Effective anaesthesia of the acutely inflamed pulp: part 1. The acutely inflamed pulp

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VERIFIABLE CPD PAPER

IN BRIEF

- Outlines a clinical profile of the acutely inflamed pulp to aid in diagnosis and treatment planning.
- Discusses key pathophysiological changes in the pulp.
- Analyses theories that attempt to explain why it is more difficult to attain clinically acceptable anaesthesia in the acutely inflamed pulp.

PRACTICE

Achieving profound pulpal anaesthesia in a mandibular molar diagnosed with irreversible pulpitis can be argued to be the most testing of dental anaesthetic challenges. This can be attributed to the technical complexities of conventional techniques and the presence of pulp pathosis. Reasons for why the latter influences the ability to attain pulpal anaesthesia is not yet fully understood, but its frequent occurrence is well documented. In light of overcoming this it has become common practice to prescribe antibiotics, refer onto secondary care or to even commence treatment without appropriately anaesthetising the tooth. Therefore, this two part series aims to help practitioners attain clinically acceptable pulpal anaesthesia in the most testing of scenarios; the acutely inflamed mandibular molar. They should then be able to apply these same principles to other teeth presenting with similar symptoms. This section outlines the clinical presentation and pathophysiology associated with an acutely inflamed pulp, defines what it is to attain pulpal anaesthesia and critically analyses theories as to why these teeth are up to eight times more difficult to anaesthetise than their healthy counterparts.

INTRODUCTION

Achieving profound pulpal anaesthesia can be attributed to having competent technical ability, a basic understanding of anatomy and the effective use of behavioural management skills.[1–2] However, in the presence of pulp pathosis these factors may not produce the same result.[3] The reasons are not yet fully understood but this occurrence is well documented with reports of anaesthesia being up to eight times more difficult to attain, when compared to that of their healthy counterparts.[3] By combining these facts with the technical complexities of an inferior alveolar nerve block (IANB), one could argue the most testing of anaesthetic challenges is the mandibular molar diagnosed with acute irreversible pulpitis. Some have dubbed this as the infamous 'Hot Tooth', as a testament to its symptoms, but it has gained more notoriety for its inability to become effectively anaesthetised.[3] Conventional techniques are only successful 20-50% of the time and in an attempt to overcome this, it has become common practice to prescribe antibiotics, refer onto secondary care, or to even commence treatment without appropriately anaesthetising the tooth.[4–9] Therefore, this two part series aims to help practitioners attain the correct amount of anaesthesia required to allow treatment of an acutely inflamed mandibular molar (AIMM). Practitioners should then be able to apply the same principles to anaesthetise any other tooth presenting with an acutely inflamed pulp (AIP).

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CLINICAL PRESENTATION

The first signs of encountering a patient with an AIP can be witnessed as early as welcoming them in the waiting room. The severity of their pain can be noticed from a distance and their desperation to get rid of it has overcome any anxiety that often prevents them from attending regular dental appointments.

A detailed history of the pain is essential and it is commonly described as a severe dull throbbing ache, which may be exacerbated when provoked by thermal or postural changes resulting in loss of sleep.[10,11] It tends to linger for long periods (minutes to hours) and over the counter analgesics often do not have any significant effect. It is not uncommon for patients to also complain of spontaneous and unprovoked sharp bursts of pain in combination with referred pain. Over time, the intolerance to cold stimuli can reduce and may actually alleviate symptoms indicating the progression of the pulp to a partially necrotic state known as pulp necrobiosis. In the absence of any periapical pathosis, the pain may be difficult to localise and there is no discomfort when the tooth is percussed.[11] A summary of these symptoms can be found in Table 1.

Upon visual assessment, the tooth in question may display a deep carious lesion or an extensive restoration with poor margins. It is important to keep in mind that although some restorations, deep or shallow, may appear to have sound margins, their full extent may not be entirely clinically visible (that is, proximal areas). Furthermore, if it has suffered trauma, or the adjacent teeth are also heavily restored, the offending tooth may be more difficult to identify. For these reasons, it is important to pay particular attention to subtle signs such as cracks or tooth discolouration and utilise all available tools to come to an accurate pulpal and periapical diagnosis.

When subjected to thermal sensibility tests, the patient's presenting pain will be reproduced. However, in the later stages of inflammation cold testing may relieve symptoms indicating progression of pulp pathosis to a necrosing state. Electric pulp testing (EPT) can give positive readings, however, it provides no information to the degree of pulpal inflammation and can give false positives when large restorations, partial

vitality and suppuration are present.[12,13] Its use should, therefore, be limited to when thermal testing is inconclusive and where there is a sufficient amount of natural tooth structure.[12,14,15]

It is emphasised that arriving to an accurate diagnosis is the first step in managing any condition. This can be challenging and is the pivotal moment in determining if the pain will be effectively controlled. Therefore, the importance of a detailed history and thorough examination can be appreciated as an incorrect diagnosis can lead to incorrect treatment and the presenting symptoms would still persist until the appropriate treatment has been provided. Additionally, it would be useful to adopt a practical classification system where diagnostic terms represent clinical findings. A good example of this is the one set out by Abbott & Yu[16] which is easy to follow and depicts the progressive nature of pulp and apical pathosis.

ENDODONTIC PATHOPHYSIOLOGY

From health (Fig. 1a), pulpal inflammation commences when a carious lesion passes the amelo-dentinal junction and enters into dentine.[18] As the first line of defence, odontoblasts deposit tertiary and intratubular dentine to increase the resistance against an advancing lesion.[18] Acidic bacterial by-products enter the pulp chamber before the microorganisms, to stimulate the dentinal nerve endings and the fast acting Aδ nociceptors. This does not significantly impact pulpal blood flow but the localisation of inflammatory cells, together with the mild vasodilation raises the pulps haemo-dynamic pressures (Fig. 1b).[18,19] The Aδ fibres translate these changes into the short sharp pain typical of reversible pulpitis and at this point, if the cause is successfully treated, usually by caries removal and restoration, the inflammation can be resolved.[18]

If allowed to continue, bacteria will enter the pulp chamber inducing profound pulpal inflammation, marking the transition from a chronic to an acute inflammatory reaction.[20] When the deeper slow acting C nociceptors are activated, neuropeptides (Substance P) and inflammatory cytokines (PGE-2) are secreted from leucocytes, which have a drastic impact on the overall blood flow to the pulp.[18–20] The increased hyperaemia, vascular permeability and localisation of inflammatory cells significantly amplifies the haemo-dynamic pressures within the pulp (Fig. 1c).[18–20] However, unlike other tissues, the consequential oedema cannot be counteracted due to the rigid walls of the root canal system. This pressure collapses the vasculature and further sensitises the pain fibres to bring about the dull, persistent pain commonly described by patients diagnosed with acute irreversible pulpitis.[18–20]

Pulp vasodilation, in response to this thermal stimulation, causes additional increases in haemo-dynamic pressures, placing further stresses onto the nociceptors.[18] Consequently, this produces the hyperalgesic response patients experience after consuming hot or cold foods.[18] Eventually, the pulp degenerates when the number of entering bacteria exceeds the ability of the pulps vasculature to deliver a sufficient amount of leucocytes.[20] When this occurs, a large number of neutrophils infiltrate the inflamed pulp and cause collateral damage to local cells, fibres and ground substance, causing the pulp to start necrosing. In this stage, pulp necrobiosis, cold stimuli can relieve symptoms.[16]

Ultimately, the pulp becomes completely necrotic and acts as a nutrient source for the invading bacteria. This results in a pulpless and infected root canal system where the suppuration extends into the periapical region to form an abscess.[16] This can take between two to ten months after initial bacterial invasion and results in pain when forces are apically placed onto the tooth (Fig. 1d).[16,18–20]

PULPAL ANAESTHESIA

Studies investigating the efficacy of local anaesthetics have defined pulpal anaesthesia as a tooth exhibiting '2 consecutive EPT readings of 80 within 15 minutes of local anaesthetic administration, which is sustained for 60 minutes.'[4,21–30]

Despite this knowledge, it has become common practice to use subjective methods

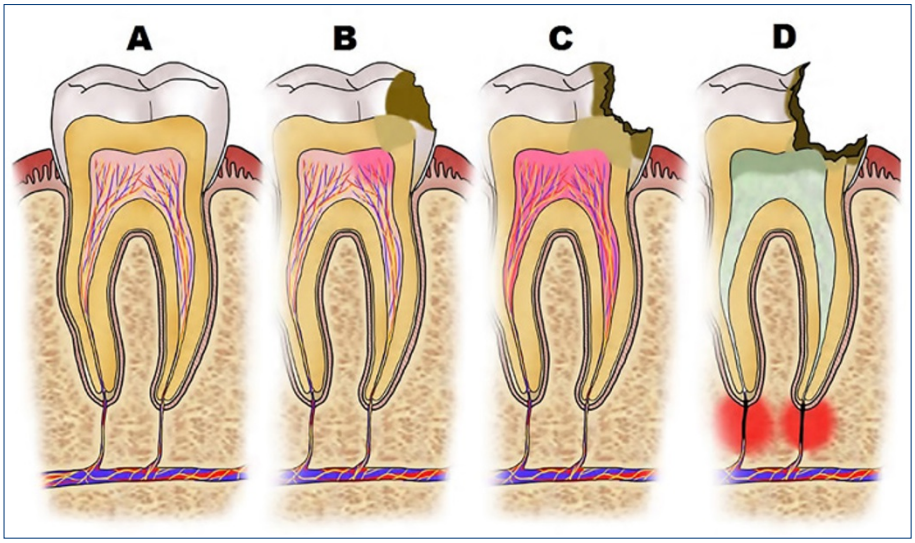

Fig. 1 Endodontic pathophysiology. (a) Healthy pulp with no symptoms. (b) Reversible pulpitis resulting in short lasting sharp pain to thermal stimuli. (c) Irreversible pulpitis resulting in long lasting dull pain to thermal stimuli. (d) Complete pulp necrosis following necrobiosis, leading to apical periodontitis resulting in pain to mechanical stimulation

Table 1 A guide to taking a pain history & the respective symptoms associated with an AIP[11,16,17]

	Findings	
Presenting complaint	**Severe dental pain**	
Pain history	Severity	Moderate–severe
	Onset	History of pain with sensitivity to thermal changes
	Character	Initial sharp burst progressing to a lingering dull ache or throbbing pain
	Radiation	Referred pain often to adjacent teeth, and ipsilateral side of face and jaw
	Association	Loss of sleep
	Time	Long duration: minutes to hours
	Exacerbation	Thermal changes: persistent after removal of stimuli Postural pain: lying down may worsen pain Tender to percussion: with periapical involvement
	Site	With no periapical involvement: poorly localised

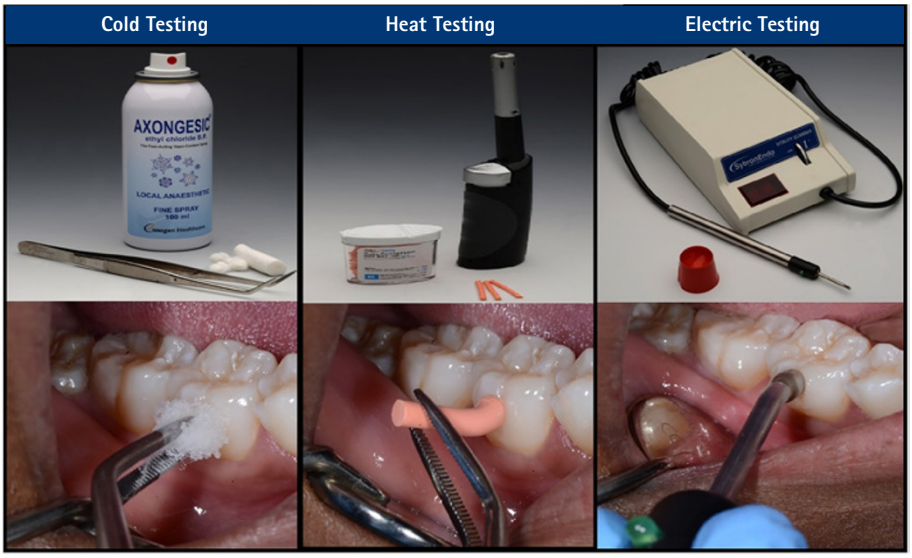

Fig. 2 Pulp sensibility testing. Cold testing: apply a cold agent (ethyl chloride) onto a dried tooth via a cotton wool pledget. Heat Testing: heat the tip of a GP stick under a flame until it becomes soft and then apply it to a Vaseline coated tooth for no more than 5 seconds. Electric testing: coat the tip of the EPT probe in a conductive medium (prophy paste or proprietary lubricant) and then apply onto a dried tooth

such as probing the gingiva or checking for lip numbness to assess the degree of anaesthesia following an IANB. However, these signs are only indicators for soft tissue anaesthesia and have repeatedly been shown to be an unreliable measure of pulpal anaesthesia.[4–9] In a clinical trial containing 57 subjects, it was found that approximately 50% of healthy molars attained pulpal anaesthesia following an IANB, despite all participants experiencing profound lip numbness.[30] A similar clinical trial found this percentage fell to approximately 20% when the same methods were used to investigate AIMMs.[4]

Therefore, it is clear to see that following an IANB, pulpal and soft tissue anaesthesia are not coincidental. It is the former that will allow for pain free treatment and objective tests (cold, heat or electric) are more reliable for determining if this has been achieved opposed to subjective methods outlined above (Fig. 2).[31] Further accuracy can also be gained by testing the neighbouring teeth.[31]

Therefore, if the tooth is responding to sensibility tests following anaesthetic administration, then this would certainly mean adequate pulpal anaesthesia has not been attained which will need to be rectified before proceeding. On the other hand, if the tooth is unresponsive it is important to keep in mind that this does not always guarantee pulpal anaesthesia as even objective tests can result in false negatives, particularly in teeth with an AIP.[31] In this situation it would be reasonable to proceed cautiously with an awareness that the patient may still feel pain on treatment to which supplemental anaesthesia will be required.

LOCAL ANAESTHETIC PHARMACOLOGY

Local anaesthetics are weak bases that exist within an equilibrium between ionised and unionised forms.[32] The latter are very effective at penetrating the neuronal cell membrane, however, it is the actions of the former, from within the cell, that prevent the propagation of nerve impulses.[32] It is the pH of the anaesthetic solution and the surrounding tissues that determines the balance between both forms.[32] More acidic environments favour the production of ionised particles, which in turn reduces local anaesthetic activity and *vice versa*.[32] Although these agents can affect all nerve fibres, they are particularly effective on nociceptors making them ideal for clinical application.[32]

When injected into the tissues, an equilibrium is established where the unionised particles penetrate the cell membrane of local neurons (Fig. 3, labels 1 and 2).[32] Once inside, the naturally acidic physiological pH of the cytoplasm re-establishes this equilibrium to favour the production of ionised particles

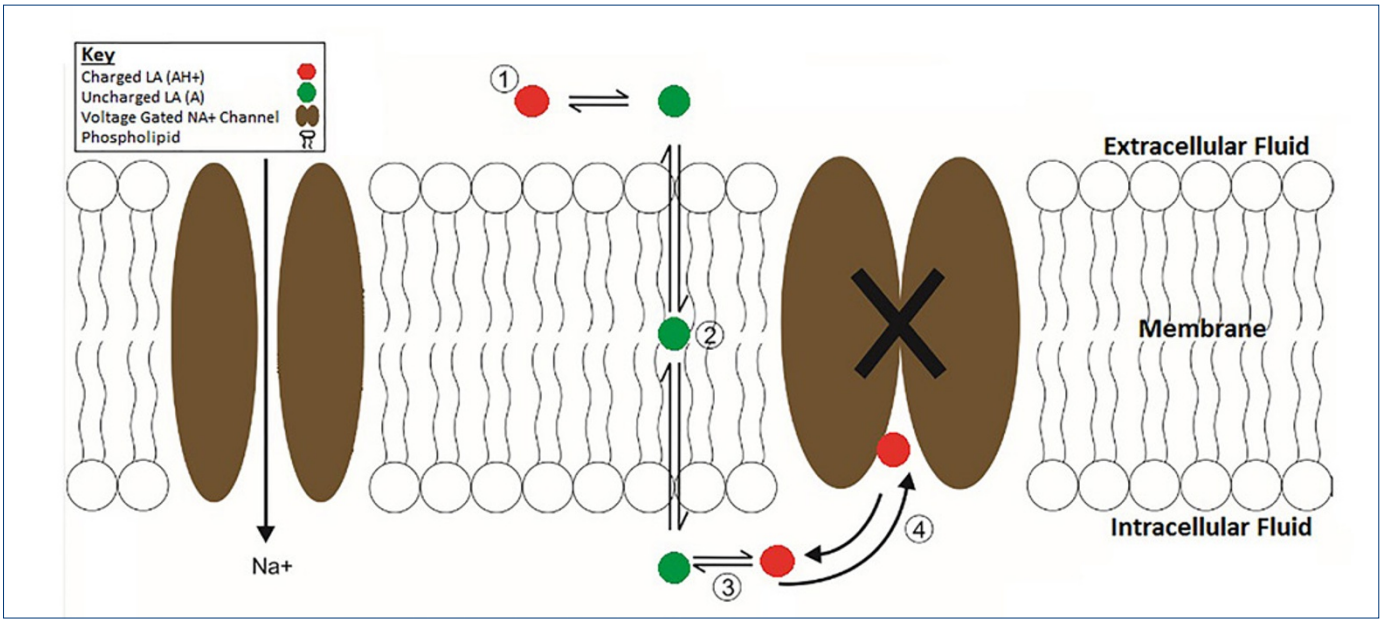

Fig. 3 Local anaesthetic (LA) mechanism of action. (1) Equilibrium between uncharged (A) and charged (AH+) LA particles in extracellular fluids. (2) Uncharged LA passes through phospholipid bilayer. (3) New equilibrium, favouring charged LA particles, established within the neurone. (4) Intracellular charged LA particles reversibly bind and close voltage gated Na^+ channels preventing influx of Na^+ ions inhibiting propagation of an action potential

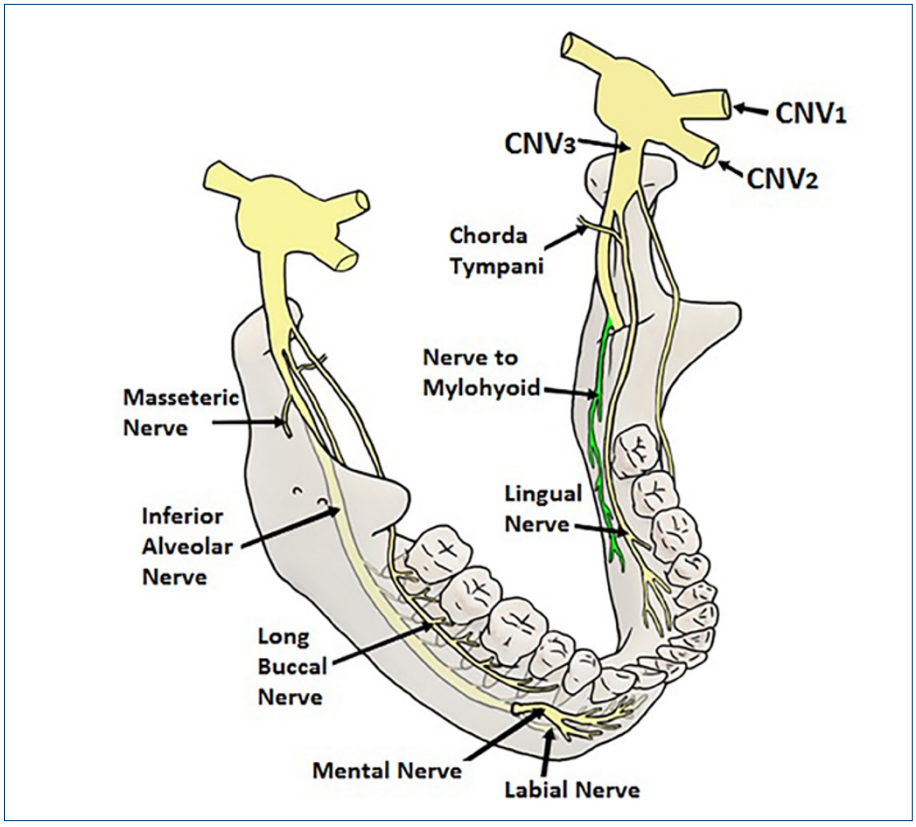

Fig. 4 Accessory innervation. Diagram depicting the anatomical relation of the trigeminal nerve (CNV) and its three divisions, ophthalmic (CNV1), maxillary (CNV2) and mandibular (CNV3) in relation to the mandible. It is suggested that the nerve to mylohyoid (green) provides accessory sensory innervation to the mandibular molars

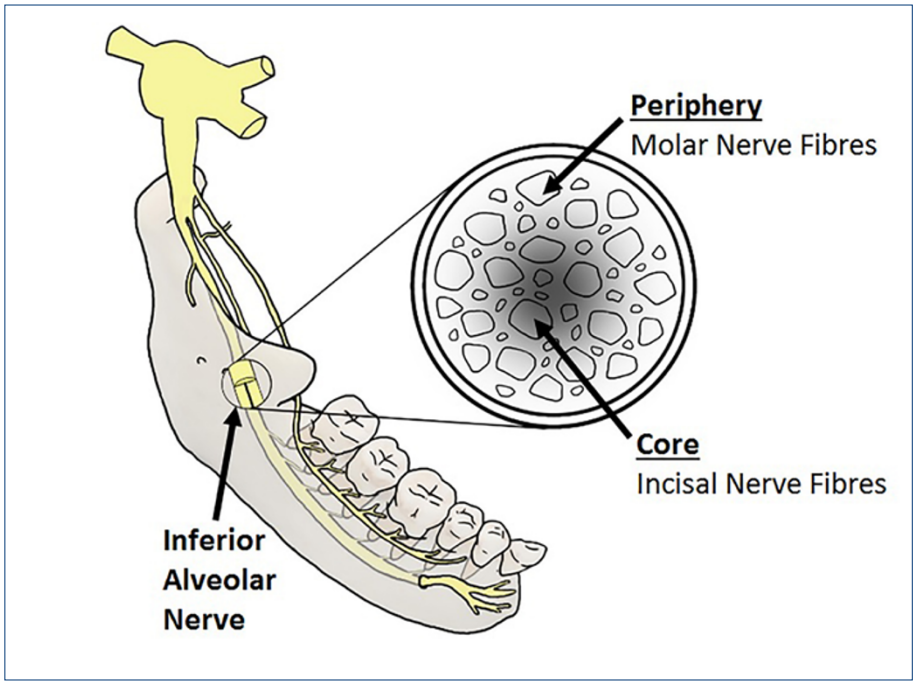

Fig. 5 Central core hypothesis. Nerve fibres supplying molars are distributed across the periphery of IAN and those supplying the incisors are located at the core. The anaesthetic solution diffuses from the periphery to the core

(Fig. 3, label 3).[32] They then act to reversibly bind with the transmembrane sodium ion channels to physically block the pore from within the neuron and subsequently prevent the influx of sodium ions (Fig. 3, label 4).[32] This inhibits depolarisation of the cell membrane in that region, preventing the transmission of nerve impulses from the peripheral nociceptors to the brain.[32] As a result, the patient does not feel any pain.

THEORIES FOR FAILED PULPAL ANAESTHESIA

Accessory nerve hypothesis

The nerve to mylohyoid has been commonly implicated to supply accessory sensory innervation to the mandibular molars. Originating from the inferior alveolar nerve (IAN) it branches off at the level of the mandibular foramen to supply motor innervation to several muscles of the floor of the mouth (Fig. 4).[33] It is suggested that this variation in anatomical distance between the IAN and the nerve to mylohyoid, determines if both are anaesthetised during an IANB.[34] If the distance is too great, the nerve to mylohyoid will escape the anaesthetic solution and if this branch does supply sensory innervation to the mandibular molars, it could explain the high failure rates.[35]

Central core hypothesis

Clinical trials have demonstrated the degree of pulpal anaesthesia, achieved from an IANB, is not uniform across the arch.[21–24] Mandibular incisors are significantly less affected than premolars and molars, and the central core theory states this variation is due to the anatomical structure of the IAN.[21–24] Peripheral fibres supply molars while core fibres supply incisors and it is the inability of the anaesthetic to diffuse completely through the entire nerve bundle that may result in failure after an IANB (Fig. 5).

Ion trapping hypothesis

This widely accepted theory suggests local anaesthetic particles become trapped within inflamed tissues and are prevented from entering into the neuron due to the inflammation induced tissue acidosis.[36–39] Pathological changes brought about by bacterial metabolic by-products result in a drop in pH within the affected tissues. This acidic environment favours the production of charged local anaesthetic ions, which are incapable of penetrating the nerve sheath.[32] Therefore, fewer particles are able to enter into the nerve and block the sodium channels which prevent the onset of pulpal anaesthesia.[32]

Systemic absorption hypothesis

Profound pulpal inflammation following bacterial contamination results in marked vasculature changes. The resultant hyperaemia caused by vasodilation and vascular proliferation, drastically improves the blood flow to the pulp.[18–20] The systemic absorption theory draws upon these facts and proposes that when administered into inflamed tissues, the local anaesthetic is systemically

absorbed at a significantly higher rate.[40] Therefore, it is taken away from the site of infiltration before it has had time to act on the pulp's nociceptive fibres.[40]

Altered nociceptor hypothesis

Research has brought to light the existence of different classes of sodium channels that reside on the pulp's nociceptors.[41,42] The one that is of particular interest is the tetrodotoxin-resistant (TTXr) subclass, which has been shown to be heavily involved in the pain sensation.[43] The name is derived from its property of being resistant to certain toxins, but more importantly, it has gained notoriety for its lack of sensitivity to Lidocaine.[44] In the presence of inflammatory mediators such as PGE-2, the depolarisation threshold of these channels is reduced to almost double its activity.[45] It has been proposed that this altered membrane potential is too low for anaesthetics to have any real effect.[36 46–48] This is in addition to an increased expression of sodium channels in a pulp that is diagnosed with acute irreversible pulpitis.[49]

Central sensitisation hypothesis

Central sensitisation is the increased excitability of the pain fibres within the central nervous system (CNS) bringing about a painful response that is of no biological benefit.[50] This hypersensitivity is triggered by a burst of activity such as a barrage of impulses sent from peripheral nociceptors within inflamed pulp and periapical tissues, strengthening central synaptic connections along the pain pathway.[50] When in this pathological state, low threshold sensory fibres begin to activate nerves within the CNS that would normally respond to noxious stimuli to induce a painful response.[50] It would only take a small amount of peripheral fibres to avoid the anaesthetic to maintain this barrage of impulses.

Anxiety hypothesis

There are well documented differences in the onset of local anaesthesia across the population. Some patients have slower onsets than others and there are even those that do not feel any differences up to 60 minutes after administration.[51,52] One explanation that can account for this variation is the different degrees of anxiety individuals have when coming to the dentist.[53] Anxiety is a common feature of patients suffering from an AIP and it has been suggested that it is the apprehension of pain that reduces their pain thresholds making it more difficult to attain pulpal anaesthesia.[53]

DISCUSSION

Despite there being several theories for this phenomenon, the research does point to some being less plausible than others. For example, accessory innervation from the nerve to mylohyoid did not prove to be a major contributing factor to anaesthetising an AIMM as a mylohyoid block, in addition to an IANB, did not increase success rates.[28] Furthermore when Hannan *et al.*[24] used an ultrasound to guide the needle to a precise location during an IANB, there was no significant improvement in pulpal anaesthesia.[24] Therefore, lack of technical accuracy has consistently shown not to be the primary reason for failure.

Additionally, the ion trapping and the systemic absorption hypotheses do not explain why pulpal anaesthesia fails during an IANB where the solution is deposited at a site away from any inflammation. Even when applied to infiltration anaesthesia, the evidence suggests the pH drop is not substantial enough to induce the ion trapping proposed by this theory. Clinical trials have also demonstrated anaesthetic solutions buffered with varying degrees of sodium bicarbonate, to reduce the change in pH, had no impact when injected into inflamed tissues.[48,54,55] Futhermore, the clinical implications of the systemic absorption theory would suggest increasing anaesthetic volume or vasoconstrictor concentration could improve success. However, these variables have also been shown to have no significant effect, for example Dhager *et al.*[56] concluded there was no difference in the pulpal anaesthesia attained after administering an IANB with Lidocaine 2% and different epinephrine concentrations (1:50000, 1:80000 & 1:100,000). Therefore despite the popularity of these theories, they do not entirely explain this phenomenon and practices such as providing antibiotics to improve local anaesthetic efficacy are rendered void.

On the other hand, the central core theory may very well explain why anaesthesia still fails despite the solution being deposited at a site away from any inflammation. Multiple randomised controlled trials that have also demonstrated the differential degree of anaesthesia achieved across the arch from an IANB, supporting the notion that the IAN may be structured in this manner.[21–24] However, if the nerve bundles supplying mandibular molars are located at the periphery of the nerve, then one may assume these would be the first fibres exposed to the anaesthetic solution. Therefore, although this may explain high failure rates in acutely inflamed mandibular incisors, where the respective nerve bundles are located centrally, it may not apply as much too AIMMs.

A leading contender is the nociceptor physiology theory, as the physiological changes of pulp nociceptors in the presence of acute inflammation have been objectively established and do provide a well-supported explanation. Multiple studies have been able to reproduce these alterations in neuronal activity and have demonstrated that nerve impulses in inflamed tissues do have a higher conduction rate and are markedly more difficult to anaesthetise.[43–47] For example, Scholz *et al.*[57] demonstrated that the TTXr sodium channels were five times less sensitive to Lidocaine than the TTXs sodium channels. Rood *et al.*[48] found nociceptors in inflamed tissues became sensitised with the rate of nerve impulses being significantly greater than those from healthy tissues.[48] This increase in impulse rate, decrease in activation threshold and increase in sodium channel expression is likely to be a major contributing factor to failed anaesthesia and it would provide a logical explanation as to why changes in solution volume, epinephrine concentration and technique have no significant impact.

Although the central sensitisation theory provides an explanation to many unsolved clinical pain conditions, it is poorly understood. This lack of understanding into the mechanisms of action, pathophysiology and the triggers that sustain this phenomenon does not allow us to completely appreciate its contribution to anaesthetic failures. It implies that an adequate reduction in afferent impulses to the CNS would prevent the exaggeration of small stimuli. Clinically, this would mean to extirpate the pulp without the appropriate degree of anaesthesia which would be painful and unethical. On the other hand it would explain the lack of pulpal anaesthesia during an IANB, however, further research is required.

Finally, the relationship between anxiety and dental pain is well recognised and supported by literature. For example, it was found those exhibiting higher levels of anticipatory anxiety before endodontic therapy were more likely to experience pain throughout the procedure.[58,59] Therefore, although it may not be the sole reason for local anaesthetic failure, it is safe to assume that psychological factors do contribute and need to be taken into account. Fortunately there is a wide range of non-pharmacological and pharmacological strategies at the dentist's disposal to help counteract this.

CONCLUSION

No single hypothesis entirely explains this phenomenon, however; it would appear that a combination of theories may provide a more credible explanation opposed to any one alone. It may be several overlapping mechanisms acting cumulatively to produce the hyperalgesic effect which results in the failed

anaesthesia. Alternatively, future research may bring to light a more definitive explanation that has yet to be disclosed. Nevertheless, it is fundamental to have an understanding of these theories and other features outlined in this article before attempting to diverge from conventional approaches and onto more advanced techniques, outlined in part two.

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