 21.5 mm. The standard deviation was 4.8 mm and the middle 50% of scores lay between 20 – 27 mm. The data are presented the frequency distribution (fig 134) and normal distribution (fig 135) graphs.
Fig 134: The frequency distribution of the measurement of the FO – LPP segment

Fig 135: The normal distribution of the measurement of the FO – LPP segment
The percentage scores of this upper segment range from a minimum of 45% to a maximum of 87% of the FO – MF line, a range of variation of 42%. The mean percentage was 58.9% and the median 59%. The standard deviation was 9.0% and the middle 50% of scores lay between 53.5 – 64%. This data is shown in the frequency distribution (fig 136) and normal distributions (fig 137). The Q-Q plot (fig 138) shows a high degree of fit with the normal distribution.

Fig 136: The frequency distribution of the percentage scores of the FO – LPP segment
Fig 137: The normal distribution of the percentage scores of the FO – LPP segment

Fig 138: The Q-Q plot of the percentage scores of the FO – LPP segment
The lower ‘exposed’ segment

The length of the ‘exposed’ segment from the LPP intersection point to the mandibular foramen (LPP – MF segment) ranged from a minimum of 5 mm to a maximum of 24 mm (an overall range of 19 mm). The mean was 16.12 mm, almost identical to the median score of 16 mm. The standard deviation was 4.21 mm and the middle 50% of scores lay between 13.75 – 19.25 mm (a range of 5.5 mm). The data are presented in the frequency distribution (figs 139) and normal distribution (fig 140).

Fig 139: The frequency distribution of the measurement of the LPP – MF segment

X-axis values are in millimetres
Discussion

The lateral pterygoid plate has been shown to have a high degree of variability (section 5.2) and this is reflected in the wide range of screening values of the FO – MF line. Of greater potential clinical significance is the length of the lower segment – the ‘exposed’ section – of the FO – MF line, as it is this segment which is most likely to be bathed in local anaesthetic solution for nerve block. The length of nerve trunk that is exposed to local
anaesthetic agents has been shown to be an important factor in achieving successful nerve block (Raymond et al, 1989; Taboada et al, 2006). These results suggest that the lateral pterygoid plate and muscle may have a negative impact on nerve block outcomes in a percentage of the population.
5.4.3 Nerve path anatomy for the closed-mouth nerve block techniques

The closed-mouth inferior alveolar nerve block was pioneered by Vazirani (1960). Akinosi (1977) and Wolfe (1992) also published closed-mouth approaches for the inferior alveolar nerve block. However, these techniques all differ in their targeting of the nerve bundle. This part of the study considered the relationship between the FO – MF line and the hamular notch as, in all three published techniques, the insertion point of the needle is immediately adjacent to the hamular notch. The distance to the nerve path and the vertical and horizontal angular relationships were measured.

**Distance**

The distance from the hamular notch to the FO – MF line was measured at the point of intersection with the lower border of the LPP. The lower border of the lateral pterygoid plate represents the highest possible level at which a closed-mouth nerve block may be given without penetration of the lateral pterygoid muscle. The minimum distance was 15 mm and the maximum was 25 mm, giving a range of 10 mm. The mean was 20.4 mm and the median 20 mm. The standard deviation was 2.3 mm and the middle 50% lay between 19 – 22 mm. The frequency distribution (fig
141) and normal distribution (fig 142) are shown below. The Q-Q plot (fig 143) shows the high level of conformity with normal distribution.

Fig 141: The frequency distribution of the distance to the FO – MF line

![Graph showing frequency distribution](image)
Fig 142: The normal distribution of the distance to the FO – MF line

Fig 143: The Q-Q plot of the distance to the FO – MF line
Vertical angulation

Because of the vertical variability of the lower border of the lateral pterygoid plate, the angular relationship between the hamular notch and the intersection point was also variable.

The vertical angle ranged from 10 degrees superiorly (from the horizontal plane) to 20 degrees inferiorly, a range of 30 degrees. The mean was 1.5 degrees inferiorly and the median 0 degrees (i.e. horizontal). The standard deviation was 8.0 degrees and the middle 50% lay in a 10 degree range, from 5 degrees superiorly to 5 degrees inferiorly. The data is presented in the frequency distribution (fig 144) and normal distribution (fig 145). The Q-Q plot (fig 146) shows slight variation at the ends of the range, but this is not statistically significant.
Fig 144: The frequency distribution of the vertical angulation to the FO – MF line

X-axis values in degrees
Negative numbers indicate angulations above the horizontal plane
Positive numbers indicate angulations below the horizontal plane

Fig 145: The normal distribution of the vertical angulation to the FO – MF line

X-axis values in degrees
Negative numbers indicate angulation above the horizontal plane
Positive numbers indicate angulations below the horizontal plane
Horizontal angulation

The variability in the position of foramen ovale and the variation in the angular relationship to the mandibular foramen (section 5.4.1) means that the horizontal relationship of the FO – MF line to the hamular notch must also be variable.

The range of angular variation is 50 degrees, from 10 degrees medially to the hamular notch (sagittal plane) to 40 degrees laterally. The mean is 19.4 degrees laterally, with the median being 20 degrees laterally. The standard deviation is 14.0 degrees and the middle 50% of scores lies between 10 – 30 degrees laterally. The data is presented as the frequency distribution (fig 147) and normal distribution (fig 148). The Q-Q
plot (fig 149) shows minor variations, but these are not statistically significant.

Fig 147: The frequency distribution of the horizontal angulation to the FO –MF line

X-axis values in degrees

Negative values indicate lateral angulation, positive values medial angulation
Fig 148: The normal distribution of the horizontal angulation to the FO – MF line

Fig 149: The Q-Q plot of the horizontal angulation to the FO – MF line
Discussion

The horizontal spatial relationship between the hamular notch and the FO – MF line is demonstrated in the two-dimensional graph (fig 150). The graph provides visual evidence of the potential variability of the path of the nerve trunk where it emerges from behind the lateral pterygoid plate and muscle.

Fig 150: Two-dimensional graph of the distance (V14) from the hamular notch against the horizontal angulation (V16) to the FO – MF line

The three closed-mouth techniques recommend various depths of needle insertion. Vazirani (1960) recommended 15 mm; Akinosi (1977) recommended 25-30 mm; and Wolfe (1992) advocated 20 mm as a maximum. The range of distance measurements from the hamular notch
to the FO – MF line, in this study, ranged from 15 mm to 25 mm, which is 
conformity with the recommendations of all three techniques.

The variability in the horizontal angular relationship between the hamular 
notch and FO – MF line suggests a similar degree of clinical variability of 
the position of the nerve trunk and this is a factor that has not been 
considered in these techniques. More significantly, none of these 
techniques has considered the variability of the lateral pterygoid plate and 
muscle as a possible complicating factor in the administration of local 
anaesthetic, either by the effect of screening of the nerve or by 
inadvertent penetration of the muscle by the needle.
5.5 Commentary: the limitations of the present study

The present study examines 34 dried skull specimens, from almost 150 specimens in the various collections, which were found to be suitable for the research. This demonstrates the major problem in the field of anatomy, which is that research material is quite difficult to obtain. In respect of anatomical research 34 specimens constitutes a medium-size study. Many published studies are based on far fewer specimens, e.g. Coleman and Smith (1982). The study by Bremer (1952) is remarkable and almost unique for having collected 400 specimens.

However, with such small numbers meaningful statistical analysis can prove difficult. The specimens were not analysed in respect of either gender or ethnicity for the same reasons that are seen in the division of the 34 specimens into two facial height groups – the numbers become too small to have meaning.

Because of the small size of the study, an attempt was made to assess its relevance in a more general population. To this end the Q-Q plots were created for the various data sets. The Q-Q plot compares the actual data to a hypothetical normal distribution, which is based on statistical normative values embedded within the SPSS programme. The closer the study values approximate the ideal line, the more likely are the data to have general application. The collected data sets all show a high degree
of fit in this respect and on this basis they have been applied to the general discussion which follows. The statistical opinion of the data sets is that they represent normal distribution, but that a larger study would produce a wider range of values.

Regional Anatomy

The basic anatomy of the trigeminal nerve has been understood for centuries and well recorded in classic texts. However what is detailed and discussed in these texts is a normative concept and, in general, there is little or no discussion of normal variability. This is because anatomy texts consider the pathways and relationships of structures in relative terms, rather than by measurement. This view of anatomy has carried over into the clinical realm and most discussions on local anaesthetic technique, and the failures of local anaesthesia, only consider the anatomy in general terms. Malamed (2004) describes the path of the mandibular nerve according to the traditional anatomical presentation: the nerve trunk descends from foramen ovale for a short distance downward, medially to the lateral pterygoid muscle (Davies, 1967; Malamed, 2004). Branching from this, the inferior alveolar nerve descends medial to the lateral pterygoid muscle and lies posterior and lateral to the lingual nerve (Davies, 1967; Malamed, 2004). When it reaches the region between the sphenomandibular ligament and the medial surface of the ramus, it enters the mandibular foramen (Davies, 1967; Malamed, 2004). When Malamed (2004) describes the osteology of the maxilla and mandible, he discusses the two bones in
isolation and does not consider their relationships either to each other or to the general anatomy of the region. Although his discussion is more detailed than many authors, Malamed’s description still follows the textbook anatomical perspective rather than considering the structures from a clinical perspective (Malamed, 2004). Malamed (2004) does not relate the path of the nerve to the structures of the mouth, nor is it described in terms of how it would be perceived from the perspective of a clinician examining a patient. In terms of the administration of local anaesthetic, Malamed (2004) provides no description of the relationships that the needle has to the target area. Malamed (2004) does acknowledge some anatomical variability, with the observation that bifid inferior alveolar nerves have been found and double mandibular canals have been observed on radiographs, citing an incidence of 0.95% of such cases. However, that is the extent of his discussion of this issue. Van Eijden and Langenbach (2009) similarly describe the classic, textbook anatomy, but fail to consider any variability.

Anatomical variation of the mandibular nerve has been often acknowledged, but it has been generally consigned to the realm of anomaly. Desantis and Liebow (1996) list four ‘anomalies’ that might affect successful mandibular nerve block anaesthesia:

- cross links from the mylohyoid nerve
- a bifid mandibular nerve
- additional sensory supply from the facial nerve or cervical nerve plexus via a retromolar foramen
- contralateral crossover of nerve fibres in the midline of the mandible.

Desantis and Liebow (1996) claim that the incidence of such variations is exceedingly small. However, anatomical research over the years has demonstrated that the presumed anatomical consistency is far less common than might be supposed for such a relatively small area as the infratemporal fossa.

The foramina of the mandibular nerve

In 1952, Bremer studied 400 mandibles and demonstrated that a significant degree of variation existed in the position of the mandibular foramen in respect of the mandibular dentition. He also demonstrated that the relationship between the lingula and the mandibular foramen possessed much greater range of variability that previously supposed (Bremer, 1952). Bremer’s (1952) measurements demonstrated a situation that was significantly different from the prevailing ideas of the clinicians of the day. Bremer’s (1952) results showed that the position of the lingula varied from the level of the occlusal plane, in the vertical dimension, to up to 19 mm above it. Although 90 per cent of specimens showed the vertical range to be less than 9 mm, 10 per cent of cases had a vertical range from 10 to 19 mm above the occlusal plane. More significantly, in
42% of the specimens the lingula was 0 – 3 mm above the occlusal plane and it was no more than 5 mm above the occlusal plane in 63% of cases. From these data, Bremer (1952) concluded that a presumptive height for the mandibular foramen of 10 mm above the occlusal plane could not be seen as a normative value. Yet 10 mm still remains the assumed normative value used for injection techniques (Malamed, 2004).

As well as finding that the range of variation in the vertical relationship of the lingula and the mandibular occlusal plane was surprisingly large, Bremer (1952) also found that presumptions concerning the relationship between the lingula and the mandibular foramen were also incorrect. Bremer found that the mean distance between the tip of the lingula and the mandibular foramen was 8.3 with the standard deviation being 2.32 mm. The range of this distance varied from 2 mm to 14 mm (Bremer, 1952). This outcome shows that using the lingula as a target for the inferior alveolar nerve may be less reliable than presupposed.

Bremer (1952) placed his results in a clinical context. He cited other studies that reported the depth of needle penetration required to reach the lingula. He quoted the various reports on the horizontal range – from ‘10-35 mm, ‘15-20 mm’, ‘18-20 mm’, ‘20-25 mm’ etc. – to demonstrate the lack of consensus. Bremer’s own measurements demonstrated that the mean depth was 23.67 +/- 0.31 mm (Bremer, 1952). Although written almost 60 years ago, Bremer’s (1952) article is still significant for it
highlights the high degree of variability in the normal anatomy of the mandibular foramen.

In a more general study, Berge and Bergman (2001) found significant variations in size and shape of the various foramina of the human skull, in particular foramen ovale, the mandibular foramen and the mental foramen. Foramen ovale showed a significant range in size, from 5 x 2 mm to 8 x 7 mm, with an average of 7.11 x 3.6 mm (Berge and Bergman, 2001). Fifty-eight percent of the specimens showed bilateral asymmetry of foramen ovale and there were other variations, such as partial or complete confluence with foramen lacerum, foramen spinosum and/or the foramen of Vesalius (Berge and Bergman, 2001). The mandibular foramen varied in size from 1 x 1 mm to 6.5 x 6 mm, with an average of 3.29 x 3.51 mm, but it showed a high degree of bilateral symmetry (92%) (Berge and Bergman, 2001). The mental foramen also had a wide range in size, from 0.52 x 0.52 mm to 5.5 x 3 mm (average 2.43 x 1.76 mm). The mental foramen had bilateral symmetry in 80% of cases, but 1% had double foramina and another 1% had triple foramina (Berge and Bergman, 2001). However, unlike Bremer (1952), the authors did not examine the relative or absolute positional relationships of the various foramina.
The anatomy of the mandibular nerve

Branching patterns

Kim et al (2003) studied the mandibular nerve in respect of its supply to the lateral pterygoid muscle. They found significant variation in the branching pattern of the nerve and the source of supply. Innervation to the superior head of the lateral pterygoid muscle came from the buccal nerve in 45.8% of cases and the nerves innervating the inferior head of the lateral pterygoid originated from both the buccal and mandibular nerve trunk in 58.3% of cases (Kim et al, 2003). Kim et al (2003) found additional nerve branches in almost 46% of the cases studied. The authors pointed out the discrepancy between their findings and the descriptions contained in anatomy textbooks and they considered that these discrepancies were clinically significant in the management of disorders of the lateral pterygoid muscle (Kim et al, 2003). Shimokawa et al (2004) studied the relationship between the mandibular nerve and the muscles of mastication. They found examples where the auriculotemporal branch penetrated the lateral pterygoid muscle, the lingual nerve penetrated the medial pterygoid muscle, and the mylohyoid nerve penetrated the mylohyoid muscle (Shimokawa et al, 2004). The lack of any previous reporting of these findings was noted, as was the potential significance that these variations had for the nerves to be affected by myalgia, neuralgia and neuropathy (Shimokawa et al, 2004).
The mylohyoid nerve

There has been debate for many years regarding the potential for the mylohyoid nerve to carry sensory fibres to the mandibular dentition. Sillanpaa et al (1988) conducted a trial in which local anaesthetic was deposited below the mylohyoid muscle to anaesthetise the mylohyoid nerve. They found partial anaesthesia of the mandibular dentition was achieved in 21% of the subjects (Sillanpaa et al, 1988). The authors claimed that this outcome demonstrated that the mylohyoid nerve, considered to contain solely efferent (motor) neurones, could carry sensory supply to the mandibular teeth (Sillanpaa et al, 1988). Stein et al (2007) published a review of studies on the mylohyoid nerve and also concluded that the nerve could carry sensory fibres and could enter the mandible at points along the medial (lingual) aspect of the bone. They found that the origin of the mylohyoid nerve was variable and could arise from the inferior alveolar nerve sufficiently far from the point of deposition of anaesthetic, delivered by the standard technique, to remain unaffected by the anaesthetic (Stein et al, 2007). Conversely, Jablonski et al (1985) had previously found that the mylohyoid nerve could arise from the lingual nerve and that the buccal nerve could arise from the inferior alveolar nerve. They estimated these variations to occur in approximately 6% of their study population, which was from southern China (Jablonski et al, 1985). Coleman and Smith (1982), however, rejected the idea that supplementary innervation from the mylohyoid nerve was a cause of the failure of local anaesthetic to achieve
blockade of the inferior alveolar nerve, although they acknowledged that
the mylohyoid nerve did occasionally innervate the lower incisor teeth. In
their opinion, the mylohyoid nerve would have to branch from the inferior
alveolar nerve significantly above its usual site of origin, near the
mandibular foramen, in order to avoid the effects of anaesthetic deposited
at the foramen (Coleman and Smith, 1982). These differing views remain
unresolved.

The microanatomy of the mandibular nerve

In 1993, Zoud and Doran reported significant variations in the structure of
the inferior alveolar nerve. They noted that there were a number of
differing observations regarding the structure of the nerve, but that a
general consensus persisted, which was that the nerve was a single trunk
(Zoud and Doran, 1993). However, Zoud and Doran (1993) found that the
inferior alveolar nerve often formed a plexus after arising from the
mandibular nerve. They found that the so-called trunk of the nerve was,
in their words, ‘a meshwork of nerves with much fine branching and re-
branching’ (Zoud and Doran, 1993). Also of importance, the authors found
that there were numerous cross-communications between the individual
components (Zoud and Doran, 1993). These communications included fine
fibres that linked to the auriculotemporal nerve, both before and after its
origin. More importantly from the clinical perspective, the authors
observed in one of their specimens nerve fibres entering the mandible
through the retromolar fossa (Zoud and Doran, 1993). Zoud and Doran (1993) also found that the vasculature associated with the inferior alveolar nerve was intertwined with the nerve rather than being in approximation but distinct from it. These variations matched those found within the mandible by Carter and Keen (Carter and Keen, 1971). Roy et al (2002) noted variations in the origin of the inferior alveolar nerve, in which the nerve branch originated from two roots. They also found examples where the maxillary artery was seen to perforate the inferior alveolar nerve trunk (Roy et al, 2002).

Other anatomical structures

Akinosi (1977) disputed the concept of anatomical precision for nerve block anaesthesia. He noted that problems with the standard mandibular nerve block technique can occur when there are anatomical variations in the shape and size of the mandible, because these may make accurate localisation of the mandibular fossa difficult (Akinosi, 1977). He also noted that the width of the ascending ramus and its angle of divergence would affect the position of the mandibular foramen relative to the superficial anatomy (Akinosi, 1977). Akinosi (1977) opined that such variations could cause the standard inferior alveolar nerve block to fail in over 15% of cases. The variability of the width and angle of flare of the ramus was also considered by Milles (1984) in his discussion on failures of mandibular nerve blocks.
In 1982, Coleman and Smith challenged the anatomic precepts underlying the Gow-Gates block. They based their arguments on findings from dissections that they undertook to examine Gow-Gates’ (1973) and Watson’s (1973) explanation of the anatomical underpinnings of the technique. Their study indicated that the lateral pterygoid muscle was too large to permit the diffusion of anaesthetic to the nerve trunk at the level claimed by Gow-Gates (Coleman and Smith, 1982). The weakness in Coleman and Smith’s argument was that it was based on only two dissections.

Coleman and Smith’s (1982) conclusions are based on the assumption that what they observed in their dissection was the general, normal anatomy, with the implication that this was invariable. However this cannot be assessed from their study. The difference of anatomical opinions, between Watson (1973), Gow-Gates (1973) and Coleman and Smith (1982), should have prompted further study into the issue. However, no further investigation has been published.

The variability of the posterior aspect of the lateral pterygoid plate and the pterygospinous ligament was reviewed by Koepsell (2006). This study found significant variability in the shape of the lateral pterygoid plate, particularly in the area of the ligament, which can be partially or fully ossified (Koepsell, 2006). These ossifications can create lacunae or even foramina in the lateral pterygoid plate through which the mandibular nerve passes (Koepsell, 2006).
3.2 Recent advances in nerve block techniques

Introduction

The successful delivery of local anaesthetic sufficiently close to the target nerve has posed a challenge to clinicians for decades. Conventional methods for nerve or plexus blockade, for both medical and dental regional anaesthesia, rely on the identification of surface anatomical landmarks (Urmey, 2007). These landmarks provide the starting point from which to search for the target nerve (Urmey, 2007). Urmey (2007) identified two types of ‘endpoint’, that is the position at which the anaesthetic solution is to be deposited within the tissues. The anatomic endpoint is defined by the particular structures (nerves or other tissues) in the deep tissue planes (Urmey, 2007). The functional endpoint is defined by the patient’s response to either the presence of the needle or the effect of the local anaesthetic solution (Urmey, 2007). The use of anatomic landmarks can sometimes be of limited value when employed with conventional targeting techniques because of individual variations (Urmey, 2007). Traditional techniques for targeting can be further complicated by the use of measurements and geometric calculations or through the use of arbitrary guidelines (Urmey, 2007). Recently, the functional endpoint for nerve targeting has been achieved through the use of nerve stimulation. The position of the needle is assessed by monitoring the nerve’s response to single or multiple electrical inputs that are delivered to the tissues in the
vicinity of the target nerve (Urmey, 2007; Casati and Putzu, 2007). However, these techniques are still considered to be “blind” procedures, often requiring a trial and error approach (Perlas and Chan, 2007).

As in medicine, conventional methods of nerve targeting in dentistry have relied on the use of superficial anatomical landmarks to identify an appropriate injection point followed by the explorative advancement of the needle to locate a pre-identified anatomic endpoint (Bremer, 1952; Gow-Gates, 1973; Malamed, 2004). The targeting of the nerve has also, on occasion, involved the use of geometric calculations (Sargenti, 1966).

Most recently another technique for nerve targeting has involved the use of ultrasound guidance (Gray, 2007; Urmey, 2007). Recent advances in ultrasound technology have meant that this technique is currently being viewed as the ‘gold standard’ for regional anaesthesia in medicine (MacLennan, 2007).

Ultrasound guided regional anaesthesia

Ultrasound imaging utilises high-frequency sound waves in the range of 3-17 MHz (Gray, 2007). Within this range it is the upper end (10-15 MHz) that provides the highest degree of resolution (Chan, 2009 [a]). The limitation with higher frequencies is the depth of penetration, which is only 20-30 mm (Chan, 2009 [a]). For deeper tissue penetration (up to 60 mm) the
lower frequencies (2-5 MHz) must be used, but the images that are produced by these frequencies are greatly reduced in quality (Chan, 2009 [a]). The development of transducer-receivers that have a larger surface area, combined with improved computer software, has allowed the clear identification of individual structures (including colour Doppler imaging of arteries and veins), the path of the anaesthetic needle, and even the real-time dispersion of local anaesthetic (figs 66, 67, 68).

Fig 66: Ultrasound image of the axillary artery and veins

The upper picture shows the standard imaging, the lower picture shows the effect of colour Doppler enhancement

AA = axillary artery (red Doppler)

AV = axillary vein (blue Doppler)

From: www.usra.ca, 2009
Fig 67: Ultrasound image of the needle insertion for an axillary nerve block

Arrows show needle within the tissue plane

M = median nerve
U = ulnar nerve
R = radial nerve
H = head of humerus

From: www.usra.ca, 2009

Fig 68: Ultrasound image of local anaesthetic deposition

Arrows = needle
U = ulnar nerve
R = radial nerve
LA = shadow caused by inflow of local anaesthetic

From: www.usra.ca, 2009
As a result of the high quality imaging now being achieved, there have been numerous studies published within the past few years. Perhaps most importantly, ultrasound guidance has been demonstrated to be more reliable in the targeting of nerve trunks than either nerve stimulation or traditional localisation techniques for regional anaesthesia of the upper and lower limbs (Marhofer et al, 1997; Casati et al, 2007; Chan et al, 2007; Perlas et al, 2008; Kapral et al, 2008). As well, the ability to use real-time imaging of the deposition of the local anaesthetic solution has demonstrated a number of significant factors relevant to nerve block techniques.

All the nerve trunks that have been studied with ultrasound imaging have been found to have significant structural and positional variability (Chin et al, 2008; Chan, 2009 [b]). Nerve trunks have been found to exist as single or multiple trunks, or even in lamellar or plexiform arrangements (Chan, 2009 [b]). They may also exist in different locations or in different tissue planes, for example on the opposite side of structures (such as blood vessels and muscles) than is described in standard anatomy texts (fig 69) (Chin et al, 2008; Chan, 2009 [b]). These findings are mirrored in anatomical dissection studies of the inferior alveolar nerve (Jablonski et al, 1985; Sillanpaa et al, 1988; Zoud and Doran, 1993; Kim et al, 2003; Shimokawa et al, 2004; Stein et al, 2007). It is because of this degree of normal variability that ultrasound guidance has proved beneficial through its ability to visualise the actual position of the targeted nerve trunk (Chan, 2009 [a]).
Ultrasound studies have shown that precise targeting of the target nerve trunk is not essential for successful anaesthesia. Hannan et al (1999) used an intra-oral ultrasonic transducer to demonstrate that the deposition of local anaesthetic solution immediately adjacent to the inferior alveolar nerve did not result in an increase in the percentage of successful nerve blocks over the deposition of the solution within the pterygomandibular fossa in the vicinity of the nerve trunk. Recent studies on peripheral nerve trunk anaesthesia have confirmed that deposition of local anaesthetic solution immediately adjacent to a nerve trunk does not improve clinical outcomes, whether measured in terms of time to onset of anaesthesia, depth of anaesthesia, or duration of anaesthesia (Casati and Putzu, 2007; Chan et al, 2007; Chan, 2009 [c]). However, studies have demonstrated that deposition of local anaesthetic within the correct tissue plane is essential.
to successful anaesthesia and that this can be confirmed by observation of the dispersion of the local anaesthetic solution to engulf the targeted nerve trunk (www.usra.ca, 2009; Chan, 2009 [a]). Significantly, it has been shown that other anatomical structures (such as blood vessels) lying within the tissue plane can impede, or even prevent, the diffusion of the local anaesthetic solution along the tissue plane to reach the nerve trunk (Abrahams et al, 2008).

Ultrasound studies have also confirmed that the volume of local anaesthetic that is deposited is a significant factor in achieving a clinically successful outcome (Ifeld et al, 2008; Taboada et al, 2006). Increasing the volume of the deposited solution has been shown to bathe longer sections of the nerve trunk in local anaesthetic and achieve a higher percentage of successful outcomes (Taboada et al 2006). Increasing the concentration of local anaesthetic in the solution has also been shown to improve the success rates for nerve block, but this is not as effective as increasing the volume and the difference in the rates of success is significant (Ifeld et al, 2008). The improvement in the rates of successful clinical outcomes for dental anaesthesia through the deposition of increased volumes of local anaesthetic solutions has also been demonstrated in studies of both infiltration anaesthesia and inferior alveolar nerve block (Vreeland et al, 1989; Brunetto et al, 2008).
An important finding demonstrated by ultrasound imaging is that the penetration of nerve trunks by needles during the deposition of local anaesthetic solutions does not result in lasting damage to nerves (Hogan, 2008; Hebi, 2008). Instead, nerve damage effects (such as paraesthesia and paresis) have been shown to be solely due to the local anaesthetic agents (Hogan, 2008), particularly when local anaesthetic is injected within the nerve trunk (Hebi, 2008).

The high degree of accuracy that ultrasound guidance provides for nerve targeting might be expected to result in a 100% success rate for clinical outcomes. However, Chan’s (2009) review of a number of studies has shown that there is still significant variability in the rates of successful outcomes (Chan, 2009 [c]). While some studies have claimed successful outcome rates of 97-99%, most have rates of success to the order of 85-95% or thereabouts (Chan, 2009 [c]). The onset times for surgical anaesthesia, when local anaesthetic was deposited by ultrasound guidance) still ranged from five to fifteen minutes, although this represented a significant improvement over onset times for nerve blocks that utilised nerve stimulation or traditional targeting techniques (Chan, 2009 [c]).

The apparent success of ultrasound guided regional anaesthesia has raised hopes that all potential complications of local anaesthetic nerve block can be overcome (Hebi, 2008). However, problems such as
mechanical nerve trauma and intravascular injection still persist (Swenson and Davis, 2008; Shankar, 2008). This has led to an ongoing discussion concerning the often highly optimistic clinical expectations and actual outcomes (Hadzic et al, 2008). These issues will only be resolved with continuing research and clinical reports.
3. A Review of Recent Research in Local Anaesthesia

3.1 Recent concepts in nerve structure and physiology and the pharmacology of local anaesthetics

Introduction

In most clinically focussed presentations, the problems with achieving acceptable levels of anaesthesia and the adverse effects of the various local anaesthetic agents form important points for discussion. However, the limited information on the interaction of local anaesthetic drugs with the sodium channel that has to date been available has resulted in a quite simplistic view of this fundamental aspect of local anaesthetic pharmacology (Tetzlaff, 2000).

Haas (2002) described local anaesthetics as simply blocking ‘the entry of sodium ions into their channels’. Although referring to the concepts of molecular dissociation (pKa) and tissue pH, Haas appeared unable to elaborate on their implications for the achievement of nerve block (Haas, 2002). Subramaniam and Tennant (2005) described the action of local anaesthetics as impeding the permeability of the nerve cell membrane to the influx of sodium ions. They were able to note that local anaesthetic agents linked with specific receptor sites on the sodium ion channel which
they described as ‘intracellular’, but they did not explain that it is the undissociated form of the anaesthetic molecule that passes through the cell wall while it is the dissociated form that links to the ion channel receptor site (Subramaniam and Tennant, 2005). The authors were able to provide a paragraph to explain the importance of tissue pH and its effect on the dissociation constant (pKa) of local anaesthetic agents in reaching and permeating the nerve cell (Subramaniam and Tennant, 2005). Becker and Reed (2006) described the action of local anaesthetics in one sentence, simply stating that these molecules entered the sodium channels and prevented them from assuming an active or “open” state. They were able to provide one paragraph on a discussion of pKa and pH, before moving onto the wider issues of local anaesthetic toxicity and allergy (Becker and Reed, 2006). Frankhuijzen (2009) identified the fact that the anaesthetic molecule enters the ‘open’ sodium channel, thereby effecting conduction blockade. However, the author then made an unreferenced statement that the passage of the anaesthetic molecule through the cell membrane caused membrane expansion, which was responsible for ‘approximately 10% of the total activity of most local anaesthetics’ (Frankhuijzen, 2009). This effect has been studied. De Paula and Schreier (1996) found that local anaesthetic agents could create micelle-like aggregates (small vesicle-like structures) within the cell membrane bi-layer. The authors found that this effect might account for neurotoxic effects of local anaesthetic agents, but that it did not enhance anaesthesia (De Paula and Schreier, 1996). Choi et al
(2000) also found that intra-membranous expansion could occur, but that this made no contribution to the achievement of anaesthesia.

These references demonstrate the lack of information that has been available to clinicians. However, recent studies in the structure and function of the nerve cell membrane and sodium ion channel can provide much new information about the action of local anaesthetic in achieving nerve blockade. Much of this research has come from studies on the structure and function of the ion channel which have used local anaesthetics as research tools. As a result, a much clearer understanding of how local anaesthetic agents act is now available. This information fills a significant gap that still exists in the clinical literature.

**Sodium channel activity and local anaesthetics**

The basic action of the sodium channel has been well known for decades. When an action potential is generated in a nerve or muscle cell, the cell membrane’s permeability to sodium ions increases by approximately 600-fold and these ions enter the cell via the sodium channels (Vander et al, 1975). The actual numbers of sodium ions that enter the cell at any one point are, however, very few – it is estimated that this is of the order of $4 \times 10^{-12}$ eq. per cm$^2$ (White et al, 1968; Hille, 2001). Yet this small influx of sodium ions is sufficient to cause the trans-membrane potential difference to change from -70 mV to +30 mV at the site (Vander et al, 1975). The
duration of this change is 1.0 msec, which is long enough to affect the adjacent areas of the cell and produce a wave of depolarisation. After this, the cell membrane returns to its resting state (Stryer, 1975; Vander et al, 1975).

Hille (2001) found that sodium channels first activate and then inactivate. During the membrane depolarisation that occurs in the propagation of an action potential, the sodium channel opens rapidly (activation). Then the membrane repolarises causing a rapid closing of the channel (inactivation). The opening and closing transition of the sodium channel not only creates a physical pathway for the passage of sodium ions, it also changes the binding energies of the channel. This change can allow a wide variety of drugs and toxins, including local anaesthetic, to bind to a number of different sites on the channel macromolecule. This effect was called ‘state-dependent binding’ by Hille (2001).

Local anaesthetic agents can only bind to the sodium channel when it is in the activated (open) state (Hille, 2001). Once the anaesthetic has bound to its specific receptor site the channel becomes inactivated. The duration of the nerve block is dependent on maintaining the sodium channel’s inactivated state (Hille, 2001). As well as binding to the sodium channel, local anaesthetics also induce a hyperpolarising shift in the steady-state inactivation curve, which slows the rate of recovery of the sodium channels from the inactivated state (Ribeiro and Costa, 2003).
An important feature of the sodium channels is that over 95% of the sodium ion channels inactivate with a single membrane depolarisation to 0 mV and beyond (from the resting state of -70 mV) (Hille, 2001). Once a sodium channel is inactivated, the nerve cell membrane must be repolarised or hyperpolarised, often for a period of many milliseconds, to remove the inactivation (Hille, 2001). If the area of repolarisation is too small, or the duration of repolarisation too short, the sodium channels remain inactivated (Hille, 2001). The failure to remove the inactivation means that the local anaesthesia will be unable to block the sodium channel, since the anaesthetic can only bind with the receptor site when the channel is open (Hille, 2001).

Maintaining the open, activated state also has an adverse effect on local anaesthetic block. Hille (2001) noted that certain reactive agents and enzymes within the axon can eliminate the inactivation phase of the sodium channels. Lowering intracellular pH and calcium ion concentration also eliminates the inactivation phase, reducing the anaesthetic effect (Hille, 2001). Further, even when the local anaesthetic molecule is bound within the sodium channel a sufficiently large hyperpolarisation of the cell membrane will overcome the inactivated state of the sodium channels and cause them to reopen (Mulroy, 2002).
While the local anaesthetic molecule can only bind with the ion channel when it is open, it is only temporarily trapped when the channel closes. This is due to the sodium channel having a higher affinity for the local anaesthetic molecule when it is in the open state and a lower affinity when it is in the resting state (Li et al, 1999). Hille (2001) reported that the local anaesthetic molecule can leak from the closed channel because of its lipophilic component and that this can occur over a period of a few hundred milliseconds. This transience is offset by repetitive membrane depolarisations, which produce accumulation of local anaesthetic molecules within the sodium channels and continuing re-binding of the molecules within the ion channel (Hille, 2001). Hille (2001) called this effect ‘use-dependent block’. For local anaesthetic to maintain its blocking effect there must be short time intervals between membrane depolarisations, otherwise the use-dependent block wears off spontaneously (Hille, 2001). According to Hille (2001), the inactivation of the ion channels can wear off in less than a minute when the nerve cell is at rest, enabling the axon to transmit a subsequent impulse. Fortunately for the clinical effectiveness of local anaesthetic, pain fibres have low conduction velocities but high signal frequencies (Mulroy, 2002). According to Mulroy, when stimulated, nociceptive fibres produce more action potentials than other nerve cells, such as motor neurones. The more action potentials produced, the more often the sodium channels are opened. The higher frequency of impulse production means that use-dependent block is more effective in pain fibres than in other sensory, or even motor, neurones (Mulroy, 2002).
The structure of the sodium channel and the action of local anaesthetic within it

Since Hille (2001), there have been a series of advances in the understanding of the structure of the sodium channel. The concept of its structure has been refined from that of simple tubes to more complex molecular shapes and models. Sato et al (2001) used cryo-electron microscopy and x-ray crystallography to determine the physical structure of the sodium channel (fig 58). The overall shape of the sodium channel was described by Sato et al (2001) as being ‘bell-shaped’ (fig 58, third line of images). In size, the sodium channel is 135 Angstroms in height and 100 Angstroms in the side length of the base, which is somewhat square in shape (fig 58). The spherical top, which is the extracellular component known as the ‘outer vestibule’, has a diameter of 65 Angstroms (Sato et al, 2001). The inner structure was found to have a large central cavity which was connected to four smaller peripheral channels (fig 59). There are also a number of apertures that link the channels to both the extracellular and the cytoplasmic membrane surfaces. These structures are unique to sodium channels (Sato et al, 2001).
Fig 58: X-ray crystallography (top row) and Cryo-electron images (second and fourth row) of the sodium channel

Columns a, b, c, and d indicate different views of the ion channel

The images on row three are computer generated reconstructions

3a = the cytoplasmic ‘base’ of the ion channel

3b = on oblique view of the outer vestibule

3c and d = side views of the structure

From: Sato et al, 2001
The main component of the sodium channel is made up of a large glycoprotein chain (fig 60), called the alpha unit (Siegel et al, 2006). It is divided into four subunits, called domains I, II, III, and IV. The glycoprotein chains cross and re-cross through the cell membrane. Each domain is further subdivided into six segments, S1 to S6, depending on their location within their domain (Hille, 2001; Siegel et al, 2006). The loops which project into the extracellular matrix form the section of the ion channel called the outer vestibule and those loops which project into the cytoplasm form the section known as the inner pore and the supporting structures and channels seen by Sato et al (2001).
Functionally, the sodium channel has three parts – the outer vestibule, the sodium selectivity filter, and the inner pore (Hille, 2001; McNulty et al, 2007).

The outer vestibule contains several aspartic acid and glutamic acid amino acid groups. These amino acids have carboxylate side chains, which create a negative field-charge within the vestibule (fig 61) (McNulty, 2007). This negative field attracts cations (sodium, potassium, calcium) into the vestibule.
In the centre of the sodium channel is a group of four amino acids – aspartic acid (D), glutamic acid (E), lysine (K), and alanine (A) – which form the selectivity filter (fig 62). This is the narrowest region of the sodium channel, being approximately 4 x 6 Angstroms in size (Hille, 2001). The structure of this group (known as DEKA, for their one-letter symbols) allows only sodium ions to pass through into the inner pore. In this group, it is the effect created by the cation displacement of the ammonium side chain of the lysine residue (K1418) that causes the selection of sodium over potassium (McNulty et al, 2007).
The target sites of local anaesthetic are the inner pores of the ion channels in nerve and muscle cell membranes. Like most drugs, local anaesthetics dock with their target by means of weak inter-molecular forces – van der Waals bonds (Lipkind and Fozzard, 2005; Stryer, 1975). Therefore their efficacy is dose dependent and is affected by physiologic factors.

In the inner pore, the role of a phenylalanine amino acid residue (F1759) appears to be pivotal in sodium channel function (Lipkind and Fozzard, 2005; McNulty et al, 2007). Studies have shown that replacing this amino acid has dramatic effects on both the function of the sodium channel and the effect of local anaesthetic (Lipkind and Fozzard, 2005; McNulty et al, 2007). Replacement with a positively charged residue (such as lysine or arginine)
reduced the sodium ion permeation rate, while negatively charged amino acid replacements (like aspartate or glutamate) increased sodium ion permeation (McNulty et al, 2007).

Lipkind and Fozzard (2005) found that the aminoalkyl (hydrophilic) end of the anaesthetic molecule docks in the inner pore by an interaction with two amino acid residues, the phenylalanine residue (identified as F1579 in 2005, but subsequently re-identified in 2007 as F1759 by McNulty et al)\(^1\) in domain IV and a leucine residue (L1280) in domain III. The aromatic (lipophilic) ring segment of the local anaesthetic molecule interacts with a tyrosine residue (Y1586)\(^1\) of domain IV and an asparagine residue (N434) of domain I (Lipkind and Fozzard, 2005). McNulty et al’s (2007) studies, using lignocaine, show that the site of binding is eccentric within the inner pore and is found just below the sodium selectivity filter. They also found strong evidence to confirm that the aminoalkyl end of the local anaesthetic molecule interacts with F1759.

Lipkind and Fozzard (2005) examined the docking configurations and binding energies of several anaesthetics. They found that area where local anaesthetic interacts – the ‘dock’ – is a ‘groove’ created by the domains (fig 63). In size, it is approximately 6 Angstroms wide and 10 Angstroms long. At the upper (selectivity filter) end, where the hydrophilic part of the local anaesthetic molecule ‘sits’, are the residues F1759 and L1280. The lower part of the groove is formed by the Y1586
and N434 residues, which link with the lipophilic end of the anaesthetic molecule. The length of this groove (10 Angstroms) allows for the insertion of the alkyamino end of the anaesthetic molecule. They found that the van der Waals bond energy for lignocaine was $-4.1$ kcal/mol at the hydrophilic end and $-0.5$ kcal/ml on the aromatic ring (Lipkind and Fozzard, 2005).

![Fig 63: The local anaesthetic docking site in the sodium channel](image)

From: Lipkind and Fozzard, 2005

It appears that the local anaesthetic molecule does not physically block the pore and that sodium ions could still pass through. McNulty et al (2007) have calculated that the volume of the inner pore is approximately 400 cubic Angstroms. The van der Waals volume of local anaesthetic molecules is approximately half this (lignocaine 212 cubic Angstroms, bupivacaine 260 cubic Angstroms) (McNulty et al, 2007). Therefore there must be other factors at work to impede sodium ion passage. It has been
shown that sodium ion permeation is prevented by the creation of a positively charged electrostatic barrier from the hydrophilic domain of the local anaesthetic molecule (McNulty et al, 2007). This barrier fills the 10 angstrom space between the lysine residue (K1418) in domain II of the selectivity filter and the field charge of the local anesthetic arising from its interaction with the phenylalanine F1759 (McNulty et al, 2007). Thus, both the phenylalanine (F1759) and lysine (K1418) residues are crucial to the effectiveness of the local anaesthetic. Figure 64 maps the area of positive charge and the degree of change created by the local anaesthetic molecule (McNulty et al, 2007). The graph shows the normal, negative electrostatic potential of the sodium channel and tracks the change to positive electrostatic potential, peaking within the inner pore around F1759, caused by the presence of local anaesthetic.
The distance between the hydrophilic end of the local anaesthetic molecule and K1418 in the selectivity filter (10 Angstroms) suggests the possibility that other factors may be involved in the creation of the positive electrostatic field, such as a conformational change (Hille, 2001). Molecular bond lengths usually range from 1.24 – 1.49 angstrom (Stryer, 1975). Ten angstroms is therefore equal to approximately seven molecular bond lengths, which is a significant distance over which to develop a strong interactive force.
Although the hydrophilic part creates the positive electrostatic field near the selectivity filter, the lipophilic segment also appears to have a role in the inactivation of the sodium channel. Zamponi and French (1993) used diethylamide and phenol to mimic the separate parts of the lignocaine molecule. They found that diethylamide mimicked the fast mode of the local anaesthetic block while phenol mimicked the slow mode and they considered that this demonstrated that lignocaine was able to bind to both the open sodium channel as well as the inactivated (closed) form (Zamponi and French, 1993). It was presumed by Zamponi and French (1993) that the lipophilic phenol binds to a tyrosine residue (Y1766) in the inner pore. However, subsequent studies indicated that it is phenylalanine (F1710) and tyrosine (Y1717) that are important for state-dependent block (Li et al, 1999). Of these two residues, F1710 appears to act as a hydrophobic receptor site. Both phenylalanine and tyrosine are aromatic amino acids. This means that their active side chain is a benzene ring and this explains the creation of the Van der Waals’ bonds, which are caused by electron flow through the benzyl groups (Stryer, 1975). Nau and Wang (2004) opined that the effects caused by F1710 and Y1717 implied that conformational changes must occur during state transitions, however Lipkind and Fozzard (2005) considered that these residues exerted only an indirect effect and were not actually involved in the local anaesthetic binding site. Instead, they found that Y1586 an N434 were more significant (Lipkind and Fozzard, 2005).
The hydrophobic segment of the local anaesthetic molecule may also have a role by permitting slow penetration to the inner pore, via a hydrophobic side channel, when the inner pore is closed. It is hypothesised that this pathway may play a role in both the resting block and use-dependent block (Tikhonov et al, 2006). Further adding to the complexity of the local anaesthetic-sodium channel interaction, Tsang et al (2005) found that a tryptophan amino acid residue in the outer vestibule – W1531 – appears to play a role in the ability of local anaesthetic to inactivate the channel. Fraceto et al (2006) also found that the linker peptides between S4 and S5 of domain IV, which play a role in the conformational changes of the sodium channel during activation, also interact with the local anaesthetic molecule.

The interaction of local anaesthetics with the sodium channel is further complicated by the effects of other amino acid residues. Tsang et al (2005) found that substitutions of certain amino acids in the outer vestibule could abolish the local anaesthetic block. Fraceto et al (2006) found that an amino acid sequence linking segments four and five in domain IV also interacted with local anaesthetics. These results demonstrate that the effects of local anaesthetic on the sodium channel are still not fully understood.
The effect of pKa and pH on local anaesthetics

All local anaesthetics have a lipophilic domain and a hydrophilic domain (Malamed, 2004). The lipophilic domain allows the molecule to cross the cell membrane without the need for a carrier protein (Patrick, 2005) and for this to occur the molecule must be in its un-ionised (lipid soluble) form. Inside the cell the anaesthetic molecule exists in an equilibrium state between its ionised and un-ionised form (Mulroy, 2002). It is the ionised (cationic) form that enters the inner pore of the sodium channel and docks with it. It is, largely, the ionised hydrophilic domain that is responsible for the sodium channel blockade (Mulroy, 2002).

The effectiveness of local anaesthetics is measured by determining the minimum concentration necessary to block impulse conduction of a nerve of given diameter within a period of time: this is designated $C_m$ (Mulroy, 2002). Because local anaesthetics must be able to penetrate the cell membrane in order to work, there is a correlation between their lipid solubility and their potency (Mulroy, 2002). This is further influenced by the dissociation constant of the drug (the pKa), as the dissociated (ionised) form will not cross the cell membrane (Mulroy, 2002). At the same time, only the ionised (water soluble) form will penetrate tissue. Thus an effective local anaesthetic must have sufficient dissociation to penetrate to the nerve in sufficient concentration and, once there, must have a dissociation equilibrium that allows sufficient un-dissociated molecules to
re-form and pass through the cell membrane (Mulroy, 2002). A pKa of 7.4 for a particular drug means that, at normal body pH, half the drug will be dissociated. The closer the pKa of a drug is to normal pH, the faster will be its onset of action (Mulroy, 2002). This is why lignocaine (pKa 7.72), mepivacaine (pKa 7.6) and prilocaine (pKa 7.7) have a relatively rapid time to onset of anaesthesia, whereas procaine (pKa 8.9) and bupivacaine (pKa 8.1) are slower to act (Mulroy, 2002).

Changes in tissue pH, such as the increased acidity that occurs in inflamed tissues, have a major impact on the efficacy of local anaesthetics. Lowering tissue pH means that more of the drug exists in its protonated (cationic) form. This reduces the cell membrane permeation of the local anaesthetic agent (Mulroy, 2002). Conversely, those local anaesthetic molecules that are already within the nerve cell become trapped, due to the higher percentage of ionised molecules in the cytoplasm (Schwarz et al, 1977). It is the reduction in cell membrane permeability, combined with the intrinsically low therapeutic index of local anaesthetic agents that results in their clinical loss of efficacy in inflamed tissues.

Clearance of local anaesthetics

Local anaesthetics are effective only if sufficient concentration of the drug remains within the nerve cell. As extracellular molecules of local
anaesthetic are carried away in the bloodstream, the intracellular molecules will diffuse out of the cell to maintain the overall equilibrium. Gradually, the intracellular concentration falls until action potentials begin to be transmitted. The reactivation of the sodium channels is initially intermittent, due to reuptake of local anaesthetic, producing the period of paraesthesia that occurs during the recovery phase of nerve block anaesthesia. Sinnott et al (2003) found that the clearance of lignocaine from the nerve had two phases. The first phase was a ‘fast decaying transient’ phase, in which a relatively high concentration of local anaesthetic rapidly entered the bloodstream. This was shortly followed by a ‘very slowly decaying’ phase, in which the rate of clearance tapered away in a direct ratio to the tissue concentration. The addition of adrenaline to the local anaesthetic solution did not affect the neural concentration of the anaesthetic ‘for the first 10 minutes after injection’, the transient first phase being the same for local anaesthetic agents with no vasoconstrictor (Sinnott et al, 2003). Thereafter, in the slowly decaying phase, the presence of adrenaline increased the concentration of anaesthetic in the nerve tissues by ‘threelfold to fourfold’ and this increased concentration prolonged the nerve blockade ‘by almost fourfold’ (Sinnott et al, 2003).

As previously noted, a low tissue pH can cause ‘ion trapping’, preventing the diffusion of local anaesthetic molecules out of the nerve cell. Schwarz et al (1977) found that while lowering the extracellular pH reduced the
concentration of local anaesthetic reaching the neurone, once inside the cell the majority of anaesthetic molecules became protonated. Not only did this trap the local anaesthetic molecules within the cell, it also trapped them in the sodium ion channels for a longer period of time. This led to a prolonged recovery period for the neurone (Schwarz et al, 1977). Returning the extracellular pH to normal caused a rapid return to the normal dissociation dynamics (Schwarz et al, 1977). Onizuka et al (2008) found that local anaesthetic agents themselves lower the intracellular pH by affecting sodium and hydrogen ion exchange. This can prolong cellular excretion of local anaesthetic leading to prolonged post-treatment paraesthesia (Onizuka et al, 2008).

**Anaesthetic effectiveness and the length of nerve exposed**

Hille (2001) noted that the effect of myelination was to greatly concentrate the ion channels at the nodes of Ranvier, to at least 2,000 channels per square micrometre (fig 65). This high density of sodium channels at the nodes is necessary to generate rapid depolarisation of the long internodal section of the cell membrane. Because an influx of only small numbers of sodium ions at one point will generate an action potential, there must be sufficient concentration of local anaesthetic at the node of Ranvier to interact with the vast majority of the ion channels there and block the nerve impulse (Hille, 2001).
Because local anaesthetic must be concentrated at the nodes of Ranvier, the length of nerve trunk (and hence the number of nodes) that is available to be bathed in local anaesthetic is important for the achievement of nerve block. Rood (1977) stated that a minimum of three internodal lengths of the axon needed to be bathed in anaesthetic to achieve blockade. He noted that the longest internodal distances in the inferior alveolar nerve were up to 1.8 mm (Rood, 1977). This means that an absolute minimum length of 6 mm of nerve trunk must be bathed in local
anaesthetic to achieve anaesthesia. However, Raymond et al (1989) found that only very high concentrations of local anaesthetic would block impulse conduction when it was applied to a short length of nerve (three nodes of Ranvier, or 3 mm length in the nerves used for these experiments). If lower concentrations of local anaesthetics were applied, longer lengths of nerve trunk had to be bathed in the local anaesthetic to achieve effective block (Raymond et al, 1989). Measuring exposure distances from 6 mm to 30 mm, it was found that exposure of lengths of 25-30 mm of the nerve trunk were blocked at half the concentration of anaesthetic needed to block lengths of 10-15 mm, and that lengths of 5-7 mm required doses of 5 times the concentration to that of the 25-30 mm lengths to achieve nerve block (Raymond et al, 1989).

**Therapeutic index and toxicity**

The therapeutic index measures both the effectiveness and the safety margin of any drug, by comparing the drug’s beneficial effects at low dose levels to its harmful effects at high dose levels (Patrick, 2005). For example, a drug that produces a beneficial effect at the 1 mg level but has no harmful effects until a dose level of 500 mg would be said to have a wide therapeutic index. Local anaesthetic agents all have a narrow therapeutic index (MIMS, 2009). They do not achieve their therapeutic effect until some tens of milligrams of drug are administered. Typical doses for trigeminal nerve anaesthesia range from 40 – 100 mg. Adverse systemic effects
from local anaesthetic can, however, begin to occur with doses from 300 – 500 mg, which may be only three to five times the minimal effective dose (MIMS, 2009).

Adverse outcomes, such as prolonged paraesthesia and nerve damage that sometimes arise after the administration of local anaesthetic, can be explained by the pharmacology. Hogan (2008) found that physical damage caused by needle penetration produced minimal lasting damage to nerve trunks. Instead, Hogan (2008) found that most neuronal damage was caused by the anaesthetic agents themselves. The neurotoxic effects of local anaesthetics have been known for many years. Myers et al (1986) found that local anaesthetics applied to nerve trunks produced reduced perineural permeability, caused oedema within the nerve trunk and damaged both Schwann cells and axons. Kalichman et al (1993) found that drug potency and the potential for nerve cell injury was directly proportional. They found that increased concentrations of local anaesthetic agents increased the incidence of nerve injury and that lignocaine was more neurotoxic than procaine (Kalichman et al, 1993). Bainton and Strichartz (1994) found that lignocaine produced an irreversible loss of impulse conduction at concentrations of 1% and that this effect increased in direct proportion to increased drug concentration. At a 2% concentration, there was complete, permanent impulse block (Bainton and Stricharz, 1994). The risk of nerve damage associated with higher concentrations of local anaesthetic may be a factor in the reported
incidence of nerve injury following the administration of articaine, which is supplied as a 4% solution. The limited data published to date (mainly case reports) confirms that articaine administration has been associated with permanent nerve damage, but the incidence rate appears to be similar to that of lignocaine (Pogrel, 2007). Another factor in neurologic injury may be prolonged intracellular levels of local anaesthetic (Muguruma et al, 2006).

De Paula and Schreier (1996) studied the effects of local anaesthetics on cell membranes and found that they could create micelle-like aggregates (small vesicle-like structures) within the cell membrane bi-layer. The authors found that this effect might account for the neurotoxic effects of the local anaesthetic agents, but that the micelles did not enhance anaesthesia (De Paula and Schreier, 1996). Choi et al (2000) also studied the effect of lignocaine on the expansion of the cell membrane and found that intra-membranous expansion could occur, but that this made no contribution to the achievement of anaesthesia.

Local anaesthetics have been found to cause nerve cell apoptosis in vitro via mitochondrial pathways (Werdehausen et al, 2007), through the activation of stress-activated protein kinases (Lirk et al, 2007). The inhibition of p38 mitogen-activated protein kinase has been shown to prevent apoptosis in vitro and may be one possible pathway for nerve injury (Lirk et al, 2007). Local anaesthetics have also been found to suppress nerve growth factor,
which may also play a role in the inhibition of nerve recovery following local anaesthetic-induced injury (Takatori et al, 2006).

Lignocaine has been shown to cause a hyperpolarising shift in the steady-state inactivation curve (Castenada-Castellanos et al, 2002). This effect occurs at concentrations which provide only minimal open channel block (Castenada-Castellanos et al, 2002). The hyperpolarising shift appears to be the cause of at least some of the central nervous system effects of local anaesthetic overdose, such as agitation, psychosis and seizures (Castenada-Castellanos et al 2002). Hara and Sata (2007) found that both procaine and lignocaine acted on glycine and gamma-aminobutyric-acid (GABA) receptors in vitro. At low concentrations, the agents enhanced glycine receptor function, but at higher concentrations caused inhibition of both glycine and GABA<sub>A</sub> receptors. The authors opined that these effects might explain why local anaesthetics cause central antinociception and convulsion (Hara and Sata, 2007).

Notes
1. Drug binding to aromatic amino acid residues, in particular phenylalanine and tyrosine, is well recognised. Identification of particular residues is achieved through molecular modelling, however the complexity of the structure and the abundance of these residues can make precise identification difficult. A recent example of this is provided by Lipkind and Fozzard (Lipkind GM and Fozzard HA, ‘Molecular Model of Anticonvulsant Drug Binding to the Voltage-Gated Sodium Channel Inner Pore’ Molecular Pharmacology, doi:10.1124/mol.110.064683, July 2010). Here, Tyr-1771 and Phe1764 are involved, but this binding site overlaps the local anaesthetic site and raises the possibility of more complex interactions.
2.3 The techniques of maxillary nerve block anaesthesia

Introduction

There are, for the most part, fewer issues with the delivery of local anaesthetic to the maxilla. This is because simple field anaesthesia, called infiltration anaesthesia in the dental context, is usually successful. The reason behind this high degree of success lies in the thinness of the maxillary bone, which permits adequate perfusion of the anaesthetic solution to the end branches of the maxillary nerve (figs 38). The thinness of the maxilla is particularly apparent in the posterior, lateral and anterior walls, within which the superior alveolar nerves lie in the nasal mucosa. Local anaesthetic deposited adjacent to the outer aspect of these walls can readily permeate the thin bone in sufficient concentration to achieve anaesthesia. Because of this there has been less focus on technical precision for most maxillary injection techniques and this extends to some of the nerve blocks for the maxillary division of the trigeminal nerve. Effective infiltration anaesthesia is significant because some of the nerve block techniques for the maxillary division of the trigeminal nerve rely on diffusion of the anaesthetic solution through the maxillary bone for their success.
Fig 38: Disarticulated right maxilla, viewed from the medial aspect.

The lateral wall can be seen through the ostium and the thinness of the bone is demonstrated by its translucency.

The various techniques of maxillary nerve block anaesthesia

There are thirteen different maxillary nerve block techniques that have been described. These are:

Anterior-superior alveolar nerve and infraorbital nerve blocks, via the
- intraoral approach
- extraoral approach
- nasal approach

Posterior-superior alveolar nerve block (tuberosity block)

Middle-superior alveolar nerve block (buccal approach)

Middle and anterior-superior alveolar nerve block (palatal approach)

Sphenopalatine (incisive) nerve block
Greater palatine nerve and lesser palatine nerves block

Maxillary nerve blocks, via the
- intraoral approach
- nasal approach
- lateral extraoral approach
- supra-zygomatic extraoral approach
- anterior-lateral extraoral approach.

There is also a previous technique for achieving a maxillary nerve block by approaching the pterygomaxillary fissure from the maxillary buccal sulcus. This technique is mentioned in the section on the posterior superior alveolar nerve block. However, the equipment required for this technique is no longer available.

1. The anterior superior alveolar and infraorbital nerves block

The anterior-superior alveolar nerve block is more commonly known as the infraorbital nerve block. The aim of this block is to deposit anaesthetic as closely as possible to the infraorbital foramen, which lies within the maxilla just below the lower border of the orbit. There are two approaches to the foramen. The intraoral approach is generally favoured by dentistry, whereas medicine has usually preferred the extraoral approach.
a. The intraoral approach

The intraoral approach has been described by many authors. All recommend palpating the infraorbital foramen on the face before retracting the lips and cheek to visualise the intraoral vestibular fold. However, there is some variation in the recommendations for the point of insertion of the needle (fig 39). Roberts and Sowray (1979) recommended inserting the needle adjacent to the second bicuspid. Malamed (2004) recommended the first bicuspid as the injection point. Eriksson (1969) showed the needle being inserted adjacent to the canine tooth. Budenz (2007), who recommended the vestibular fold above the bicuspid as the injection site, called the infraorbital block the ‘anterior middle superior alveolar block’. This is somewhat confusing, as he also uses this term to describe the palatal injection technique (Budenz, 2007).

Fig 39: An intraoral approach to the infraorbital foramen

The blue line indicates the approximate level of the vestibular fold
Whatever the name it is given, the effect of this injection is to block both the infraorbital nerve and the anterior superior alveolar nerve. Although the anterior wall of the maxilla lies between the anterior superior alveolar nerve and the point of the deposition of the anaesthetic, the bone is thin and the anaesthetic solution is able to diffuse through it in sufficient quantity to achieve blockade of the anterior superior alveolar nerve branches lying in the nasal mucosa.

b. The extraoral approach

Rosenberg and Phero (2003) and Rathmell and Pollack (2007), advocate an extraoral approach for the infraorbital nerve block injection. The technique is described thus:

- The infraorbital foramen is palpated approximately 2 cm from the lateral surface of the nose
- The needle should start 5 mm below and slightly medial to the foramen to allow for the backward and upward slant of the infraorbital canal
- The needle must be advanced past the opening of the infraorbital canal so that the anterior superior alveolar nerve is not blocked, but no more than 5 mm past the entry into the infraorbital foramen
- A volume of 1 to 3 ml of local anesthetic is sufficient for nerve blockade.
Eriksson (1969) and Roberts and Sowray (1979) recommended a lower insertion point, approximately 10 mm below the foramen (fig 40). Eriksson does not recommend insertion of the needle into the foramen.

Fig 40: The infraorbital block, extraoral approach
From: Eriksson, 1969

c. The nasal approach

The nasal approach is an infiltration technique using anaesthetic applied topically to the lateral wall of the nose. This technique is traditionally used for intranasal procedures (fig 41) (Eriksson, 1969). However, the thinness of the lateral wall of the nose permits the diffusion of anaesthetic into the anterior antral mucosa to anaesthetise the anterior superior alveolar nerves. It is particularly effective for children. The technique is to insert a cotton-wool pellet, soaked in either a 2% or 4% solution of anaesthetic,
into the anterior nasal cavity (not the nares) (Eriksson, 1969). This is left in situ for the duration of the procedure. Once the pellet is removed, sensation usually returns within minutes.

Fig 41: The application of anaesthetic to the lateral wall of nose

1. anterior ethmoidal nerve
2. posterior superior nasal nerves
3. pterygopalatine ganglion
4. posterior inferior nasal nerves

From: Eriksson, 1969

2. The posterior superior alveolar nerve (tuberosity) block

This technique is, in essence, a high level infiltration technique whereby the anaesthetic is deposited against the posterior-lateral curvature of the maxillary tuberosity at or above the level of the apices of the teeth (Eriksson, 1969). It has been confused with an old maxillary block technique, called the posterior infraorbital approach, which has the same
insertion point (Roberts and Sowray, 1979). Both intraoral and extraoral versions have been described.

The intraoral approach (fig 42) is to insert the needle into the vestibular fold behind the root of the zygomatic buttress and advance at approximately 45 degrees for 20-25 mm, keeping the needle against the maxillary bone (Eriksson, 1969; Roberts and Sowray, 1979).

![Fig 42: The posterior superior alveolar nerve block](image)

There is one mention of an extraoral approach, which was described by Eriksson (1969). The needle is inserted at the lower border of the zygoma in front of the coronoid process and advanced until bone is contacted. There seems little advantage in this approach above that of the intraoral approach.
Badcock and McCullough (2007) reported that buccal deposition of local anaesthetic for the removal of the upper third molar tooth often obviated the need for palatal anaesthesia. They suggested that this may be due to the diffusion of the anaesthetic solution through the maxillary bone to reach the palatal tissues. Unfortunately, their survey did not assess the techniques, types or volumes of anaesthetic, that were used to achieve this result. Anatomically it can be seen that depositing a sufficient volume of anaesthetic against the posterior wall of the tuberosity could result in diffusion of the solution not only into the posterior antral lining (and hence the posterior superior alveolar nerves) but also into the tissues of the soft palate and the lesser palatine nerves via the hamular and palatine-maxillary sutures (fig 43).

Fig 43: The site of deposition of anaesthetic for the maxillary third molar (red arrow) and the potential route of diffusion to the palate via the sutures (blue arrow)

Malamed (2004) takes the tuberosity technique further, describing a ‘high tuberosity approach’ as a maxillary nerve block. Such a technique was
first described by Labat (1928) and again by Roberts and Sowray (1979). For this maxillary nerve block technique a special attachment designed for the glass Luer-Lok™ syringe was required. The device consisted of a metal tube with a 110 degree bend and the appropriate connectors for the Luer-Lok syringe and needle. This was placed onto the syringe and to it was attached a 45 mm needle (Roberts and Sowray, 1979). The technique (figs 44 and 45) was:

- the patients mouth was closed and the commissure of the lip retracted as far posteriorly as possible
- the needle was inserted at the most posterior and superior part of the maxillary sulcus and directed at about 45 degrees
- the needle was advanced until bone was contacted (presumably the sphenoid bone)
- after aspiration, the anaesthetic solution was deposited.

Fig 44: Photograph of the 110 degree adapter and 45 mm needle

From: Roberts and Sowray, 1979
Changes in infection control practices, however, rendered both the glass syringe and the attachment obsolete. Austin (1987) attempted to recreate the tuberosity approach by bending a 42 mm needle at the hub and inserting it upwards behind the maxilla. However, Austin found that the length of the needle was insufficient for success. Baart and Brand (2009) however included the ‘high tuberosity’ block in their text, claiming that the pterygopalatine fossa could be reached by this approach using a 35 mm long needle. The image used to demonstrate this (fig 46) shows the needle tip adjacent to the pterygomaxillary fissure (not in the pterygopalatine fossa as stated). This image also shows the hub of the needle positioned at a level that would place it through the buccinator muscle in a patient (fig 46).
3. The middle superior alveolar nerve block

The superior alveolar nerves tend to form a plexus within the mucosa of the maxillary sinus (Davies, 1967). In most individuals this plexus arises from the anterior and posterior superior alveolar nerves. However, in approximately 28% of the population a distinct middle superior alveolar nerve can be found (Malamed, 2004). This branch can supply the pulps of the first and second bicuspid and the anterior part of the first molar teeth (Malamed, 2004).

As with other maxillary blocks, the middle superior alveolar block is achieved through infiltration. However authors disagree on where the anaesthetic should be administered. Eriksson (1969) advocates depositing it above the apex of the relevant tooth. Roberts and Sowray (1979) advocate that the branch will be anaesthetised by an infraorbital block.
Malamed (2004) advocates deposition at the anterior border of the zygomatic buttress, above the apex of the second bicuspid.

4. The anterior and middle superior alveolar nerves block (palatal approach)

This technique was first advanced by Friedman and Hochman (1998, 1999), following the development of an automated anaesthetic delivery system (Friedman and Hochman, 1997). In this technique, the anaesthetic is deposited at the junction of the palatine process and alveolar process of the maxilla at a point between the apices of the first and second bicuspid teeth (fig 47). The anaesthetic solution diffuses through the palatal alveolar bone, which is both thin and well perforated by many vascular channels, to block the nerves to the dental pulps of the maxillary anterior and bicuspid teeth. The benefit of this approach is that, because the anaesthetic is unable to reach the nerve endings from the infraorbital nerve, the soft tissues of the anterior mouth, lips and mid-third of the face remain unanaesthetised.
Malamed (2004) points out that the rate of anaesthetic deposition in this area must, of necessity, be extremely slow. Rapid deposition into the tightly bound, dense tissue causes severe pain and can damage the tissue (Malamed, 2004). While it is possible to deposit the dose recommended by Friedman and Hochman (1998) – between 1.4 and 1.8 ml – with a manual syringe, the slowness of the delivery is very tiring for the operator and the rate can be difficult to control. To this end, the automated system is greatly advantageous. One disadvantage, however, is that the duration of anaesthesia produced by this technique is relatively short compared to the standard labial or buccal infiltration techniques. Budenz (2007) attributed this lack of duration of anaesthesia to the fact that the anaesthetic was deposited at the ends of the nerve branches. Lee et al (2004) found that the rate of successful anaesthesia for this technique was quite low. Using the Wand Plus™ (a computer-controlled, automated local anaesthetic
delivery system) their rate of successful outcomes for the palatal approach ranged from 35-58%. However, they found that when using a standard syringe for the technique the success rate dropped to 20-42% (Lee et al., 2004). Another disadvantage found by Lee et al (2004) was that the onset of anaesthesia was slow compared with other techniques and the duration of effective anaesthesia was no more than 60 minutes.

5. The incisive canal (nasopalatine, sphenopalatine) block

The incisive canal (fig 48) may also be used as a route to provide anaesthesia to the incisor teeth as well as the incisive (sphenopalatine) nerve (Budenz 2007). The incisive papilla overlies the canal and deposition of a small volume of anaesthetic into this structure will anaesthetise the anterior one-third of the vault. By advancing the needle into the canal proper the anaesthetic deposited there will diffuse through the thin alveolar bone to anaesthetise the incisor teeth (figs 49). This technique is another advocated by Friedman and Hochman (1999) for use with an automated delivery system. However, despite their claim, the technique is by no means a new one, having been described by both Eriksson (1969) and Roberts and Sowray (1979).
The incisive canals (there are usually two) are generally wide and patent through to the floor of the nose and a needle can be carefully advanced within them. The space is not large and will accommodate only a small volume of anaesthetic. Unlike Friedman and Hochman (1999), who recommended that 1.4 ml of solution be injected, Eriksson (1969)
recommended only ‘a few tenths of a ml’, and Roberts and Sowray (1979) advocated ‘approximately 0.5 ml’ to be injected very slowly.

6. The greater palatine nerve (and lesser palatine nerves) block

The greater palatine canal lies at the junction of the palatal and alveolar processes of the maxilla approximately adjacent to a line between the second and third molar teeth (Malamed 2004). The canal is not a true foramen and is formed by the junction of the maxilla and palatine bones (fig 50). The greater palatine nerve descends from the sphenopalatine fossa through the canal to emerge into the soft tissue of the hard palate, where it runs anteriorly (Davies, 1967). The lesser palatine nerves descend in close association with the greater palatine nerve but emerge through the lesser palatine foramina in the palatine bone, from which they travel posteriorly (Davies, 1967). The soft tissue overlying the greater palatine canal is the site of deposition of anaesthetic to anaesthetise the soft tissues of the posterior two thirds of the vault of the palate. This site of the canal is adjacent to the maxillary second and third molar teeth and may often be detected by palpation (Malamed, 2004). Usually deposition of no more than 0.5 ml of anaesthetic is required to achieve anaesthesia (Eriksson 1969, Roberts and Sowray 1979, Malamed 2004). The lesser palatine nerves are also usually blocked by diffusion of the anaesthetic through the tissue plane.
The maxillary division of the trigeminal nerve exits the skull through foramen rotundum, which lies on the posterior wall of the pterygopalatine fossa just below the infraorbital fissure and just lateral to the lateral wall of the posterior nasal cavity. The nerve passes anteriorly across the fossa and starts dividing almost immediately (Davies, 1967). Therefore the pterygopalatine fossa is the only site to achieve a true maxillary nerve block. However, it is a site that is very difficult to access. With the unavailability of the intraoral tuberosity approach (Vide: 2. The posterior
superior alveolar nerve (tuberosity) block), there are five techniques for this block.

a. The intraoral (greater palatine canal) approach

The greater palatine canal is actually a series of foramina through various parts of the maxilla. These can create a pathway from the vault of the hard palate and through the posterior wall of the maxilla into the pterygomaxillary fissure, which is the lateral continuation of the pterygopalatine fossa (Davies, 1967).

The technique, as described by Roberts and Sowray (1979) and Malamed (2004), is as follows (figs 51 and 52):

- the palatal tissues are anaesthetised first
- the needle is advanced along the canal at an angle of about 45 degrees to the occlusal plane and a few degrees laterally (fig 51)
- the needle should penetrate approximately 30 mm before contacting bone
- when bone is contacted (this should be the sphenoid bone – fig 52), aspiration is performed and, if negative, approximately 2 ml of anaesthetic is then deposited.
Fig 51: The needle inserted into the greater palatine canal

Fig 52: The needle (arrow) emerging through the posterior wall of the maxilla into the pterygomaxillary fissure

The anaesthetic solution is deposited in the lateral portion of the pterygomaxillary fissure. It then diffuses medially into the pterygopalatine fossa to anaesthetise the nerve trunk. Adjacent nerves can also be affected. The pterygopalatine (parasympathetic) ganglion can be anaesthetised, affecting the secretions of the eye, nose and mouth. The
motor nerves to the eye – the oculomotor, trochlear and abducent nerves – can also be blocked, leading to diplopia. These effects have been observed clinically, however are not generally reported in the literature. The optic nerve is rarely affected, although Malamed (2004) lists it as a possible complication.

Problems with the technique include positive aspiration and trauma to the maxillary artery, which can be impaled between the needle and the sphenoid bone (Malamed, 2004). There may be difficulty in navigating the needle through to the pterygomaxillary fissure (Malamed, 2004), or the needle may pass into the nasal cavity (fig 53).

Fig 53: The needle deflected into the nasal cavity
Even if the needle cannot be advanced to the pterygomaxillary fissure, if it can be advanced through the canal some 10 – 15 mm deposition of local anaesthetic at this level will provide anaesthesia to the maxillary sinus.

b. The nasal approach

Local anaesthetic can also be delivered to the maxillary nerve by a per-nasal approach (Kanai et al, 2006). The technique is similar to the topical deposition of anaesthetic to the lateral wall of the anterior nasal cavity (Vide: 1. The anterior superior alveolar and infraorbital nerves block; c. The nasal approach). In this technique the topical deposition is to the lateral wall of the posterior nasal cavity, behind and above the middle turbinate (Kanai et al, 2006). At this site it can effect complete maxillary nerve blockade due to diffusion of the anaesthetic through the sphenopalatine foramen into the pterygopalatine fossa. The sphenopalatine foramen lies in the bony wall dividing the medial aspect of the sphenopalatine fossa from the nasal cavity, so that the two compartments are separated only by a thin mucosa (Davies, 1967). Once it diffuses into the pterygopalatine fossa it readily reaches the maxillary nerve, which is immediately adjacent. Usually a high concentration of anaesthetic (e.g. 8%) is applied to ensure adequate anaesthesia (Kanai et al, 2006).
c. The lateral extraoral approach

The classic extra-oral approach, the technique as described by Roberts and Sowray (1979), is to advance the needle between the lower border of the zygomatic arch and the sigmoid notch of the mandible, with the patient’s mouth closed (fig 54). This is an entirely blind technique, as there are no landmarks to guide the passage of the needle. The needle must be advanced until the lateral pterygoid plate is contacted, then redirected until the pterygomaxillary fissure has been reached (fig 55) (Roberts and Sowray, 1979). The needle (usually 50 mm or more in length) is passed into the fissure and the anaesthetic solution deposited (Roberts and Sowray, 1979). Because the needle must pass thorough the masseter muscle, and may also impale the lateral pterygoid muscle, it is a technique that is often quite painful for the conscious patient. The injection pain is exacerbated if heavy gauge needles – 19 G and even 16 G have been recommended by some authors – are used for the technique (Singh and Bhardwaj, 2002; Kumar and Banerjee, 2005). There is also the risk of trapping the maxillary artery as it emerges from between the two heads of the lateral pterygoid and enters the pterygomaxillary fissure.
Rosenberg and Phero (2003) opined that the maxillary nerve block was more easily and reliably obtained by the use of the lateral extraoral approach than by the intraoral techniques used in dentistry. The technique they describe is very similar to that of Roberts and Sowray (1979). The needle enters the skin at the point of the intersection of the
lower border of the zygoma and the anterior border of the mandibular ramus through the sigmoid notch, but is directed slightly upward, forward, and medially until it meets the greater wing of sphenoid (rather than the lateral pterygoid plate). From this point it is then redirected into the pterygomaxillary fissure (Rosenberg and Phero, 2003).

d. The supra-zygomatic approach

In 1997 Stajcic and Todorovic offered an alternative insertion point for the extraoral maxillary block, being above the zygomatic arch at the frontozygomatic angle (fig 56). The authors used either an 18 G 73 mm injection port or a 20 G 80 mm spinal needle. This was inserted in a posterior direction from the insertion point at an angle of 60 degrees, and superiorly at an angle of 10 degrees. The needle was inserted until it perforated the nasal mucosa through the sphenopalatine foramen (tested by the aspiration of air), then withdrawn 3 – 5 mm. This, according to the authors, would ensure that the anaesthetic was deposited adjacent to foramen rotundum (Stajcic and Todorovic, 1997). The authors recommended 3 ml of anaesthetic solution be deposited. The reported success rate of this approach was 84% (Stajcic and Todorovic, 1997).
e. The anterior extraoral approach

The anterior extraoral approach, described by Eriksson (1969), passes the needle through an insertion point below the zygomatic arch and anterior to the coronoid process of the mandible (fig 57). As with the lateral approach the technique is a blind one, because there are no landmarks to guide the correct placement of the needle. This approach relies on the palpation of the posterior maxilla and/or the lateral pterygoid plate with the tip of the needle to determine the location of the pterygomaxillary fissure (Eriksson, 1969). The main advantages of this approach over the classical technique are that there are no major structures in the path of the needle and that trapping the maxillary artery is far less likely.
Rosenberg and Phero (2003) regarded the anterior approach as ‘a consideration’ for a maxillary nerve block, but held the view that the lateral approach offered the more consistent results for nerve blockade.

![Fig 57: The anterior extraoral approach](image)

*From: Eriksson, 1969*
2.4 Discussion on the mandibular and maxillary nerve block techniques

The single common feature of all the nerve block techniques for the mandibular and maxillary nerves is that they are based upon the traditional paradigm of anatomical constancy and target acquisition through the use of superficial anatomical landmarks (Eriksson, 1969; Hadzic, 2007). The majority of the techniques for mandibular nerve block aim to deposit the anaesthetic solution as close to the nerve trunk as possible. These techniques are:

- the standard direct technique
- the standard indirect technique
- the mental nerve block
- the Clarke-Holmes technique
- the Sargenti technique
- the Wolfe technique
- the ipsilateral open-mouth technique
- the extraoral submandibular technique
- the lateral extraoral approach
- the anterior extraoral approach.

However those mandibular nerve block techniques that do not deposit their anaesthetic solution adjacent to the nerve trunk achieve success
rates that are as good as, or even better than, those which target the nerve trunk. These techniques are:

- the Vazirani technique
- the Gow-Gates technique
- the Akinosi technique
- the Morishita technique.

For the maxillary nerve block techniques, it is only the supra-zygomatic technique that deposits the anaesthetic solution in the immediate vicinity of the target nerve trunk. All the other maxillary nerve block techniques rely on a varying degree of diffusion of the anaesthetic solution along or across tissue planes. The clinical outcomes of those techniques that deposit the anaesthetic solution at varying distances from the target nerve trunk must call into question Malamed’s assertion that anaesthetic deposition must occur to ‘within 1 mm of the target nerve’ in order to achieve a successful outcome (Malamed, 2004), as well as the rationale for techniques such as Clarke-Holmes (1959), Sargenti (1966) etc.

In respect of the use of superficial anatomic landmarks, it is acknowledged that they do not always correlate with the position of the underlying anatomical structures (Urmey, 2007). It is also considered that the addition of geometric linear and angular measurements to try to improve nerve targeting only make techniques more complex and do not, in fact, improve accuracy (Urmey, 2007). As for the position of the mandibular foramen, it
should be noted that while most authors agree on its location, there remains debate on the reasons for failure to target the site. In discussing the standard technique, for example, Clarke and Holmes (1959) and Sargenti (1966) held that the standard technique deposited the anaesthetic solution too far posteriorly, whereas Milles (1984) opined that the site of anaesthetic deposition in the standard technique was too far anterior to the foramen. It is notable that the debate about targeting the mandibular foramen has remained unchanged for at least sixty years (Bremer, 1952).

Although it is generally not stated, it appears that the usual criterion for a successful mandibular nerve or inferior alveolar nerve block is the achievement of surgical anaesthesia with the deposition of ‘one cartridge’ of local anaesthetic solution. The concept of ‘one cartridge’ is imprecise, as the volume may vary from 1.8 ml to 2.2 ml. The question of whether this variation is significant was raised by Coleman and Smith (1982) but there has been no resolution on the issue. The concept of using just one cartridge of local anaesthetic to achieve nerve block is based on another long-accepted principle of trigeminal nerve anaesthesia – that only minimal volumes of anaesthetic should be used to achieve clinical effectiveness. This view is exemplified by Rood (1977) who asserted that 1.0 ml of a 2% lignocaine solution, with adrenaline, would consistently achieve complete nerve block and that as little as 0.5 ml of the same solution could provide a satisfactory block. Rood went further in his opinion, claiming that volumes in excess of 1.0 ml would cause a ‘large’
increase in tissue pressure within the pterygomandibular compartment (Rood, 1977). Rood’s implication was that volumes above 1.0 ml were both unnecessary and undesirable. However, this position is not invariable. Although Gow-Gates initially stated that a single 2.2 ml cartridge was sufficient to achieve anaesthesia with his technique (Gow-Gates, 1973), this was increased to 3.3 ml (Levy, 1981) and then to 3.6 ml (i.e. two 1.8 ml cartridges) (Kohler et al, 2008) as the recommended dosage for this technique. Morishita (2007) also recommended a minimal dose of 3.6 ml – the equivalent of two 1.8 ml dental cartridges – for his technique. Other authors have recommended the use of additional volumes of anaesthetic should the onset or depth of anaesthesia prove unsatisfactory (Sargenti, 1966; Wolfe, 1992).

One area of difference between the various published intraoral techniques and extraoral techniques is the gauge of the needle that is often utilised. Although it is not often discussed, the standard dental needle is generally either 25 G or 27 G with lengths varying between 20 – 42 mm (Malamed, 2004). In contrast, peripheral nerve blocks routinely use spinal needles or Tuohy needles with gauges that range from 22 G to 16 G and lengths up to 80 mm (Chan, 2009, a, b). The use of these large gauge needles tends to be recommended for extraoral mandibular and maxillary nerve blocks (Rosenberg and Phero, 2003). However, there seems to be little benefit in their use in the maxillofacial region, particularly when the dosages used for trigeminal nerve anaesthesia – usually 2 – 5 ml – are significantly
lower than those administered for other peripheral nerve blocks (Loadsman, 2009).

The issues surrounding the necessity of nerve targeting, the reliability of superficial landmarks, and the appropriate volumes of anaesthetic solution that should be administered in order to achieve a high rate of clinical success remain largely unanswered in the dental clinical literature. Recent advances in the fields of pharmacology, ultrasound-guidance for regional anaesthesia, and anatomy may help to answer these questions.
2.2 The techniques of mandibular nerve block anaesthesia

Introduction

The quest to achieve improved clinical outcomes in regional anaesthesia has seen numerous alternative delivery techniques proposed. The search for the optimal techniques has been particularly evident in mandibular nerve block (inferior alveolar nerve block) anaesthesia. MacLennan (2007) has ascribed five characteristics to the ‘ideal’ nerve block:
- it must be successful
- it must be safe to the tissues (including the target nerves)
- it must be easy to learn and to teach
- it should be economical
- it must be acceptable to patients.

For MacLennan (2007), success is measured by clinical outcome. The safety of any new technique lies in the understanding of the anatomy concerning the tissues in and surrounding the path of the needle. The ease of learning, and teaching, a new technique comes from the pre-existing knowledge of related techniques and also from the simplicity of the instructions for the new technique. Economy can be measured in terms of the time, equipment and level of expertise required for the new technique in comparison to other techniques. For any new techniques this should at least be equivalent to existing, standard local anaesthetic
techniques. The acceptability of any technique, from the patients’
perspective, varies with their expectations. In dentistry, the intraoral
techniques of mandibular and maxillary nerve blocks are the ones
generally perceived as more acceptable to patients because of existing
familiarity, whereas the extra-oral techniques are more familiar in
medicine. When considering new techniques, patient acceptability should
be similar or better than that found in existing techniques. In dentistry,
extraoral techniques may produce an increased level of anxiety in patients,
as they are often unexpected. Clinicians, too, may have increased anxiety
about using extraoral techniques as they are unfamiliar with them.
However, when there is proven ease of administration and minimal
discomfort for the patient, acceptance will occur.

Over the past 50 years, a number of different techniques of local
anaesthesia for the mandibular division of the trigeminal nerve have been
published. However, to date, no one technique has been able to claim
100% efficacy in terms of the clinical outcome. Budenz (2007) gave a brief
overview of the history of inferior alveolar techniques, starting with the
traditional inferior alveolar nerve block technique as first described by
William Halsted in 1884, and then considered both the Gow-Gates
approach and the Vazirani-Akinosi technique. Budenz (2007) noted that
the reported success rates for the various techniques have varied
considerably from one study to another. However the Gow-Gates
technique is most frequently reported to have the highest success rate,
ranging from at least 90% to even 100%. By comparison, the success rate of the standard (Halsted) technique has been reported to be between 65% and 86% (Budenz, 2007). Falling between these, the success rate of the Vazirani-Akinosi technique has been reported to be between 76% and 93% (Budenz, 2007).

Budenz (2007) also reviewed other factors. He found that the occurrence of positive aspirations was highest with the standard technique, having an occurrence of between 7% and 22%. The Gow-Gates and Vazirani-Akinosi techniques were found to have a far lower incidence of positive aspiration, both having similar values of around 2%. The Vazirani-Akinosi technique was found to have the highest reported incidence of anaesthesia of structures other than the intended inferior alveolar nerve block, although Budenz did not elaborate on this. This outcome may simply reflect the fact that, because the site of deposition of anaesthetic is closer to other branches of the mandibular nerve than the site of the standard technique, structures supplied by these branches will be affected by the anaesthetic. Budenz (2007) found that the standard technique had the highest reported incidence of both trismus and paresthesia, whereas the Gow-Gates technique had the lowest reported incidence of all types of unusual side effects. The negative aspects of the Gow-Gates technique included a slower rate of anaesthetic onset (being up to 10 minutes for full anaesthesia) and a greater degree of difficulty in learning the technique (Budenz, 2007).
Apart from simple field (infiltration) anaesthesia, there are sixteen different techniques for mandibular nerve block anaesthesia that have been published, including the mental/incisive nerve block of which there are three versions. These are:

The standard (Halsted) technique
The standard indirect technique
Mental nerve (incisive nerve) block
  - standard approach
  - anterior approach
  - extraoral approach
Clarke-Holmes technique
Vazirani technique
Sargenti technique
Gow-Gates technique
Akinosi technique
Wolfe technique
Ipsilateral open-mouth technique
Morishita (positive aspiration) technique
Extraoral submandibular approach
Lateral extraoral approach
Anterior extraoral approach.
1. The standard (Halsted) technique

The standard technique has been utilised for over a century, Halsted having first described blocking the mandibular nerve in 1884 (Austin, 1987). The technique provides a relatively simple and safe approach to the mandibular (inferior alveolar) nerve and it remains the most commonly used and taught technique to date.

Malamed (2004) describes the current version of this technique. First, the injection site is determined by palpating the anterior border of the ramus (the coronoid notch). The insertion point of the needle is identified as being immediately lateral to the raised line of soft-tissue that is the pterygomandibular raphe and at a height that is 6 to 10 mm above the occlusal plane of the mandibular teeth (fig 4). The approach to the target site is from the opposite (contralateral) side and the average depth of penetration of the needle is 20 to 25 mm, at which depth the tip of the needle should be in contact with the medial surface of the ramus (fig 5).
The major criticism directed towards the standard technique is that it has a relatively high failure rate in achieving clinically acceptable nerve block anaesthesia. The most common reason that is given for this lack of success is that the anaesthetic solution is deposited at a level that is too
low, which is to say that it is deposited below the level of the mandibular foramen. Most alternative techniques have therefore tended to focus on depositing the solution at higher levels in respect of the superficial anatomical landmarks and the ramus of the mandible. Budenz (2007) noted that the success rate of the Halsted technique has been reported to be only between 65% and 86%, although Donkor (1990) achieved a 93% success rate. Lai et al (2006) found an even lower success rate following a single dose of 2.1 ml of a 2% lignocaine solution. In this study, anaesthesia of the first molar tooth occurred in 90% of subjects, but this fell to 55% for the first bicuspid and 38% for the canine (Lai et al, 2006).

The standard technique was also found to have the highest incidence of positive aspiration (7% to 22%) and the highest incidence of both trismus and paresthesia (Budenz 2007). Baart and Brand (2009) stated that the contralateral approach used in the standard technique risked damaging the medial pterygoid muscle through needle penetration or deposition of the anaesthetic into the body of the muscle.

Clarke and Holmes (1959) advanced their own rationale for the high incidence of failure of the standard technique. They held that because the standard technique for the inferior dental nerve block attempted to place the anaesthetic behind the mandibular foramen, the anterior part of the nerve would be concealed by the lingula and the sphenomandibular ligament. Thus, the local anaesthetic solution placed in this location would diffuse less readily to the anterior fibres of the nerve trunk, which would
be screened by the sphenomandibular ligament (Clarke and Holmes, 1959).

Milles (1984) considered that the size of the ramus and the degree of its lateral flare (angulation) were significant factors in the failure of the standard technique. As well as depositing the anaesthetic solution too far inferiorly, Milles opined that deposition of the solution in the medial aspect of the pterygomandibular space was also a reason for failure.

2. The standard indirect technique

A variation of the standard technique is the indirect approach (fig 6). The injection site for this technique is identical to that of the standard technique. However, in this approach, the needle is advanced to contact the anterior border of the ramus (steps 1-2 in fig 6). The syringe is then moved from the contralateral side to the ipsilateral side. The needle is advanced along the medial surface of the bone to the same depth recommended in the standard direct technique (steps 3-4 in fig 6). In cases where the ramus flares widely, the syringe may be again moved to the contralateral side to complete the advance of the needle tip to contact the bone (step 5 in fig 6).
The purpose of this approach is to ease the passage of the needle between the ramus and the medial pterygoid muscle and to reduce the risk of inadvertently penetrating the body of the muscle, which may then produce trismus through bruising or spasm. Trismus is one of the reported potential problems in the standard technique (Budenz 2007). All other comments and criticisms of the Halsted technique, such as the incidence of failure and positive aspiration, apply equally to the indirect technique.

3. The mental nerve (incisive nerve) blocks

As noted by Roberts and Sowray (1979), the aim of the mental nerve block is, often, to anaesthetise the other terminal branch of the inferior alveolar nerve – the incisive nerve. However, depositing anaesthetic solution at
the site of the mental foramen will certainly block the mental nerve. Both intraoral and extraoral approaches to the mental foramen have been described (Eriksson 1969; Roberts and Sowray 1979). Because the path of the mental nerve to the mental foramen is in a superior and posterior direction (fig 7), the traditional intraoral approach has been to insert the needle into the vestibular fold in a vertical direction so that the point of the needle is directed inferiorly towards the foramen (fig 8), although it is not recommended that the needle be inserted into the foramen due to the high risk of causing damage to the nerve bundle or vasculature within it.

![Fig 7: A radiographic image showing the intraosseous path of the mental nerve (indicated by the arrows) in a superior and posterior direction from the mandibular canal to the mental foramen.](image)

Eriksson (1969) does not describe the technique for the extraoral approach to the mental foramen but does provide a photographic image (fig 9).

Eriksson states that the target nerve can be located by palpation of its trunk under the skin, as it exits the foramen (Eriksson, 1969). This may not be reliable. Eriksson does not warn against inserting the needle too high above the lower border of the mandible. If this is done, there is the risk that the needle will pass through the oral mucosa and enter the buccal sulcus.
Recently, Malamed (2004) has recommended an anterior intraoral approach to the mental foramen. The rationale is that there is no need to try to deposit the anaesthetic at the entrance to the foramen. This approach has the advantage of being less intimidating for the patient (fig 10). An image showing a similar approach appears in Eriksson (1969), but with little description.
4. The Clarke-Holmes technique

In 1959, Clarke and Holmes published an indirect technique that they called a ‘Modified Indirect Method’. This approach placed the anaesthetic solution against the mandibular ramus at a higher level than the standard technique. Their technique was subsequently redescribed as a direct technique by Roberts and Sowray (1979).

The intraoral insertion point for the Clarke-Holmes technique is located by placing a finger over the occlusal surfaces of the mandibular teeth to palpate the coronoid notch. The needle is inserted above the level of the finger (fig 11). The needle approaches from the contralateral side and is directed so that it contacts the ‘internal oblique line’ at the anterior border of the ramus. The syringe is moved to the ipsilateral side and advanced along the inner surface of the ramus. This, the authors claim, results in the anaesthetic being deposited ‘half an inch’ (1.2 – 1.5 mm) above the level achieved by the standard technique. According to Clarke and Holmes, at this level the nerve trunk lies ‘free’ of the bone. However, they do not explain what they meant by the term ‘free’. The description of the advance of the needle is identical to that of the standard indirect technique.
The insertion of the needle towards a higher target area has the potential to overcome the risk of depositing the anaesthetic solution below the level of the mandibular foramen. However, there have, to date, been no published studies of this technique, its success rate, or any problems.

5. The Vazirani technique

In 1960 Vazirani published the first closed-mouth mandibular nerve block technique. He advocated using the maxillary gingival margin as the guide for the height of insertion of the needle, although the image accompanying his article shows the needle considerably higher than this (fig 12) (Vazirani, 1960). Following insertion, the needle is advanced approximately 15 mm. However, Vazirani was vague regarding the depth of penetration, suggesting that the clinician use his or her own judgement in this.
Although Vazirani was quite definite as to the constancy of the position of the mandibular foramen on the medial surface of the ramus, it was his opinion that deposition of the anaesthetic solution at a particular, precise location was not necessary. Instead he stated that simply depositing the anaesthetic in the vicinity of the nerve would produce deep anaesthesia and that the pterygomandibular space was the ideal site for approximate delivery (Vazirani, 1960). Vazirani stated that, in the confines of the pterygomandibular space, diffusion and gravitation would ensure effective anaesthesia. Vazirani’s article is the first time a reference is made to the concept of depositing anaesthetic within the appropriate tissue plane to achieve anaesthesia of the trigeminal nerve.

Vazirani described his technique in some detail (fig 13):
- The patient’s mouth is either fully closed or in the rest position
- The needle is placed parallel to the gingival margin of the maxillary molar teeth, or the edentulous maxillary alveolar ridge
- The needle is inserted into the tissues to a depth of approximately 15 mm. However this is not invariable as, according to Vazirani, the operator must use his/her own judgement to accommodate anatomic variability.

Fig 13: The path of insertion for the Vazirani technique
From: Vazirani, 1960

Vazirani stated that his technique would, in addition to anaesthetising the inferior alveolar nerve, achieve anaesthesia of the lingual and long buccal nerves. Further, he stated that it was not necessary to place the needle tip against the ramus, as advocated by other approaches. This was because the ramus diverged at an angle from the line of the body of the
mandible. As Vazirani’s approach was in line with the body of the mandible, the needle tip would lie progressively further away from the ramus as it penetrated deeper into the tissues (fig 14). However, the author was at pains to recommend that the needle still be manoeuvred so that it remained within the pterygomandibular space (Vazirani, 1960).

![Fig 14: The path of insertion of the Vazirani technique, showing the needle tip at some distance from the medial surface of the ramus](image)

According to Vazirani, the advantages of the technique are manifold:

- it is simple and direct
- it avoids trauma to the inferior alveolar nerve, artery, and veins
- it avoids interference with the styloid process
- it avoids trauma to the medial pterygoid muscle
- additional needle punctures are eliminated
- the incidence of broken needles is extremely low (Vazirani was writing at a time when needles were sterilised and re-used)
- it is ideal for a child patient
- it is less painful than conventional methods
- it is successful in 95% of cases.

Subsequent studies on the closed-mouth technique confirm that it does have a higher success rate than the standard technique and a very low rate of positive aspiration (Budenz, 2007). It is also less uncomfortable than the standard technique and is very suitable for the unco-operative patient or the patient with trismus. Some of Vazirani’s claims are somewhat dubious, such as interference with the styloid process and the avoidance of additional injections. The potential for trauma to both lateral and medial pterygoid muscles is still possible with this technique.

Unfortunately, Vazirani’s technique was largely overlooked at the time and only rediscovered some years after Akinosi (1977) had published his version of the closed-mouth approach (vide infra).

6. The Sargenti technique

In 1966, Sargenti published an alternative technique which, like that advocated by Clarke and Holmes (1959), also deposited the anaesthetic
solution against the ramus at a higher level than the standard approach. Sargenti’s diagrams are revealing not only of the technique, but also of the prevailing notion of the relative constancy of the position of the mandibular foramen on the medial wall of the ramus. Sargenti’s technique is based on his concept of ‘geometric localisation of the mandibular foramen’. In his view, the mandibular foramen is approximately at the intersection of two conceptual lines: one line is created from the posterior projection of the occlusal surface of the teeth in the mandible (labelled ‘B’ in fig 15); the other line divides the inner aspect of the ascending ramus vertically from the sigmoid notch to the lower border (fig 15) (Sargenti, 1966). According to Sargenti, when the mouth is opened widely, a line representing the posterior projection of the maxillary occlusal plane passes almost exactly through the mandibular foramen (labelled ‘A’ in fig 15). Therefore, if the needle is held adjacent and parallel to the upper dental arch it will reach the foramen upon insertion (Sargenti, 1966).

Fig 15: Sargenti’s analysis of the position of the mandibular foramen

From: Sargenti, 1966
Sargenti asserted that one of the most common causes of failure of the standard inferior alveolar nerve block injection was that the needle was inserted too deeply. As a result the anaesthetic solution was deposited too far away from the nerve. He stated that the deposition of the anaesthetic solution needed to be made at the level of the lingula. The correct level for this was, according to Sargenti, found to be at the mid-point of the nail of the clinician’s index finger when it palpates the retromolar triangle. However, for this position to be correct the mouth must be opened to its widest extent (Sargenti, 1966).

Sargenti based his technique on two principles. The first principle was that the position of the mandibular foramen is relatively constant on the medial aspect of the ramus and has a direct relationship with the dentition (fig 15). The second principle was that the position of the mandibular foramen varies, with respect to the superficial landmarks, depending on the degree of mouth opening (fig 16). In figure 16, the group of parallel lines, indicated as 'B', demonstrate how increasing the patient’s mouth opening affects the relationship between the superficial landmarks and the mandibular foramen (Sargenti, 1966). In contrast, the group of lines marked by the 'A's demonstrate that the relationship of the maxillary dentition and the mandibular foramen remains constant despite the degree of mouth opening (Sargenti, 1966).
Sargenti’s technique requires the patient’s mouth to be opened as widely as possible. The index finger of the clinician’s supporting hand is used to palpate the depth of the coronoid notch. The needle is inserted at the level of the mid-point of the finger nail and a few millimetres medial to the tip of the finger. The angulation of the syringe is determined by keeping the barrel in contact with the upper dental arch in the canine-premolar region of the opposite side. The needle is advanced so that the point of the needle contacts the bone after no more than 10 mm of soft tissue penetration. Sargenti claimed that, with his technique, it was ‘practically impossible’ to deposit the anaesthetic solution posterior to the mandibular foramen, because of the needle’s contact with the inner aspect of the ramus (figs 17 and 18).

Fig 16: Sargenti’s analysis of the effects of variation in the degree of mouth opening on the targeting of the mandibular foramen

From: Sargenti, 1966
Nevertheless Sargenti did acknowledge that a successful clinical outcome was not guaranteed and advised that when his technique failed the following steps should be adopted:

- ‘Learn to wait patiently’, because delayed onset would occur in the event of an inaccurate injection
- ‘Repeat the injection’. The purpose of this is to increase the dose of anaesthetic (or in Sargenti’s words, the ‘quantity of solution’)
- ‘Use a solution with a higher concentration of vasoconstrictor’
  Sargenti’s rationale for this was that the anaesthetic solution acted as a ‘buffer’ against the vasoconstrictor effects of the adrenaline and made it sometimes necessary to increase the concentration of adrenaline to 1:50,000
- in the case of anterior teeth and premolars attempt local infiltration
- in the molar region use anaesthesia by ‘compression’ or inject directly into the pulp.

These recommendations unfortunately detract from Sargenti’s argument concerning the precision of his technique, for if the technique was so consistently precise then problems should not occur.

Like the Clarke-Holmes (1959) technique, Sargenti’s approach has been largely forgotten and no studies of its effectiveness or of adverse effects and complications have been undertaken.

7. The Gow-Gates technique

In 1973, Gow-Gates published a technique that has since become world-famous. The underlying principle is the deposition of anaesthetic at a high level against the fovea of the neck of the condyle at the level of the lower
border of the lateral pterygoid muscle (Gow-Gates, 1973, 1983). Uniquely for an intraoral technique, Gow-Gates utilised external landmarks – the tragus of the ear, the angulation of the pinna of the ear from the head and the corners of the mouth – to determine both the puncture point and the path of insertion of the needle (figs 19 and 20). The purpose of the technique was to ensure that the anaesthetic was deposited at an ‘adequate height’ above the lingula (Gow-Gates, 1973, 1983).

Fig 19: The Gow-Gates technique demonstrating the positioning of the needle in line with the tragus and the corner of mouth

From: Gow-Gates, 1983
Gow-Gates described his landmarks in terms of a series of geometric planes. The puncture point lies on a plane that extends from the lower border of the intertragic notch of the ear and through the corners of the mouth. The tragus of the ear is the external landmark toward which the needle is aimed in order to contact the fovea (figs 20 and 21). The angulation of the ear was, in Gow-Gates’ opinion, a guide for assessing the divergence of the ramus, although the rationale for this was not explained (Gow-Gates, 1973, 1983).
The Gow-Gates technique requires the patient to open as widely as possible and to maintain this posture until the onset of anaesthesia (Gow-Gates, 1973). With the mouth opened maximally, the condyle translates forward to lie approximately in the same coronal plane as foramen ovale or, as Gow-Gates described it, 'lies in a closer relationship to the mandibular nerve' (Gow-Gates, 1973). Gow-Gates opined that the insertion point was very close to the anterior border of the ramus, however this is inaccurate as the coronoid process is translated forwards and down during opening. Using the tragus as the guide, the needle is advanced to contact the neck of the condyle at the fovea – also called the sulcus colli (fig 22). Gow-Gates was adamant that if the bone was not contacted when the needle has penetrated to a depth of 25 mm, this could indicate that the syringe had not been correctly positioned (Gow-Gates, 1973).
Budenz (2007) noted that the Gow-Gates technique is the technique most frequently reported as having the highest success rate, ranging from 90% to 100%. The technique is reported to have approximately only 2% of positive aspirations and also the lowest incidence of side effects. However it does have a slower time to onset (taking on average 10 minutes) and ‘a more difficult learning curve’ (Budenz, 2007). Watson (1973) claimed that the success of the Gow-Gates block was ‘almost invariable’. He attributed this level of success to:

- the extreme forward position of the condyle, which brought it into a lateral relationship with the path of the nerve trunk
- the restriction on the dispersion of local anaesthetic by the interpterygoid fascia, keeping the solution within the plane of the pterygomandibular space.
Levy (1981) reviewed the Gow-Gates technique and noted that a volume of 3.3 ml was, at that time, recommended by Gow-Gates using a 4% prilocaine solution. Levy found that patient preference (which he did not define, but which may relate to patient discomfort from maintaining the jaw in its maximal opening position for a prolonged period of time) somewhat favoured the standard technique over the Gow-Gates approach, but that the success rate was significantly higher for the Gow-Gates injection (96% compared to 65% for the standard technique) (Levy, 1981). However, Levy also found that long buccal nerve anaesthesia was not always obtained and opined that this might be due to anatomic variation (Levy, 1981).

Kohler et al (2008) reviewed the Gow-Gates technique, which they regarded as being ‘very close to a true mandibular nerve block’. They found that for successful anaesthesia to be achieved with this technique, a doubling of the standard anaesthetic dose (in this case from 1.8 ml to 3.6 ml) was required. At this higher dose a success rate of 82.5% was obtained, whereas deposition of 1.8 ml of anaesthetic achieved successful nerve blockade in only 17.5% of cases (Kohler et al, 2008). These comments and those of Budenz (2007) are in keeping with the assessment on the Gow-Gates block by Coleman and Smith (1982) who argued that nerve block was achieved by this technique through diffusion of the anaesthetic along the pterygomandibular tissue plane. Baart and Brand (2009), despite
acknowledging the improved success rate over the standard approach (95% compared with 85%), considered the Gow-Gates technique to offer only ‘limited’ advantages. However, Baart and Brand did not describe the technique correctly and, more significantly, failed to mention the use of extraoral landmarks. Baart and Brand claimed that the time to onset of anaesthesia for the Gow-Gates block was only 2 – 3 minutes, which is substantially faster than that acknowledged by Gow-Gates and other authors (Baart and Brand, 2009). Nor are the images supplied with Baart and Brand’s description a true reflection of the Gow-Gates block (figs 23 and 24). Fig 23 shows an ipsilateral approach with the needle passing medially to the fovea and into the superior head of the lateral pterygoid muscle. Fig 24 shows an insertion point that is lower than that recommended by Gow-Gates. The lateral angulation also appears to be incorrect [compare this image with figs 19 and 20 from Gow-Gates, 1983]. These errors may be the result of the greater degree of difficulty in understanding the details of the Gow-Gates block (Budenz 2007), which suggests that it is a less than ‘ideal’ delivery technique (MacLennan 2007).
Fig 23: Baart and Brand’s drawing of the Gow-Gates technique
(Note the apparent ipsilateral approach and the needle penetrating superior head of the lateral pterygoid muscle medial to the fovea)
From: Baart and Brand, 2009

Fig 24: Baart and Brand’s photograph of the Gow-Gates technique
(Note that the insertion point is too low and the angulation is incorrect)
From: Baart and Brand, 2009
8. The Akinosi technique

In 1977, Akinosi published his closed-mouth technique. The general approach is very similar to that published by Vazirani. However, because Vazirani’s report had been published in a relatively obscure journal the technique initially became known as the ‘Akinosi block’. More recently, Vazirani’s name has been added to the name of the technique (the ‘Vazirani-Akinosi block’) in recognition of his precedence. According to Akinosi, the anatomical rationale for the technique was that, in the upper part of the pterygomandibular space, the inferior alveolar, lingual and long buccal nerves all lie in sufficiently close proximity to permit a single injection to anaesthetise all three nerve branches (Akinosi, 1977).

Akinosi described his technique thus:

- The teeth are closed to assist relaxation of the cheek and lips, which are then ‘well distended’ by the clinician to permit visualisation of the injection site (fig 25)
- The needle is positioned at the level of the maxillary gingival margin, with the barrel of the syringe parallel to the maxillary occlusal plane
- The syringe is advanced and the needle then penetrates the tissues in the embrasure between the vertical ramus and the maxillary tuberosity
- The needle is advanced to a depth of between 25 and 30 mm (fig 26).
The needle at this point lies in the pterygomandibular space, having passed through the buccinator muscle. The tip of the needle, according to Akinosi (1977), now lies close to the main branches of the mandibular
nerve and these are easily reached by the diffusion of the anaesthetic solution.

Akinosi stated that the onset of anaesthesia was very rapid with his technique: ‘When correctly given, the patient experiences altered sensations in the tongue and lip from about 40 seconds after the injection and surgical anaesthesia is obtained in about 1 ½ minutes’ (Akinosi, 1977). He also claimed that all the sensory divisions of the mandibular nerve, with the exception of the auriculotemporal nerve, (i.e. the inferior alveolar, lingual and long buccal nerves) would be anaesthetised (Akinosi, 1977).

Akinosi claimed a 93% success rate ‘at the first attempt’. However he reported that his technique was not as reliable in children as in adults. He attributed this to the ‘difficulty experienced in estimating the depth to which the needle should penetrate in the growing child’ (Akinosi, 1977).

Akinosi’s technique was redescribed by Gustainis and Peterson (1981) as the ‘tuberosity technique’. These authors attributed the success of the Akinosi technique to diffusion of the anaesthetic through the pterygomandibular space to reach the ‘nerve plexus’ supplying the mandibular tissues. They claimed that, anecdotally, the Akinosi technique was no more successful than either the standard approach or the Gow-Gates technique (Gustainis and Peterson, 1981).
Budenz (2007) noted that ‘the success rate of the Vazirani-Akinosi technique has been reported to be between 76% and 93%’. Donkor (1990), in his study, achieved a much lower level of success than with the standard technique. But Donkor did admit that his trial was also his first experience with the technique and that he had only Akinosi’s article for guidance. Budenz (2007) noted that a low level of positive aspirations occurred with the closed-mouth technique (2%), but also reported that the technique had ‘the highest reported incidence of anaesthesia of [other] structures’.

9. The Wolfe technique

In 1992, Wolfe published a variation on the closed-mouth technique, using a needle that was curved by the operator to facilitate the deposition of the anaesthetic as closely as possible to the medial surface of the ramus.

Wolfe recommended using a 30 mm-long needle, as opposed to the 41 or 42 mm-long needles usually employed for mandibular nerve blocks. This needle was to be given ‘a slight curvature’ before use (Wolfe, 1992). This was achieved by using the needle’s protective cap to apply a lateral force to the shaft of the needle as the cap was being removed. The mid-third of the shaft was the area subjected to this curving. Wolfe asserted that, through the creation of this curve, directing the needle to the correct site would be greatly enhanced and that it would enable deposition of the
anaesthetic to be made much more closely to the medial surface of the ramus (Wolfe, 1992). The curvature of the needle was necessary, according to Wolfe, to overcome the concavity of the medial surface of the ramus. Wolfe stated that his modified closed-mouth technique avoided the failures of anaesthesia that occurred with the Akinosi block. Wolfe further stated that failures of the Akinosi technique were solely due to the anaesthetic solution being deposited medially to the sphenomandibular ligament (Wolfe, 1992).

Unlike many of the other techniques, Wolfe attempted to provide as detailed a description of his approach as possible. However, this is still not as clear as the author intended. Being a closed-mouth technique, the approach is ipsilateral. The point of penetration of the needle is described as being midway between the coronoid process (immediately above the palpated coronoid notch) and the lateral surface of the maxillary tuberosity, approximately at the height of the maxillary mucogingival junction (Wolfe, 1992). This is slightly higher than that described by both Vazirani and Akinosi. Wolfe’s description of the angulation of insertion is overly complex and confusing, but the intent is to keep the syringe parallel to the line of the occlusion in the horizontal plane and parallel to the posterior arch of the dentition in the vertical plane so that the needle is directed more laterally toward the ramus. The needle is to be advanced to a depth of half the width of the ramus, which according to Wolfe will never exceed 20 mm (Wolfe, 1992). The important part of this technique,
according to Wolfe, is that the needle is advanced so that the curvature faces the ramus. The imparted curve causes the needle to deflect even closer to the ramus. This, Wolfe stated, was to overcome the problem of the Vazirani-Akinosi technique in that it failed to contact the ramus (Wolfe, 1992).

For all the claimed precision of the technique, Wolfe admitted that it was often necessary to wait for three to five minutes before objective signs of anaesthesia occurred. Wolfe stated that should anaesthesia fail to occur the patient should be sat upright so that gravity would allow the anaesthetic to reach the nerve trunk. Wolfe did not venture to explain why the onset of anaesthesia was prolonged in some cases, nor why gravity would assist its success (Wolfe, 1992).

Malamed (2004) was dismissive of Wolfe’s approach. However, he misdescribed the technique, claiming that Wolfe had recommended bending the needle to an angle of 45 degrees (Malamed, 2004). Malamed (2004) also stated that because bending the needle increased the risk of fracture the technique was not recommended. But fracture of modern, single-use needles is highly unlikely. Malamed did correctly state, however, that a successful closed-mouth block can be administered without recourse to bending the needle (Malamed, 2004).
The issue that remained unresolved was whether deposition of anaesthetic against the ramus, as recommended by Wolfe, was more effective that the sites of deposition recommended by Akinosi or Vazirani.

10. The ipsilateral (open-mouth) technique

In 2007 Dubash et al produced a written description of the standard indirect inferior alveolar nerve block. However, their accompanying photograph depicted instead an ipsilateral approach, which was not described in the text. The images appear to show a combination of features of the indirect technique and the closed-mouth technique (fig 27) (Dubash et al, 2007). Such a technique might be suitable for those patients whose mandibular ramus did not flair widely. However the approach, as depicted, would pose a high risk of depositing the anaesthetic solution either below the mandibular foramen or into the medial pterygoid muscle. The apparent depth of penetration of the needle (which is shown to have been advanced almost to the hub) is too far for the closed-mouth technique even if a 35 mm-long needle has been used, for according to the Akinosi technique penetration should be no more than 25-30 mm (Akinosi, 1977). From the image provided by Dubash et al (2007) and in accordance with most of the recommendations from other techniques, it would appear that for this technique to be successful, the insertion point should be higher and the barrel of the syringe parallel to the line of the dentition.
Baart and Brand (2009) refer to this ipsilateral approach as ‘the direct technique’. The use of this term, however, risks the possibility of confusing this approach with the standard technique. Baart and Brand (2009) state that this approach does pose the risk of depositing the anaesthetic solution too medially, but do not see any risks for the medial pterygoid muscle.

11. The Morishita (positive aspiration) technique

Morishita (2007) reported on a technique that not only deliberately deposits local anaesthetic at some distance from the inferior alveolar nerve, but
also seeks to deliver it intravascularly. The author states that the standard technique often fails because it requires accurate deposition of the anaesthetic adjacent to the nerve and that this technique also has the potential to cause ‘serious’ injuries to both nerves and blood vessels (Morishita, 2007). Morishita describes his technique (fig 28) thus:

- the needle is inserted into the submucosa adjacent to the internal oblique line of the anterior border of the ramus, somewhere between 4 mm and 10 mm above the mandibular occlusal plane
- with the bevel of the needle facing the bone, a small (undefined) amount of anaesthetic is deposited into the submucosa
- positive blood aspiration is then attempted
- if aspiration is successful, the rest of the anaesthetic solution is deposited while keeping the needle tip absolutely steady
- if aspiration is not achieved, advance the needle over the bone surface for some 4 mm to 6 mm and again attempt to achieve positive aspiration.
Morishita (2007) recommended using 3% prilocaine, with 1:300,000 adrenaline, as the anaesthetic agent, but did not offer reasons for this choice. He recommended the minimum dose to be 3.6 ml. An analysis of Morishita’s results show that 83.3% of subjects experienced analgesia, while 16.7% still experienced pain. Only 61.9% of subjects reported complete anaesthesia. While claiming success for the technique, Morishita did not explain how anaesthesia is achieved, other than to state that the positive aspiration demonstrates that the needle tip lies within the pterygomandibular space (Morishita, 2007). Morishita also made no reference to potential complications or adverse reactions.
12. The extraoral submandibular approach

Roberts and Sowray (1979) described an extra-oral, submandibular approach to the inferior alveolar nerve. As with some other techniques, the position of the mandibular foramen is calculated with geometric precision using soft tissue landmarks. In this technique the tragus of the ear and the anterior border of the masseter muscle are used to define a diagonal line over the ramus. The midpoint of this line is considered to be the actual position of the mandibular foramen, although here is no statistical data to support this (fig 29) (Roberts and Sowray, 1979).

Fig 29: Photograph and legend describing the location of the mandibular foramen using extraoral landmarks

From: Roberts and Sowray, 1979
The technique (fig 30) is to advance the needle such that it passes parallel to the posterior border of the ramus (indicated by the line ‘D-C’ in fig 29) to the depth indicated by the external ‘line’ (‘B-A’ in fig 29). The illustration of the technique (fig 30) shows the use of a rubber stopper on the needle, which indicates the predetermined depth. The authors stress the necessity of keeping the needle tip as near to the medial surface of the ramus as possible while it is being advanced to the correct depth (Roberts and Sowray, 1979). For this to be achieved the neck must be flexed to the opposite side although Roberts and Sowray do not mention this.

Fig 30: The point and direction of insertion for the submandibular approach
From: Roberts and Sowray, 1979

No further description of this technique is provided by Roberts and Sowray, nor do they mention any risks. However, a review of the anatomy demonstrates that the needle must pass through the medial
pterygoid muscle to reach the pterygomandibular space. Because the mouth is closed when the needle is inserted, this muscle will be active and penetration by the needle is likely to be painful for the patient. The technique may also cause spasm or bruising of the medial pterygoid muscle. A potentially serious risk is impaling the facial artery, which curves through the submandibular gland (lying medial to the medial pterygoid muscle) and crosses the lower border of the mandible at the anterior border of the masseter muscle. A further complication to the technique could occur in those individuals whose neck tissues prevent correct angulation of the needle. Nowadays, the use of a rubber bung is contraindicated due to infection control risks and also the risk of damaging the needle tip during its insertion through the rubber.

The submandibular approach is another technique about which there has been no subsequent review or study to evaluate the outcomes or risks of complications.

13. The lateral extra-oral technique

The lateral extraoral technique aims to deliver anaesthetic to the mandibular nerve at or just below foramen ovale. The lateral approach inserts a needle between the lower border of the zygomatic arch and the sigmoid notch of the mandible (fig 31). The needle passes through the
masseter and lateral pterygoid muscles to reach the foramen. This is a 'blind' technique, because there are no landmarks to guide the clinician or inform him/her when the needle is correctly positioned. Roberts and Sowray (1979) describe advancing the needle until the lateral pterygoid plate is contacted. The needle is then withdrawn and redirected posteriorly until the lateral pterygoid plate is no longer contacted (Roberts and Sowray, 1979). The anaesthetic solution is then deposited at a depth of between 40 and 50 mm (fig 32) (Roberts and Sowray, 1979).

Fig 31: The insertion point for the lateral extraoral approach

From: Roberts and Sowray, 1979
Fig 32: The lateral extraoral mandibular nerve block

From Roberts and Sowray, 1979

Stajcic and Todorovic (1997) utilised the same insertion point as described by Roberts and Sowray (1979), describing it as the midpoint of the zygomatic arch (fig 31). The needle (either an 18 G 73 mm injection port or a 20G 80 mm spinal needle was recommended by the authors) is inserted perpendicularly to the mid-sagittal plane until the lateral pterygoid plate is contacted (Stajcic and Todorovic, 1997). Then the needle is withdrawn and re-inserted 60 degrees posteriorly to the same depth, at which point the needle tip is ‘expected to be in the vicinity of the foramen’ (Stajcic and Todorovic, 1997). 3 ml of anaesthetic is deposited at this location and the authors reported a 92% success rate (Stajcic and Todorovic, 1997). Stajcic et al (2002) reviewed this technique following an anatomical study of 22 dried skull specimens. They redefined the insertion point to be midway between the orbital margin and the junction point of the external
acoustic meatus and the mastoid process (fig 33) (Stajcic et al, 2002). From this point the insertion angle was calculated to be 71.86 degrees (fig 34) and the mean depth of penetration was 40.77 mm (Stajcic et al, 2002). Despite these changes, their success rate remained unchanged (91%) from the previous study (Stajcic and Todorovic, 1997).

Fig 33: The determination of the insertion point for the lateral extraoral block

From: Stajcic et al 2002

Fig 34: The determination of the angle of insertion of the needle to foramen ovale

Modified from: Stajcic et al, 2002
Rosenberg and Phero (2003) claimed that the extraoral technique was easier for clinicians than the intraoral techniques employed in dentistry. Their description of the technique is virtually identical to that by Roberts and Sowray. However, they described the insertion point of the needle incorrectly, stating that the needle penetrates at the point of intersection of the lower border of the zygoma and the anterior border of the mandibular ramus through the coronoid notch (Rosenberg and Phero, 2003), whereas it is the sigmoid notch to which they referring. An examination of a dried skull will demonstrate that it would not be possible to reach foramen ovale with a needle that is in contact with the coronoid notch. Rosenberg and Phero’s technique is to advance the needle until contact with the lateral pterygoid plate is made, then the needle is withdrawn and reinserted ‘upward and slightly posterior until a paresthesia is noted or the needle has reached a depth of 5 cm’ (Rosenberg and Phero, 2003). Following these instructions reduces the technique to mere guesswork and no information is provided regarding failure or complications.

14. The anterior extra-oral technique

Eriksson (1969) described and illustrated an anterior approach to foramen ovale. In this approach, an 80 mm needle is inserted through the cheek (fig 35) and directed upwards and posteriorly toward foramen ovale (fig 36) (Eriksson, 1969). The distance that the needle must travel makes the
technique a blind one, requiring repeated reinsertions to locate the foramen (fig 36) even with the assistance of fluoroscopy, which the author recommended (Eriksson, 1969).

Fig 35: The insertion point for the anterior foramen ovale block

From: Eriksson, 1969

Fig 36: The path of insertion of the needle for the anterior extraoral approach, showing redirection after contacting the sphenoid bone

From Eriksson, 1969
Rathmell and Pollack (2007) describe the insertion point for this technique as being between 2 and 3 cm ‘lateral to the corner of the mouth’, by which they presumably mean posterior. They recommend using a 100 mm spinal needle and state that the needle is advanced ‘toward the mandibular condyle in line with the pupil’ until the greater wing of sphenoid is contacted, somewhere between 40 and 60 mm depth of penetration (Rathmell and Pollack, 2007). The needle is then redirected further posteriorly until the foramen is located (fig 37). One of the complications listed is deposition of local anaesthetic into the internal carotid artery which, given the lack of anatomical detail supplied and the ‘blindness’ of the technique, is a definite possibility (Rathmell and Pollack, 2007).

Fig 37: Diagrams of the anterior foramen ovale approach

From: Rathmell and Pollack, 2007
2. A Review of the Nerve Block Techniques for the Mandibular and Maxillary Divisions of the Trigeminal Nerve

Introduction

Despite the overall high degree of clinical efficacy, it is acknowledged that the administration of local anaesthetic does not always achieve the level of analgesia or anaesthesia that is sought by either the clinician or the patient. The simplest local anesthetic technique for minor surgical procedures, including routine dental treatment, is infiltration anaesthesia. This involves the deposition of anaesthetic solution into the tissues in the immediate vicinity of the target site and includes direct flooding of the site with local anaesthetic or encirclement of the site by a ring of anaesthetic (field anaesthesia) (Tsai et al, 2007). This approach enjoys a high level of popularity, due to its ease of administration, safety, and clinical success (Tsai et al, 2007).

Compared to infiltration anaesthesia, nerve trunk blocks are seen as being more technically difficult to perform, with greater safety risks for the patient and lower successful outcomes in terms of producing complete or profound analgesia (Dilberovic et al, 2007; Eriksson, 1969). The problems of technical difficulty, complications, and the failure to achieve clinically
acceptable levels of anaesthesia have, for the most part, been due to the reliance on concepts of standard anatomy and the inability to determine individual anatomical variation (Dilberovic et al, 2007).

The problems that have occurred in regional nerve block techniques in medicine are also found in dentistry, primarily for nerve block injections to the mandibular or inferior alveolar nerves. The problem of unsuccessful nerve block has exercised all disciplines of dentistry. Studies have shown that the success rates of the standard technique can be as low as 70% in optimal circumstances and even lower when inflammation is present in the surrounding tissues (Budenz 2007; Hargraves and Keiser 2002). Medicine has responded to the problems associated with nerve block by developing technology to assist in locating the target nerves. The first improvement was through the use of peripheral nerve stimulators (Tsui and Hadzic, 2007). More recently, ultrasound-guided techniques have emerged as the ‘gold standard’ for nerve trunk anaesthesia (MacLennan, 2007).

Dentistry has attempted to address the issues of unsuccessful anaesthesia and adverse events in two ways. The first approach has been to focus on the refinement of the common techniques of delivery of local anaesthetic. The second response has been to seek alternative techniques that are intended to be more reliable than the standard technique. Some of these alternative techniques have been developed through the desire to satisfy the concept of perfecting the targeting of the nerve trunk (Wolfe, 1992),
while others have pursued the philosophy of the deposition of the local anaesthetic agent within the correct tissue plane (Vazirani, 1960; Gow-Gates, 1973 and 1983; Akinosi, 1977).

2.1 The concept of technical precision for nerve block

There are two assumptions which underlie the concept of the technically precise nerve block injection. The first assumption is that deposition of the local anaesthetic solution as close as possible to the nerve trunk is necessary to ensure successful nerve block anaesthesia (Malamed, 2004). The second assumption is that the anatomical pathways of the nerves and the structures associated with them have a high consistency within the population and that this consistency is either measureable or clinically demonstrable (Sargenti, 1966; Milles, 1984; Baart, 2009). With these concepts in mind it then follows that, through a thorough understanding of the deep tissue anatomy and its relationship to the superficial anatomical structures which provide the injection landmarks, a high degree of injection target accuracy can be achieved.

For the mandibular division of the trigeminal nerve and the inferior alveolar nerve in particular, the concept of targeting precision means that local anaesthetic solution will be deposited within the pterygomandibular space in as close proximity to the nerve branches as possible in every
case. The concept of technical precision has even extended to include discussions on the possible significance of the deflection of the needle during its insertion (Kennedy et al, 2003) and the potential effects of the orientation of the bevel of the needle when depositing local anaesthetic (Steinkruger et al, 2006).

The advocates of the philosophy of technical precision acknowledge that some variations in anatomy exist (Sargenti, 1966; Madan et al, 2002; Malamed, 2004). However, they generally consider these variations to be anomalies (Desantis and Liebow, 1996). Some advocates of alternative techniques also favour the notion of target reliability. Sargenti (1966), in his description of his mandibular nerve block technique, defined the position of the lingula and mandibular foramen on the medial surface of the ramus with geometric precision. Vazirani (1960) also considered that the mandibular foramen lay in the centre of the medial surface of the ramus, in a line that extended from the occlusal plane of the mandibular teeth.

Milles (1984) raised some concepts of anatomical variation that could affect successful anaesthetic delivery. These were:

- a widely flaring mandible
- a wider than normal ramus
- a longer than normal ramus
- an edentulous mandible
- bulky muscles
- excess adipose tissue.

Despite recognising these variables, Milles still held to the notion that the lingula and the mandibular foramen were invariably situated in the centre of the medial face of the ramus and argued that their position could be determined by the palpation of the ramus from both the intraoral and extraoral aspects (fig 2) (Milles, 1984). The site of the lingula and the mandibular foramen, the optimal point of deposition of local anaesthesia under this paradigm, was considered to be at the intersection of two conceptual lines; a vertical line extending between the depth of the sigmoid notch and the angle of the ramus, and a horizontal line extending between the point of greatest concavity of the anterior and posterior edges of the ramus (fig 2).

Fig 2: The concept of the localisation of the mandibular foramen

From: Milles, 1984
Baart (2009) also advocated the palpation of the points of deepest curvature of the anterior and posterior borders of the ramus to determine the site of anaesthetic deposition, claiming that the lingula lay exactly in the middle of the medial surface of the ramus (fig 3). The original caption for this image reads: ‘Lingual aspect of an adult mandibula [sic] with the lingula exactly in the middle between the front and back sides’ (Baart, 2009).

Fig 3: The palpation of the anterior and posterior edges of the ramus for the targeting of the lingula

From: Baart and Brand, 2009

Meechan (1999) stated that there were no studies on local anaesthetic efficacy that reported a 100% success rate in clinical outcomes. Nevertheless, he held to the view that failures were able to be readily rectified in most cases. Meechan claimed that the success rate for the standard technique should be greater than 90%. In his opinion, the most likely cause of failure was incorrect needle placement and that the most
common causes for this incorrect placement was either contacting the medical surface of the ramus before the needle had penetrated to the correct depth or depositing the anaesthetic solution below the mandibular foramen (Meechan, 1999). Meechan stated that the best way to achieve success was to use the standard technique and perfect the insertion point through the correct identification of superficial intraoral anatomical landmarks. His method was for the clinician to place the thumb of his/her supporting hand against the curve of the anterior border of the ramus and insert the needle at the level of the mid-point of the thumb nail. In Meechan’s view, the proper depth of penetration is reached at between 15 and 25 mm and is marked by contact with the ramus (Meechan, 1999).

Madan et al (2002) referred to anatomical factors, such as an accessory nerve supply, variability in the course of the nerve, the possibility of a bifid nerve trunk, variation in the position of the mandibular foramen, and a bifid mandibular canal as all being potential factors in anaesthetic failure. But despite listing these and other factors such as infection, the authors ascribed the comparatively high failure rate of the standard technique, which they rated at 15 to 20 percent, as being largely due to poor technique. They listed the three most commonly occurring problems as:

- Inadequate mouth opening
- Improper needle placement
- Haste.
Bremer’s (1952) study of the position of the lingula and mandibular foramen begins with a discussion on the failure of the standard mandibular block technique. In Bremer’s opinion the usual dosage of anaesthetic was insufficient in at least 15 per cent of cases. Bremer lists the primary causes of the failure of nerve block as:

- anatomical anomalies, such as aberrant nerve branches
- faulty technique
- abnormal nerve resistance to the effect of the anaesthetic agent
- divergence of the path of the nerve from what is considered normal.

In regard to the use of superficial anatomical landmarks, Bremer considers that there are three cardinal points to be considered:

- the height of the puncture point above the mandibular occlusal plane
- the lateral position of the puncture point relative to the mandibular molar teeth
- the depth of insertion of the needle and its direction.

Bremer discussed the issue of the height of the puncture point above the mandibular occlusal plane. The philosophy of the day was that the site of the insertion of the needle must be determined by the position of the lingula in relation to the occlusal plane (Bremer, 1952). Bremer was at pains to point out how numerous authors were highly specific in this detail. The underlying implication was that the lingula had a very constant position. However, Bremer’s study then demonstrated the fallacy of this viewpoint,
finding a large degree of variability in the location of both the lingula and the mandibular foramen on the medial aspect of the ramus (Bremer, 1952).

Akinosi (1977) disputed the concept of the necessity to precisely target the nerve trunk. He noted that while the standard technique for the inferior alveolar nerve block was relatively easy to learn, the technique relied on the presence of, and the identification of, certain superficial anatomical landmarks such as the teeth, the mucosal elevation caused by the pterygomandibular raphe and the apex of the buccal pad of fat. Akinosi noted that problems with the standard technique can occur when there are anatomical variations in the shape and size of the mandible, as these may make accurate localisation of the mandibular foramen difficult. He also noted that the width of the ascending ramus and its angle of divergence will affect the position of the mandibular foramen relative to the superficial anatomy. Akinosi opined that such variations, plus other factors, could cause the standard inferior alveolar nerve block to fail in over 15% of cases (Akinosi, 1977).

Based on anatomical specimens, Coleman and Smith (1982) opined that the delivery of anaesthetic solution in close approximation to the nerve trunks within the pterygomandibular space was not an absolute requirement. Their assessment of the reasons for the success of the Gow-Gates block implies that deposition within the tissue plane is sufficient for successful anaesthesia (Coleman and Smith, 1982).
The view of the necessity for target accuracy was further challenged by Hannan et al (1999), who used ultrasound to visualise the location of the inferior alveolar nerve and the position of the needle tip. The visualisation allowed local anaesthetic solution to be deposited either immediately adjacent to the nerve trunk or at some distance from it. The results of this study showed that despite the highly accurate placement of the anaesthetic adjacent to the nerve trunk, electric pulp testing of the teeth revealed no improvement in success rates. The authors concluded that factors other than precise deposition influenced the efficacy of local anaesthesia (Hannan et al, 1999). The results of this research have now been confirmed by new studies using ultrasound guidance for regional anaesthesia (vide infra).
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