Dentin Hypersensitivity: Current State of the Art and Science

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The consensus definition of dentin hypersensitivity is tooth pain that is characterized by brief, sharp, well-localized dentin pain in response to thermal, evaporative, tactile, osmotic, or chemical stimuli that cannot be attributed to any other dental diseases. The use of clinical descriptors (ie, brief, sharp, well-localized pain) distinguishes dentinal pain from pulpal pain that is prolonged, dull/aching, and poorly localized and lasts far longer than the applied stimulus. This is very important as the treatment of these two types of pain is very different. The definition of dentin hypersensitivity also requires a differential diagnosis as there are many other clinical conditions where dentin is exposed and sensitive, such as chipped teeth, fractured cusps, caries, and restorations with marginal gaps with leakage. Indeed, it is possible to have sensitive cervical dentin and sensitive marginal gaps in class II restorations in the same teeth. Arriving at a correct differential diagnosis requires careful clinical and radiographic examinations.

Inclusion criteria for the diagnosis of dentin hypersensitivity are 1) the presence of exposed dentin surfaces; 2) open tubule orifices on the exposed dentin surface; and 3) patent tubules leading to a vital pulp. The exposure of dentin often occurs as a result of removal of cervical cementum during scaling and root planing, during the finishing of restorations, or by excessive toothbrushing by the patient, especially after application of acidic food and drinks to exposed dentin.[1] Patency of tubules and vitality of the pulp can be determined by blowing a gentle air stream on the tooth in question for 0.5 to 1 second while covering the adjacent teeth with gloved fingers. Nonvital teeth or impermeable dentin do not respond to air blasts.

EPIDEMIOLOGY OF DENTIN HYPERSENSITIVITY

The prevalence of dentin hypersensitivity varies widely as a result of the use of widely different methods of evaluations. Those reports that rely on questionnaires risk inappropriate self-reports of dentin hypersensitivity by patients who may have tooth sensitivity from many different etiologies. When surveys have been published where clinicians have examined the patients, the prevalence of dentin hypersensitivity usually ranges from 4% to 57%. Although the age range for dentin hypersensitivity varies from 15 to 70 years, the peak incidence is between 20 to 40 years. Generally, dentin hypersensitivity is thought to appear with gingival recession in the third to fourth decade of life. The apparent decrease in dentin hypersensitivity in older patients may reflect reductions in dentin permeability reported in aged teeth[1] and reductions in innervation density with age.

The highest incidence of dentin hypersensitivity has been reported on the buccal cervical area of teeth. The teeth most commonly affected are canines > premolars > incisors > molars. Interestingly, a significantly higher proportion of left vs right contralateral teeth was reported in right-handed patients with dentin hypersensitivity. Addy and his colleagues[2] reported that all sensitive teeth have very low plaque scores, suggesting that toothbrushing with dentifrice may facilitate the development of dentin hypersensitivity. Others report that there is a positive correlation between dentin hypersensitivity and plaque scores. However, brushing without dentifrice lowers dentin hypersensitivity scores,

while brushing with toothpaste increases them, and argues in favor of toothpastes contributing to dentin hypersensitivity, presumably because of their abrasiveness.

HISTOPATHOLOGY OF DENTIN HYPERSENSITIVITY

To delineate the possible correlation between clinical symptoms of hypersensitive dentin and changes in pulpal histology, Brännström[3] ground through the enamel and into midcoronal dentin of premolars in children scheduled for extraction for orthodontic treatment to expose cross-sectioned dentinal tubules. When he tested the tactile sensitivity of the vital dentin initially, and then again after the ground dentin had been left exposed to saliva for 1 week, he found that their sensitivity had increased substantially. These teeth were then extracted and the pulps examined histologically. The pulpal region just below the cut tubules was found to be infiltrated with acute inflammatory cells. Brännström attributed the increase in dentin sensitivity to the presence of acute inflammatory cells. We now know that the ground dentin was initially covered with a smear layer that disappears from dentin surfaces within 1 week. Thus, the increase in sensitivity reported by Brännström may have been a result, in part, of the loss of smear layers making the dentin hyperconductive, as well as a result of the action of inflammatory mediators to make pulp sensory nerves more sensitive.

The effectiveness of saliva as a pulpal irritant in Brännström's study encouraged Lundy and Stanley[4] to include a wider range of patient ages and follow changes in pain responses and pulpal histopathology over a much longer time. Their classical study provided extremely valuable observations on the relationship between dentin hypersensitivity and histopathologic pulpal reactions. The authors recruited patients that had clinically asymptomatic teeth scheduled for extraction and cut deep class-V cavity preparations into dentin of those vital teeth. The empty cavities were left exposed to saliva for 1 to 120 days. Just before extracting the teeth, the pulpal responses to hot, cold, and electric pulp tests, plus the dentinal responses to probing and air blasts, were recorded. The teeth were then extracted and processed for light microscopy. When they correlated their clinical tests with histopathologic tests, the degree of dentin sensitivity to probing and air blasts increased profoundly during the first week but then fell rapidly over time. The teeth with hypersensitive dentin were associated with acute inflammation in the pulpal region just below the cut tubules. The subjective symptoms

and histologic reactions were completely different at the longer time periods. The patients no longer reported sensitivity to hot or cold foods even though the cavities remained open. The histologic appearance of these pulps was mild to moderate chronic inflammation. The authors speculated that the permeability of the exposed dentin decreased between 7 to 11 days, resulting in a reduction of pulpal inflammation. Later work confirmed that dentin permeability does not remain constant, but decreases rapidly and spontaneously in vivo.[5]

Generally, cervical root dentin sensitivity does not develop such profound inflammatory reaction after periodontal treatment, because the permeability of root dentin is much lower than that of coronal dentin. However, severe reactions occur with enough frequency to make some patients reluctant to have their periodontal surgical treatments completed. Clinicians must be prepared to deal with dentin hypersensitivity to remain credible to their patients. While most cases of dentin hypersensitivity associated with periodontal treatments resolve in 7 to 10 days, severe hypersensitivity is extremely unpleasant and should be aggressively treated as soon as it appears.

CAUSATIVE THEORIES OF DENTIN HYPERSENSITIVITY

Innervation of Dentin
In the 19th century, restorative dentists knew that as soon as their burs passed through enamel and touched dentin, their patients began to feel sharp, intense pain. They deduced that there must be sensory nerves that pass from the pulp, out to the dentinal tubules, to the dentinoenamel junction (DEJ). When histologists stained teeth with special silver stains used to identify nerves, although they saw the nerve plexus in the pulp just below the odontoblast layer, they could not identify nerves passing more than 100 μm into peripheral dentin. This was very confusing. How could the DEJ be so sensitive without nerves?

The pulpodentin complex is innervated by myelinated (Aβ and Aδ) and unmyelinated C-fiber sensory nerves. Dentin sensitivity (ie, hydrodynamically stimulated dentin) is a result of the activation of Aβ and Aδ sensory nerves in dentinal tubules and near the dentin-pulp junction. Their distribution is not uniform, being most numerous (innervating 40% of tubules) over pulp horns. They are progressively less frequent near cervical dentin and least prevalent in root dentin (ca 3.5%). The majority of the nerves in teeth are unmyelinated C-fibers that are responsive to capsaicin and

inflammatory mediators such as histamine and bradykinin but not to hydrodynamic stimuli. C-fibers contain neuropeptides such as substance P, CGRP, and neurokinin A. These fibers are in the pulp but not the dentin.

HISTORICAL PERSPECTIVE

In 1955, Kramer[6] proposed the "hydrodynamic theory" as follows: "The dentinal tubules contain fluid or semifluid materials and their walls are relatively rigid. Peripheral stimuli are transmitted to the pulp surface by movements of this column of semi-fluid material within the tubules." However, it was Brännström who correlated a series of in vivo experiments on painful stimulation of human teeth by negative pressure, evaporative air blasts, and chemical stimuli with measurements of fluid shifts across dentin in vitro in response to these stimuli. He popularized the hydrodynamic theory of dentin hypersensitivity through his many publications and lectures around the world.

The evidence supporting the hydrodynamic mechanism of Aδ nerve activation is based both on in vivo studies in human subjects and experimental animals. The results of human experiments confirm that open dentinal tubules are required for exposed dentin to be sensitive. A positive correlation was reported between the degree of dentin sensitivity and the density of open dentinal tubules seen in microscopic replicas of human dentin. Yoshiyama developed a method for taking biopsies of insensitive vs sensitive root surfaces using miniature diamond-encrusted coring drills and then examining the retrieved cores by scanning or transmission electron microscopy. Sensitive dentin surfaces had more and larger open tubules than insensitive areas. In vitro measurements of fluid flow through dentin disks revealed that open tubules exhibited high hydraulic conductances, but blockage of these same tubules reduced fluid flow. Thus, tubule occlusion is the basis for many professionally applied dentin desensitizing agents.
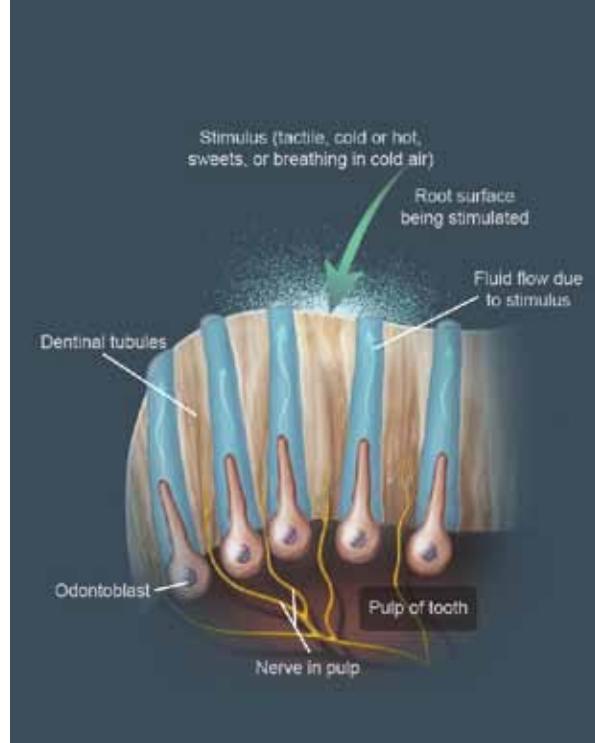
Figure 1 Gysi and later Brännström postulated that painful stimuli move fluid in or out of dentin, and that this fluid activates intradental or pulpal nerves to cause pain.

The Odontoblast Transducer Mechanism

The second possible explanation for sensitivity of the DEJ in the absence of peripheral nerves would be if the odontoblast process could serve as a sensory receptor. This would require that pulpal sensory nerves form synaptic junctions with odontoblasts. However, destruction of odontoblasts did not cause dentin to be insensitive. If odontoblasts served as sensory receptors, such dentin should be insensitive. In fact, such dentin was even more sensitive than normal. Careful transmission electron microscopy of nerves touching odontoblasts failed to demonstrate the required modifications to the plasma membranes of the nerves and the odontoblasts if they were true synapses. Thus, the hypothesis that odontoblasts serve as sensory receptors and contribute to dentin sensitivity has largely been rejected. Through a process of elimination, the third mechanism responsible for dentin sensitivity is the hydrodynamic theory of fluid flow through dentinal tubules that acts as the coupling or transducing mechanism that activates intradental nerves.

The Hydrodynamic Theory of Fluid Flow

Although the so-called "hydrodynamic stimuli" include hot and cold, tactile, evaporative, and osmotic, their final common path is fluid movement within dentinal tubules that, in turn, activate mechanoreceptors in intratubular nerves or in the superficial pulp (Figure 1). Thus, the true physiologic stimulus is inward or outward fluid shifts. This has been most difficult to measure because it involves nanoliter or picoliter fluid shifts.

Much debate has involved the question over whether exposed dentin is "sensitive" or "hypersensitive." Pain perception is a personal, subjective sensation that is influenced by a patient's previous experience, emotional state, and cultural traditions. The two essential elements of the hydrodynamic mechanism involve the dentinal tubules and mechanosensitive nerves in the pulp. The first important element is fluid flow through dentinal tubules.

The elegant research of Matthews et al[7] over the past 15 years has added much critical understanding of stimulus-response coupling in the pulpo-dentin complex. In a series of experiments in animals and humans, Matthews and his colleagues measured the rate of spontaneous outward fluid flow in exposed dentin in cats and humans and demonstrated how this could be altered experimentally by applying positive or negative hydrostatic pressures to dentin surfaces. By manipulating positive or negative pressures of known magnitudes, Matthews and Vongsavan[7] could induce action potentials in single nerves dissected from the inferior alveolar nerve in cats and record multi-unit nerve activity from the exposed human dentin.

The second element in the hydrodynamic mechanism is the pulpal sensory nerves. They fall into the category of myelinated Aβ and Aδ, and unmyelinated C-fibers. The sharp, well-localized pain of dentin sensitivity is thought to be due primarily to Aδ nerves. All nerves have thresholds for firing. Under normal conditions, these thresholds are relatively constant. However, in patent dentinal tubules, bacterial products from plaque slowly diffuse from outside into the pulp where they may induce varying degrees of inflammation (acute and chronic). Cytokines and mediators associated with inflammation are thought to down-regulate normal sodium channels (sensitive to Tetrodotoxin [TTX]) and up-regulate the expression of TTX-resistant sodium channels such as Navl.8 channels.[8] We speculate that mild pulpal inflammation beneath patent sensitive dentinal tubules may induce the expression of hypersensitive

sodium channels that respond to smaller intratubular fluid shifts than normal sodium channels, making this dentin truly "hypersensitive." This provides the rationale for clinicians who insist that their patients maintain good plaque control. In the absence of plaque, it is thought that there is less permeation of bacterial products across dentin to induce localized, mild pulpal inflammation that is thought to be responsible for inducing hypersensitive dentin.

Finally, some extreme cases of dentin hypersensitivity may be a result of stimulation of hyperconductive dentinal tubules innervated by pulpal nerves with extra low thresholds. In the presence of localized pulpal inflammation, pulpal nerves can sprout or branch, thereby increasing the receptive field of each nerve,[9] making larger surface areas of exposed dentin more sensitive.

## ETIOLOGY OF DENTIN HYPERSENSITIVITY

Gingival Recession

Perhaps the most important factor in the etiology of dentin hypersensitivity is gingival recession because it causes exposure of root surfaces. The causes of gingival recession were reviewed by Addy[10] and include the anatomy of the buccal plate of alveolar bone. As the buccal alveolar bone provides much of the local blood supply for buccal gingivae, loss of the underlying bone is associated with loss of buccal gingivae. For instance, thin, fenestrated, or absent alveolar bone predisposes someone to gingival recession. Tooth anatomy or position also affects alveolar bone thickness. Often, orthodontic tooth movement results in inadvertently moving teeth through the buccal plate that can make such sites more likely to develop gingival recession.

Poor oral hygiene may cause gingival recession indirectly by allowing for the development of periodontal disease. However, gingival recession resulting from periodontal bone loss seldom occurs on buccal-cervical sites. Clinical studies
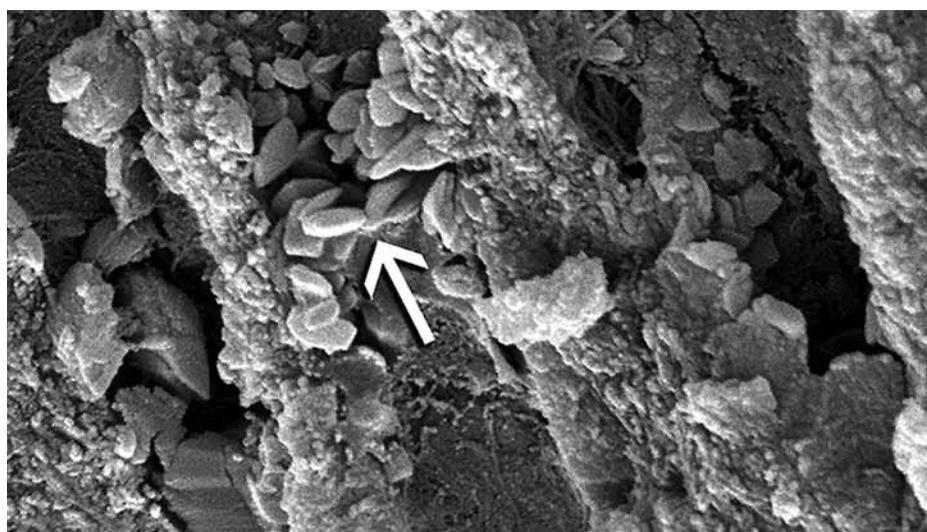
Figure 2 Scanning electron micrograph showing occlusion of dentinal tubules with calcium oxalate crystals (arrow) after the application of a slightly acidic potassium oxalate solution to acid-etched dentin.

have reported more gingival recession with good oral hygiene or improved oral hygiene. Indeed, the most brushed teeth with the lowest plaque scores exhibited the most gingival recession. This has led to the description of gingival recession/dentin hypersensitivity as "toothbrush disease." Because toothbrushing alone (without toothpaste) has no abrasive or erosive action on dentin, the loss of dentin is a result of the abrasivity of toothpastes. Once gingival recession has exposed root surfaces, the cementum is rapidly lost from brushing with toothpaste and/or professional cleaning.

Periodontal Disease

Dentin hypersensitivity is seen more frequently in patients with periodontitis. The prevalence of dentin hypersensitivity has been estimated to be between 60% and 98% in patients with periodontitis. Several studies have investigated changes in root dentin sensitivity after periodontal surgery. Nishida and colleagues[11] followed dentin sensitivity for 8 weeks after periodontal surgery. The highest sensitivity occurred 1 week after surgery. Immediately after surgery, the proportion of sensitive teeth increased from 21% to 36.8%. In many cases, by 8 weeks postoperatively, the sensitivity had largely resolved. The teeth of young patients (aged 19 to 29 years) showed a higher incidence and degree of postoperative hypersensitivity than did an older group (aged 40 to 61 years), and the spontaneous decrease in hypersensitivity required a longer time in the young group. During the first 2 postoperative weeks, the degree of sensitivity correlated with the width of the exposed root surfaces. This correlation was lost as many of the teeth became less sensitive over time.[11]

In another clinical study, there was a more than 100% increase in dentin hypersensitivity after periodontal surgery. After 8 weeks, the control group that received no treatment showed a 34% reduction in hypersensitivity, but it remained above the preoperative level. Wallace and Bissida[12] reported the results of periodontal surgery on dentin hypersensitivity. In a study on 10 patients with 42 periodontally treated teeth and 42 contralateral control teeth, root sensitivity was directly related to the extent of root surface exposure after surgery. Scaling and root planing had no significant effect on immediate root sensitivity. However, 1 day after scaling and root planing, there was a significant increase in hypersensitivity that continued for 2 to 3 days but decreased after 5 days or longer. In another study, six out of 11 patients with periodontally involved mandibular incisors showed increased dentin sensitivity to probing and air blasts after
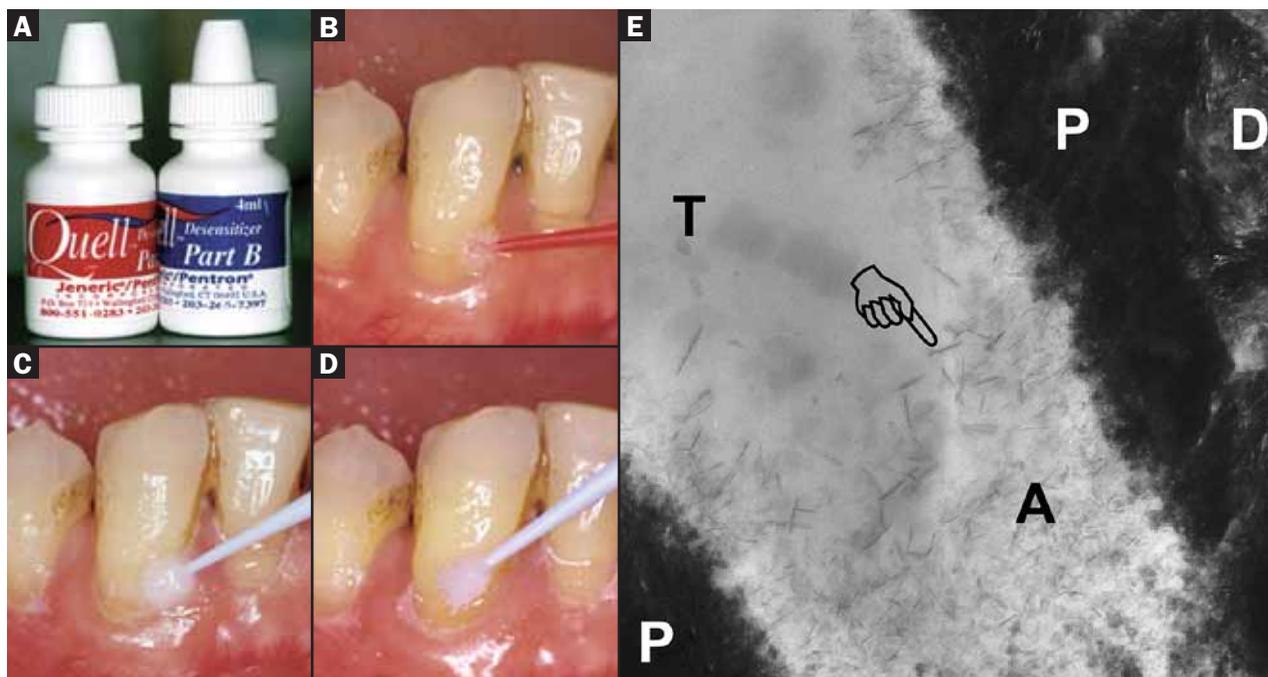
Figure 3 (A) Two-step, two-bottle type calcium precipitating solutions have been developed to occlude open dentinal tubules during in-office treatment. (B) Topical application of a phosphate-containing Solution A. (C) This was followed by the topical application of a calcium-ion containing Solution B. (D) Formation of a white calcium-phosphate precipitate could not be identified clinically from the dentin surface, but was apparent along the adjacent buccal gingivae. (E) Transmission electron micrograph showing the occlusion of a patent dentinal tubule (T) with needle-shaped apatite crystals (pointer). P: peritubular dentin; D: intertubular dentin.

periodontal treatment. The greatest increase in sensitivity occurred 1 week after subgingival root planing. However, by 8 weeks, the increased sensitivity was reduced in five of the six patients.[13] Thus, to summarize, transient to long-term dentin hypersensitivity may occur after deep scaling, root planing, or periodontal surgery.

If the hydrodynamic mechanism is correct, cases of persistent hypersensitivity must be a result of either local pulpal inflammation that causes persistent nerve sprouting or lowering of nerve thresholds, or that some dentinal tubules remain hyperconductive.

Loss of Enamel

Peripheral dentin is covered by cementum on root surfaces, and enamel on coronal surfaces. Thus, loss of enamel can expose dentin, placing it at risk of developing dentin hypersensitivity. The loss of enamel in the absence of gingival recession can involve any location on the tooth and is usually a result of the combined actions of attrition, abrasion, and erosion. Attrition is the loss of enamel resulting from tooth-to-tooth contact such as bruxism. It is usually found on incisal edges and occlusal surfaces. Abrasion involves loss of enamel by physical mechanisms not involving tooth-to-tooth contact, such as the cervical areas of teeth. It often results in angular wedge-shaped cervical lesions, generally on the buccal surfaces of maxillary canines and premolars, although such lesions can be found on the lingual surfaces of molars. Many have attributed the development of these lesions to excessive and improper toothbrushing technique, but some lesions are located subgingivally where toothbrush trauma cannot occur. In such cases, clinicians have used the term "abfraction" to describe the mechanism associated with loss of enamel and dentin.[14]

Erosion is defined as the loss of tooth structure by chemical dissolution resulting from extrinsic or intrinsic acids. Extrinsic acid exposure is a result of dietary sources of acids (citrus fruit and drinks, acidic wines, carbonated drinks) (see Zero and Lussi[15] for review). Intrinsic acids are largely gastric acid (0.1 N HCl) from inadvertent gastroesophageal reflux disease, from psychogenic vomiting syndromes (bulimia, etc) or from the side effects of drugs that irritate the gastric mucosa or cause nausea and vomiting. Erosive tooth wear, or acid wear, is a two-stage process where acids soften the surface (3 μm to 5 μm) through demineralization in a process that only takes seconds. Although these softened surfaces may reharden through the action of saliva and fluoride the process will take 1 to 2 hours. If during the vul-

nerable period the softened enamel is subject to frictional or abrasive forces the surface will be permanently removed resulting cumulatively over time as an erosive lesion.

Enamel erosive lesions appear dull, smooth, rounded, and without surface contour. That is, there is blunting of cusp tips or lingual cingulae in the early stages followed by their complete loss in advanced stages. As enamel is lost, the yellow color of dentin becomes dominant through the thinner enamel and the surface begins to appear concave. This is especially apparent with maxillary incisors. The enamel along the gingival margin often remains intact, perhaps as a result of outward gingival fluid flow, leaving the appearance of a crown or veneer preparation. On the occlusal surface, the loss of enamel cusps and exposure of underlying dentin creates the potential of abrasion lesions, which are often described as cupping. With further erosion into exposed dentin, the loss of tooth structure increases rapidly. The exposed dentin is often very sensitive and involves a large cumulative surface area of the involved teeth. Once mineralized tissues have been softened by repeated exposure to acids, they become more susceptible to combinations of attrition and abrasion. Treatment is difficult until the exposure to acids can be controlled. Enamel has the propensity to remineralize and thus reharden, albeit slowly, but dentin does not. The surface of enamel will become softened with acids at pH 5.5 and below. Dentin is demineralized with pHs as high as 6.5. Not all acids share the same softening abilities for the same pH. Softening is determined by the type of acid and whether or not it possesses chelating properties (citric acid), the buffering capacity, and the presence of calcium, phosphate, and fluoride in the acidic food or beverage. A contradiction is evident in yogurt, typically at pH 4.0, which is unable to soften the surface at all as it is saturated with respect to calcium. Therefore, no matter what the pH, it is not possible to remove additional calcium from the tooth and into the yogurt solution surrounding it.

Cracked Tooth

Patients with cracked teeth often complain of a long history of pain which has been difficult to diagnose and treatment which has failed to relieve their symptoms. They tend to have erratic pain on mastication, especially with release of biting pressure. Generally, there is no pain to percussion and radiographs are usually inconclusive. In addition, there may be a variable degree of sensitivity to temperature changes. Such diversity in the presentation of clinical signs and symptoms is a result of the presence of five types of tooth

cracks now recognized by the American Association of Endodontists: craze line, fractured cusp, cracked tooth, split tooth, and vertical tooth fracture.[16]

The type of tooth crack that is most likely to be associated with dentin hypersensitivity is the early stages of a cracked tooth. The most frequently involved teeth are the mandibular molars, followed by maxillary premolars and maxillary first molars. Such a crack extends from the occlusal surface of the involved tooth apically, without separation of the two segments. The crack may cross one or both marginal ridges and is most often oriented mesiodistally.

The signs and symptoms of a cracked tooth vary significantly depending on the progress of the crack. In its early stages, a crack may involve only the coronal dentin without extending into the pulp chamber. Clinically, such a cracked tooth may exhibit acute pain on mastication and sharp, brief sensitivity to cold with the pain disappearing on removal of the stimulus, with the pulpal diagnosis of reversible pulpitis. A recent clinical study showed that if a cracked tooth with reversible pulpitis is identified early enough, it may be salvaged with a crown and that root canal treatment will only be necessary in 20% of these cases within a 6-month period. Progression of interproximal periodontal defects associated with the crack (ie, resulting in a split tooth) was found to occur in only 4% of all the cases examined.[17]

If the crack has progressed to involve the pulp or periodontal tissue, the patient may experience thermal sensitivity that lingers after removal of the stimulus, or slight to very severe spontaneous pain that is consistent with the diagnosis of irreversible pulpitis, pulpal necrosis, or symptomatic apical periodontitis. There may even be pulp necrosis with periradicular pathosis. Under such circumstances, root canal treatment will be necessary.

CLINICAL RESEARCH ON DENTIN SENSITIVITY

Measurement of Dentin Hypersensitivity

In clinical trials of dentin sensitivity, most authorities recommend that two different stimuli be used to evaluate the sensitivity. These can be either variable stimuli to a constant response, or a constant stimulus to a variable response. In the first case, one would apply a tactile stimulus, for instance, with a dental explorer that has been modified to display the force applied from 5 g to 150 g or centiNewtons (cN). Kleinberg and his colleagues used the scratchometer, which is a hand-held analog load gauge that has a dental explorer welded to the scratch tine.[18] The scratchometer is applied perpendicular to the sensitive surface and scratched across the surface using 10, 20, 30, 40, etc, cN of force. Insensitive dentin can withstand 80 cN to 100 cN.

If one blows compressed air on an exposed dentin surface while covering the two adjacent teeth with gloved fingers at full force for 1 second at a distance of 5 cm, one can ask the patient to rate their pain perception on a visual analog scale that ranges from 0 mm to 100 mm, with zero being no pain and 100 being unbearable pain. An air blast is an evaporative stimulus, causing rapid outward fluid flow. The use of electrical stimuli, championed by Kleinberg's group, has been largely abandoned because they rely on devices that vary in voltage instead of current. A more detailed discussion of the use of electrical stimuli to measure changes in dentin sensitivity, or the details of how thermal, osmotic,

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and hydrodynamic stimuli have been used to test dentin hypersensitivity, can be found in Gillam's article.[19]

Design and Clinical Trials on Dentin Hypersensitivity

Most experts agree that clinical studies should use randomized group assignments, be doubled-blinded, and contain a placebo product that is identical to the test product except that it does not contain the active ingredient. It is critical to evaluate the placebo effect, which can be very strong in such studies.[20] Many of the early studies on dentin sensitivity did not include appropriate placebos or were only single-blinded or used inappropriate stimuli (electric pulp testing). These will not be reviewed.

Jackson reviewed the results of six "modern" clinical trials (1992-1996) on strontium-containing desensitizing toothpastes.[21] With a number of qualifications, Jackson concluded that in none of these studies was there a consistent, significant improvement in the patients' symptoms of dentin hypersensitivity for strontium-containing toothpastes compared with negative control toothpaste (ie, placebo). That is, all toothpastes gave some relief that increased over time as a result of either creation of a smear layer by the toothpaste or the placebo effect. He concluded that strontium salts appear to have only a minimal effect in reducing the symptoms of dentin hypersensitivity.

Jackson also reviewed the efficacy of eight potassium-containing desensitizing toothpaste clinical trials.[21] All of those studies (done between 1992 and 1997) demonstrated reductions in the patients' perceived symptoms of dentin hypersensitivity that increased over time, compared to control toothpastes. However, two of the eight studies failed to show any benefit for toothpaste-containing potassium compared to conventional potassium-free toothpastes.

Two clinical trials compared potassium-containing desensitizing mouthrinses compared to control mouthrinses. Although there were significant improvements in the patients' symptoms, there was no difference between the tests vs control mouthrinses.[21] This led Jackson to conclude that the effects of potassium-containing desensitizing products were marginally effective, but were not significantly different from placebos. Similar conclusions were reached in the more recent Cochrane Collaboration report on the efficacy of potassium-containing toothpastes for dentin hypersensitivity.[22] That review of 38 studies (over the period of 1994 to 2000) only accepted six studies as being valid clinical trials

for various reasons. Jackson further opined[21] that any agent (ie, strontium or potassium salts) thought to be effective in reducing dentin hypersensitivity should be effective as a simple aqueous solution, but that no such well-controlled clinical study had been reported. By delivering potassium in dentifrices, its efficacy may be due, in part, to the creation of a smear layer or partial occlusion of tubules by silica fillers in the toothpastes. The major problem in these clinical trials is that the concentration of the active ingredient (5% potassium salts) is only marginally more effective than the placebo effect (see Curro[20] for an excellent discussion of placebo effects for over-the-counter drugs). Patients have difficulty in deciding if their sensitivity to given stimulus has changed over time.

SENSITIVITY RESULTING FROM BLEACHING

Tooth whitening has become an extremely popular procedure that has left the dental office and gone "over-the-counter" as many different consumer products have been marketed. All of these products contain either hydrogen peroxide or compounds that break down to hydrogen peroxide (ie, sodium perborate or carbamide peroxide). While the popularity of tooth bleaching is expanding exponentially, a common side effect of external tooth bleaching is tooth sensitivity.
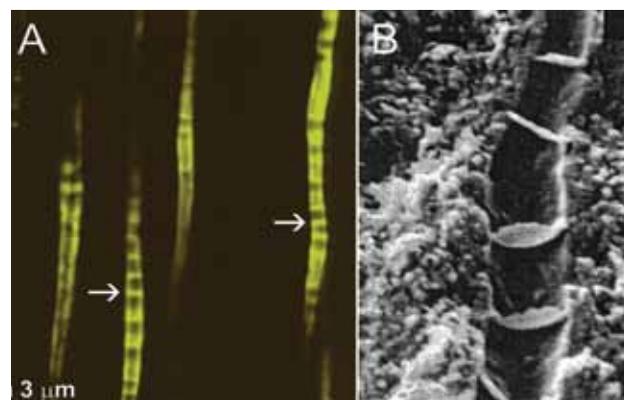
Figure 4 Fluorescence microscopy (A) and scanning electron microscopy (B) showing precipitations of plasma proteins derived from the dentinal fluid as intratubular septa (arrow) after the topical application of an aqueous solution of 35% hydroxyethyl methacrylate and 5% glutaraldehyde. These intra-tubular septa reduce the permeability of dentinal tubules to fluid movement and contribute to the reduction of dentin hypersensitivity (reprinted from Schüpbach et al, 2007, with permission from the publisher).

This sensitivity can be severe enough to cause patients to discontinue home bleaching.

The authors speculate that the dental therapeutic use of hydrogen peroxide or hydrogen peroxide-generating compounds allows hydrogen peroxide to permeate through enamel and dentin to reach the pulp's soft tissues faster than it can be inactivated by pulpal glutathione peroxidase and catalase. This may be responsible for the tooth sensitivity that is commonly associated with mouth guard bleaching.[23]

One final mechanism does involve the hydrodynamic mechanism of fluid movement, and is based on the observation that bleaching gels are all hypertonic. Those authors measured the osmolarity of a number of commercial bleaching gels using a freezing-point osmometer. The osmolarities varied from 4,900 mOsm/kg to 55,000 mOsm/ kg. Because plasma and extracellular fluids have osmolarities of 290 mOsm/kg, these bleaching gels are all extremely hypertonic and would tend to osmotically draw water from pulp, through dentin and enamel, and into the bleaching gels. This might hydrodynamically activate intradental nerves. Although many regard enamel as being impermeable, several studies have shown that enamel has a low but significant permeability to water and hydrogen peroxide. The molecular weight of water is only 18 g/L, and for hydrogen peroxide it is only 34 g/L. This small size makes hydrogen peroxide very permeable.

Mechanism of Action of Potassium Ions to Reduce Dentin Hypersensitivity

Potassium nitrate penetrates the enamel and dentin to travel to the pulp and creates a calming effect on the nerve by affecting the transmission of nerve impulses.[24] As potassium ions diffuse to the nerve, they cause the nerve to depolarize once in response
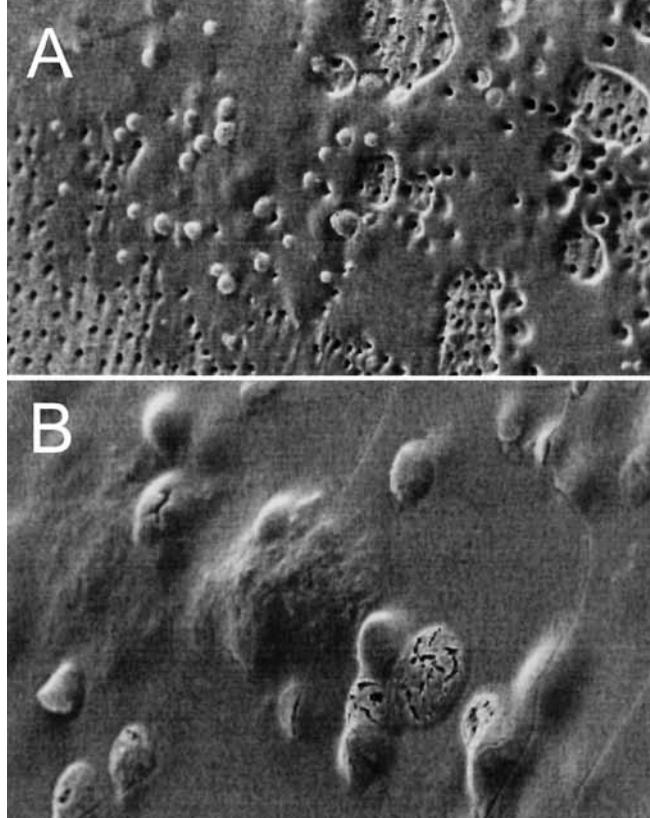
Figure 5 (A) Attempts to seal open dentinal tubules with adhesive resins can fail if the resin film is too thin and becomes saturated with atmospheric oxygen that consumes all of the free radicals generated during light-curing. The co-monomers never polymerize and the film is incomplete, leaving many tubules open. **(B)** Even thicker films can be displaced by water seeping from dentin during bonding. These water blisters represent unbonded areas that can be removed by toothbrushing (Courtesy of Dr. Stephan Paul).

to a painful stimulus. However, it cannot re-polarize, so the excitability of the nerve is reduced. Potassium nitrate has an almost anesthetic effect on the nerve.

Desensitization with Potassium Ions

The scientific evidence supporting the use of potassium salts to lower sensitivity is based largely on in vivo animal studies,[25] where the intradental nerve activity of cat teeth could be reduced by potassium but not sodium salts. Later in vitro work using rat spinal nerves revealed that if the medium potassium ion (K^+) concentration was increased from the normal value of 4 mEq/L to between 8 and 64 mEq/L, action potentials of nerves fell in a dose-response manner. The action was reversible, as when the high K^+ concentrations were returned to normal, the sensitivity of the nerves returned. Thus, clearly elevations in K^+ could block nerve conduction, but there was no evidence that the K^+, which diffused into dentin during brushing with K^+-containing dentifrices, would maintain dentinal fluid K^+ concentrations high enough to block nerve conduction. Mathematical modeling predicted that the potassium levels would not remain high enough between brushings to maintain nerve blockage.

However, in a recently published paper, Matthews' group tested the ability of filtering 3.7 wt% sodium chloride (KCl) across human dentin, in vivo, on pain sensations evoked by probing or air blasts in human volunteers.[26] In young patients (aged 17 to 30 years) scheduled for extraction of premolars for orthodontic treatment, the buccal cusps were flattened to expose dentin that was then etched to remove the smear layer and make the dentin conductive. After filtering 3.7 wt% (500 mM) KCl across the dentin using a 150 mm Hg hydrostatic pressure for 4 minutes, they tested

the sensitivity of the dentin to air blasts and probing for 2, 10, 20, and 30 minutes. The pain responses to probing and air blasts were significantly reduced during the first 10 minutes. This is the first time potassium salts have been shown to decrease tooth sensitivity through relatively thick dentin in humans in vivo, using a controlled experimental design and visual analog pain scales that can be statistically evaluated. They confirm the results of Hodosh,[27] who used topical applications of up to 15% solution of potassium nitrate to desensitize hypersensitive teeth. Although everyone now uses 5% KNO_3 or potassium nitrate, Hodosh reported that the best results were obtained with 35%. He relied on the diffusion of K^+ rather than using a hydrostatic pressure. The amount of potassium that can diffuse across dentin from a 35% solution of KCl may be similar to the amount of KCl that reaches the pulp after filtration of a 3.7% KCl solution.

MANAGEMENT OF DENTIN HYPERSENSITIVITY

Dentin hypersensitivity cannot be properly managed unless the etiology of the condition is identified and eliminated (see Figure 1 in the Introduction). For instance, if excessive eccentric occlusal contact has induced cervical abfraction on one or more teeth that have become hypersensitive, careful evaluation and correction of the occlusion may not only cure the hypersensitivity, it may prevent its reoccurrence. If the hypersensitivity was a result of bulimia, it is unlikely that any treatment of dentin will produce a lasting effect until the bulimia is first managed. By far, the most common etiologies of dentin hypersensitivity are dietary acids (citrus fruits and drinks, sports drinks, acidic wines) followed by improper toothbrushing or overly frequent, aggressive toothbrushing with toothpaste. Thus, clinicians should take careful histories of their patients' dietary habits and make patients aware of the importance of erosive influences coupled with improper toothbrushing. Patients should demonstrate their toothbrushing technique to their hygienist or dentist after every appointment until they have mastered proper technique.

Clinical trials have shown that daily use of desensitizing toothpastes twice daily requires 2 to 4 weeks to show any significant desensitization.[28] If, after using a desensitizing toothpaste, the patient's dentin sensitivity remains a problem, clinicians should re-evaluate the differential diagnosis and consider in-office treatments beginning with topically applied desensitizing agents (Table).

REFERENCES

1. Tagami J, Hosoda H, Burrow MF, Nakajima M. Effect of aging and caries on dentin permeability. *Proc Finn Dent Soc.* 1992; 88(Suppl 1):149-154.
2. Addy M, Absi EG, Adams D. Dentine hypersensitivity. The effects in vitro of acids and dietary substances on root-planed and burred dentine. *J Clin Periodont* 1987;14(5):274-279.
3. Brännström M. The elicitation of pain in human dentine and pulp by chemical stimuli. *Arch Oral Biol.* 1962;7:59-62.
4. Lundy T, Stanley HR. Correlation of pulpal histopathology

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and clinical symptoms in human teeth subjected to experimental irritation. *Oral Surg Oral Med Oral Path.* 1969;27(2):187-201.

5. Pashley DH. Dentin-predentin complex and its permeability: physiologic overview. *J Dent Res.* 1985;64(Spec Iss):613-620.

6. Kramer IRH. The relationship between dentine sensitivity and movements in the contents of dentinal tubules. *Br Den J.* 1955;98:391-392.

7. Matthews B, Vongsavan N. Interactions between neural and hydrodynamic mechanisms in dentine and pulp. *Arch Oral Biol.* 1994;39(Suppl):87S-95S.

8. Leffler A, Reiprich A, Mohapatra DP, Nau C. Use-dependent block by lidocaine but not amitriptyline is more pronounced in tetrodotoxin (TTX)-resistant Navl.8 than in TTX-sensitive Na+ channels. *J Pharm Exp Therap.* 2007;320(1):354-364.

9. Närhi M, Yamamoto H, Ngassapa D. Function of intradental nociceptors in normal and inflamed teeth. In: Shimono M, Maeda T, Suda H, Takahashi K, eds. *Proceedings of the International Conference on Dentin/Pulp Complex.* Chicago: Quintessence Publications Co, Inc, 1996;S-2-3:136-140.

10. Addy M. Dentine hypersensitivity: definition, prevalence, distribution and etiology. In: Addy M, Embery G, Edgar WM, Orchardson R. *Tooth Wear and Sensitivity: Clinical Advances in Restorative Dentistry.* London: Martin Dunitz, 2000:239-248.

11. Nishida M, Katamsi D, Uchida A, et al. Hypersensitivity of the exposed root surface after surgical periodontal treatment. *J Osaka Univ Dent Schl.* 1976;16:73-85.

12. Wallace JA, Bissada NF. Pulpal and root sensitivity rated to periodontal therapy. *Oral Surg Oral Med Oral Path.* 1990; 69(6):743-747.

13. Fischer C, Wennberg A, Fischer RG, Attström R. Clinical evaluation of pulp and dentine sensitivity after supragingival and subgingival scaling. *Endod Dent Traumatol.* 1991;7(6):259- 265.

14. Grippo, JO, Simring M, Schreiner S. Attrition, abrasion, corrosion and abfraction revisited : a new perspective on tooth surface lesions. *J Am Dent Assoc.* 2004;135(8):1109-1118.

15. Zero DT, Lussi A. Etiology of enamel erosion: intrinsic and extrinsic factors. In: Addy M, Embery G, Edgar WM, Orchardson R. *Tooth Wear and Sensitivity: Clinical Advances in Restorative Dentistry.* London: Martin Dunitz, 2000.

16. American Association of Endodontists. Cracking the cracked tooth code: detection and treatment of various longitudinal tooth fractures. In: "Colleagues for Excellence." 2008;Summer Issue. Available at: www.aae.org/NR/rdonlyres/D606816C-C43B-45D9-8EAA-A099AC70119C/0/ECFEsum08.pdf. Accessed August 1, 2008.]

17. Krell KV, Rivera EM. A six year evaluation of cracked teeth diagnosed with reversible pulpitis: treatment and prognosis. *J Endod.* 2007;33(12):1405-1407.

18. Kleinberg I, Kaufman HW, Wolff M. Measurement of tooth hypersensitivity and oral factors involved in its development. *Arch Oral Biol.* 1994;39(Suppl):63S-71S.

19. Gillam DG, Orchardson R, Närhi MVO, Kontturi-Närhi V. Present and future methods for the evaluation of pain associated with dentine hypersensitivity. In: Addy M, Embery G, Edgar WM, Orchardson R. *Tooth Wear and Sensitivity: Clinical Advances in Restorative Dentistry.* London: Martin Dunitz, 2000;283-297.

20. Curro FA, Friedman M, Leight RS. Design and conduct of clinical trials of dentin Hypersensitivity. In: Addy M, Embery G, Edgar WM, Orchardson R. *Tooth Wear and Sensitivity: Clinical Advances in Restorative Dentistry.* London: Martin Dunitz, 2000;299-314.

21. Jackson R. Potential treatment modalities for dentine hypersensitivity: home use products. In: Addy M, Embery G, Edgar WM, Orchardson R. *Tooth Wear and Sensitivity: Clinical Advances in Restorative Dentistry.* London: Martin Dunitz, 2000; 327-338.

22. Poulsen S, Errboe M, Lescay Mevil Y, Glenny AM. Potassium containing toothpastes for dentine hypersensitivity. *Cochrane Database Syst Rev.* 2006;3:CD001476.

23. Haywood VB. Current status of nightguard vital bleaching. *Comp Contin Educ Dent.* 2000;Suppl 28:S10-17.

24. Peacock JM, Orchardson R. Action potential conduction block of nerves in vitro by potassium citrate, potassium tartrate and potassium oxalate. *J Clin Periodont.* 1999;26(1):33-37.

25. Markowitz K, Bilotto G, Kim S. Decreasing intradental nerve activity in the cat with potassium and divalent cations. A*rch Oral Biol.* 1991;36(1):1-7.

26 Ajcharanukul O, Kraivaphan P, Wanachantararak S, et al. Effects of potassium ions on dentine sensitivity in man. A*rch Oral Biol.* 2007;52(7):632-639.

27. Hodosh M. A superior desensitizer-potassium nitrate. J *Am Dent Assoc.* 1974;88(4):831-832.

28. Kanapka JA. Over-the-counter dentifrices in the treatment of tooth hypersensitivity. Review of clinical studies. *Dent Clin North Am.* 1990;34(3):545-560.

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