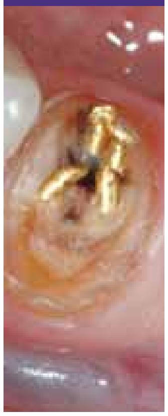

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Iatrogenically Induced Pulpitis as a Consequence of Operative Dentistry – Preventive and Remedial Considerations

Pulpite induite Iatrogéniquement, comme une conséquence de la dentisterie opératoire – considérations préventives et correctives

Abstract

A significant percentage of teeth require endodontic therapy after dental restorative and other treatments. This article will discuss the potential for inducing adverse effects from: tooth preparation, pin placement, the application of curing lights, the use of resin based composites and bonding agents, air-syringe dessication, hyper-occlusion and the effects of chemical treatments during bonding and graft regenerative processes. Also discussed and recommended are mediative protocols that can minimize or prevent adverse effects.

Key words **Iatrogenically Induced Pulpitis, Pulp Morbidity, & Effects on Pulpitis from: Tooth Preparation, Light Curing, Direct and Indirect Pulp Capping, Threaded Pin Placement, Chemical Treatments, Tooth Whitening, Adhesive-Based Restorative Procedures, Cementum Conditioning, Traumatic Occlusion**

Introduction:

While bacterial infection of the dental pulp is the primary reason for pulp inflammation and necrosis, it is estimated that a significant percentage of teeth exposed to dental restorative treatments or other dental interventions will experience iatrogenic pulpitis and that between 9 to 13% of these will experience irreversible pulpitis necessitating either endodontic therapy or tooth extractions.[1]

Pulp Morbidity:

The Dental Pulp is a highly vascular and innervated soft tissue structure whose principle role is tooth formation. Once formed however, the dental pulp continues to provide other important functions such as secretory odontoblastic activity that can form reparative dentine as a defensive response to attrition, caries and other erosive effects.[2] This highly innervated tissue also acts as an oral governing agent on noxious stimuli such as excessive thermal and acidic encounters. Because the dental pulp is encased within the non-resilient housing of dentine and enamel it is particularly vulnerable to inflammatory processes that can build up and lead to cellular hydraulic compression, morbidity and necrosis.

Effects of Tooth Preparation on Pulpitis:

Crown preparation and caries removal can place the pulp at risk a number of ways. High speed stripping of hard tooth tissue has the potential of elevating pulp temperature beyond a threshold of tolerance resulting in a disturbance of microcirculation, vascular stenosis and thrombosis.[3,4] When coronal tooth reduction encounters dentine, the dentinal tubules will be opened and a

Résumé

Un nombre important de dents demande une thérapie endodontique après la restauration dentaire, et d'autres traitements. Cet article parlera des possibilités pour induire les effets contraires, comme : préparation de la dent, placement de tenon, pratique de polymérisation par la lumière, utilisation de composites à base de résine comme agents de collage, dessiccation par air comprimé, sur-occlusion, et les effets de traitements chimiques pendant les procédés de collage et de greffe régénératrice. Également on parlera, et on recommandera, des protocoles médiateurs, qui peuvent minimiser ou prévenir ces effets adverses.

Mots-clés

Pulpite iatrogéniquement induite, morbidité pulpaire, & les effets pulpaires provenant: de la préparation des dents, de la lumière polymérisante, coiffage pulpaire directe et indirecte, tenons vissés, traitements chimiques, blanchiment des dents, procédures adhésives des matériaux, conditionnement du cément, occlusion traumatique

communication with the pulp is created. The deeper the dentine is cut away the more permeable it will become and the more vulnerable the pulp will also become to the ingress of microbial, chemical and physical irritants.[5] Exposure of the pulp to the oral bacterial flora puts it at greatest risk as bacterial contamination can cause severe inflammatory changes, resulting in micro-abcesses and progressive pulpal necrosis.[6]

While the pulp has considerable resilience to recover from irritation, cumulative repetitive injuries from caries, trauma from multiple restorative repair interventions or other traumas such as from occlusion or orthodontics may reduce the threshold of recovery due to the creation of pulpal micro-scarring to the vascular and nerve components of the pulp. An additional insult such as a crown preparation on a prior injured and predisposed tooth may be enough to cascade the pulp into degeneration with ensuing irreversible pulpitis.[7]

Because the removal of tooth material by high and low-speed produces heat from the friction between the bur and tooth substrate, it is prudent to use high volume water and air spray and high volume air suction. (Figure 1) A critical threshold temperature of 41–42°C is irreversibly harmful to pulpal tissue. A temperature rise to this magnitude should not be attainable when normal handpiece cooling water temperature of 30–34°C is effectively utilized.[8] According to Attrill et al., the maximum intrapulpal rise in temperature recorded for teeth prepared without water spray was 24.7°C, but only 3.9°C in teeth prepared with water spray.[9] (Figure 2)

According to Zach and Cohen doing in vivo studies, an intra-pulpal temperature increase of 5.5°C for 10 seconds caused histological changes in the pulp tissues, approximately 15% of which became irreversible pulpitis. When intra-pulpal temperature increases were sustained at 11.1°C for 10 seconds, there was approximately 60–70% irreversible pulpitis.[10] When using water spray in an in vitro study measuring intra-pulpal temperature increase with a 0.5 mm residual dentin thickness, Firoozmand found temperature increases of 1.8°C, 1.4°C, and 0.7°C, with a low-speed handpiece, high-speed handpiece, and laser, respectively.[11] These values are well below the physiologic

Figure 1: 4 Ports of Spray

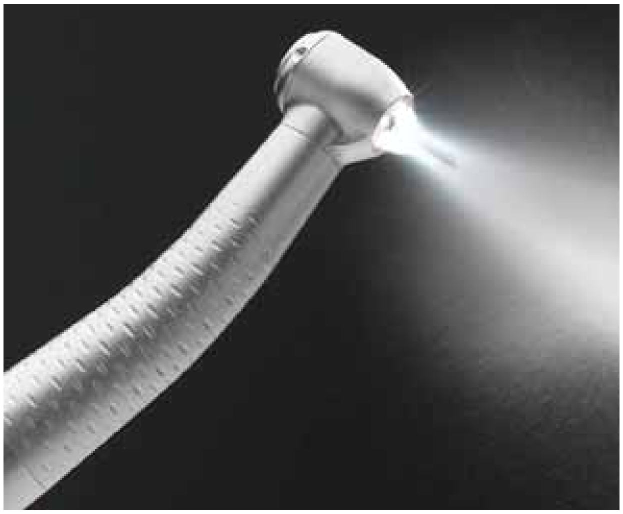

Figure 2: Spray from 4 Ports

5.5°C threshold described by Zach and Cohen so it is unlikely that thermal pulpal damage will occur unless the water spray is turned off or unless the water spray is diminished by close proximity suctioning or by water flow obstruction.

According to Baldissara, Catapano and Scotti who evaluated clinical and histological criteria, the main cause of postoperative inflammation or necrosis of the pulp is injury to the dentine.[12] It is apparent that the closer the cutting gets to the pulp the greater will be the heat effect induced.

Diamond burs generate more heat than carbide unless the carbide is worn. The difference of carbide vs. diamond selection however, appears not to be significant, if water is used.[13] However, the practice that is most likely to induce pulp damage from frictional heat arises when a worn carbide bur is used without water spray to remove last vestiges of caries and hard affected dentine, close to the pulp. This frequently used practice of shutting off water when close to the pulp can generate a significant amount of thermal injury, particularly if sustained for more than 10 seconds.[9] A more suitable and safer method of removing last vestiges of caries is by using a sharp spoon excavator.

The removal of deep caries itself has the potential for allowing microrganisms to be breached into the pulp chamber, creating a non-resolving pulpits.[14] Proliferation of bacteria in the superficial aspect of pulp tissue disorganizes the odontoblast layer and kills cells either by direct toxic action or by excessive acute inflammatory response. In some instances the pulp can withstand the microbial insult and odontoblasts will respond by deposition of new tubular dentin and deposition of mineralized intra-tubular plugs.[15]

A systematic review of MEDLINE indicates that utilizing a stepwise evacuation of dental caries that is very close to the pulp, along with a treatment lining is effective for pulp preservation by reducing bacteria and by promoting remineralization of the carious dentine.[16] The stepwise protocol, at the first visit, recommends not removing the last remnants of decay but recommends placing a layer of CaOH or other similar material prior to making a provisional restoration. Approximately nine months later, the site is re-entered and the residual caries is removed, allowing time for a reparative dentine bridge to be established.

Effects Of Light Curing on Pulpitis:

Light-curing of resin-based products also generates heat and has the capacity to increase the intra-pulp temperature high enough to induce damaging effects to a vital pulp.[17,18,19]

Tosun et al. evaluated the temperature rise in the pulp underneath caries-affected primary tooth dentine during adhesive polymerization and found it could exceed 5.5°C, (the Zack and Cohen threshold).[20] Carious dentine is normally removed during caries excavation, however, affected dentine is not usually removed, so a significant portion of a cavity wall contains caries-affected dentine.[21] This practice is significant because carious dentine or caries-affected dentine has a higher thermal conductivity when exposed to curing light energy and will generate greater heat compared to sound unaffected dentine when at close proximity to the pulp.[22] This is also the case with dental adhesives which exhibit higher temperature rises during polymerization than do the Resin-Based Composite materials (RBC's) which are placed over the adhesives.[20]

The process of light photo-activation of composite restorative materials is multi-factorial and there are several reasons which can contribute to cause a temperature rise inside the pulp chamber and which are sufficient enough to cause pulpal damage.[23,24] Polymerization of light-cured composites generates heat because of the energy absorbed during the irradiation process of the light. This, in combination with the exothermic reaction of addition polymerization that RBC's undergo creates a stepwise elevation of temperature.[25] Heat generation can be variable, depending on the intensity of the light source and on the moderating thickness of bulk placements of composite. The thicker the composite placed the less energy will reach the pulp.[26]

Another variable regarding temperature rise is the composition of the RBC itself and which is dependent on the energy density of the material used. For example Z100 with energy density of 28 J/cm^2 promoted higher temperature increases than Z250 with energy density of 14J/cm^2 when a light source of 700 W was used for the same period of time.[27] The manufacturer, (3M ESPE), recommends a cure time of 40 seconds for Z100 and 20 seconds for Z250.

Although the light source largely determines the temperature rise during curing, the heating effect also depends on the type of curing unit, the quality of the light filter, the output intensity, and the irradiation time.[28] In a study of different types of curing lights comparing LED, Quartz Halogen and Plasma Arc and exposing for the same time intervals, it is the most powerful light, the PAC unit, which registered the greatest amount of heat output.[29] The use of high-intensity PAC lights can cause increased heat generation in the dental materials being cured, potentially leading to pulpal damage. This is notably less so when using LED or QTH lights.[29,30] The practice of doubling up light-curing units to speed up polymerization doubles up the heat and should absolutely be avoided. (Figures 3, 4, 5, 6)

Adequate polymerization is a very important factor in maximizing physical the properties, clinical performance and

Figure 3: High Intensity Curing Lights

Figure 4: Heat Damage From Curing Lights – (a) Prior to Md. ¾ All-Ceramic Crowns.

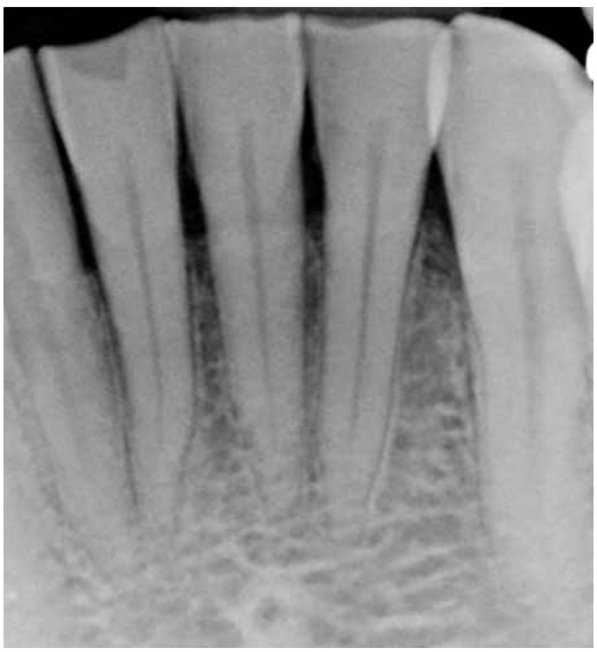

Figure 5: Heat Damage From Curing Lights – (b) Radiograph, prior.

Figure 6: Heat Damage From Curing Lights – (c) RCT's.

the biocompatibility of resin based filling materials as well as resin based luting agents (RLA's). Contemporary luting agents that are used for the cementation of etchable, all ceramic restorations for the most part, are resin-based and are either light-cured or dual-cured. Problems associated with inadequate polymerization include: inferior physical properties, solubility in the oral environment and increased micro-leakage. These factors have the potential to develop recurrent decay and pulpal irritation. As well, when RLA's are not fully polymerized, leachable components such as Bis-GMA, UDMA, TEGDMA, camphorquinone and HEMA may penetrate through dentin tubules and exert potential pulpal injury and inhibit pulp tissue repair, a cytotoxic effect.[31,32] Chen et al. have shown that the resin based components of dentine bonding agents also pose a cytotoxic effect, exerting potentially harmful effects to the pulp.[33]

The degree of conversion (DC), when using light-cured, filled, composite materials or when using light-cured or dual-cured luting agents can be highly variable giving values from 55% to 75% depending on the chemical composition of the material and on the light source used.[34,35,36] If the polymerizing light is impeded by restoration material opacity, or by access, or by bulk, then a dual-cure composite or dual-cure luting cement may be a more appropriate consideration.[37]

Recommendations to Reduce Deleterious Effects to the Pulp During Tooth Preparation and Caries Removal, and When Using Curing Wands During the Placement of Composite Restorations, Dentine Bonding Agents, and Resin-Based Luting Agents.

Dentists should give careful consideration to the manner in which enamel and dentine stripping is made, particularly when tooth reduction approaches the dental pulp. Care should also be given to the choice of LCU when curing light-activated bonding agents and restorations in deep cavities, close to the pulp. Care should also be given to reduce the amount of time curing lights are activated. Most high intensity lights, particularly new generation, high intensity LED's can generate enough heat to burn anaesthetized mucosa if the time exposure is high and there is proximity. Notwithstanding, enough light should be transmitted to accomplish adequate resin polymerization conversion. The following are guidelines that can be used to reduce operative damage to the dental pulp and perhaps the unfortunate necessity to undertake endodontic therapy.

1. *Use new, sharp burs and diamonds for gross tooth reduction and for internal caries removal.*
2. *Use handpieces that have concentric running chucks and use burs that do not wobble.*
3. *Use high-volume water coolant spray along with high volume suction when performing any tooth preparation or caries removal. Do not cut dry!*
4. *Use handpieces with at least 3 or preferably 4 water ports so that if one side is obstructed, coolant will still reach the burr.*
5. *When removing caries near the pulp use sharp spoon excavators rather than burs or diamonds.*
6. *Use a stepwise caries removal protocol when caries is very near the pulp.*
7. *When using bonding agents on dentine that is close to the pulp, keep the curing light further away from the tooth and do interval curing rather than long concentrated exposures.*
8. *Use a pulp-covering/capping agent on dentine when in close proximity to the pulp to reduce the cytotoxic effect of dentine bonding agents and resin based luting agents.*
9. *Use high-energy composites that cure in a shorter time and according to manufacturers recommendations.*
10. *Use moderate energy LCU's; either LED or QTH rather than PAC units but of an output adequate to effect high polymerization conversions.*
11. *Do not use two curing wands simultaneously to accelerate the polymerization process.*
12. *Whenever light exposure may seem to be excessive use, an air syringe and a high-volume suction as a cooling mechanism.*
13. *Place your light wand against your ungloved fingernail bed and expose for 2 or more cycles to appreciate the degree of heat generated.*
14. *Use dual-cure luting agents instead of light-cure luting agents whenever there is doubt about the degree of polymerization conversion.*

Indirect and Direct Pulp Capping:

Direct pulp capping (DPC), is a procedure of covering an area of *exposed* vital pulp with one or more bioactive materials to preserve pulp integrity. The intention is to induce a reparative dentinogenic response to seal off a pulpal wall breach by the formation a bridge of reparative hard tissue.[38] A successfully sealed-off zone of dentine repair can obviate the need for root canal treatment and the possible sequelae of tooth loss. (Figure 7)

The indirect pulp cap, (IPC), is a procedure where an application of a layer of a specific material is made over a deep dentine zone of close, but not actual pulpal exposure in order to protect the pulp against further operative interventions, bacterial ingress or against the potential toxicity from various restorative materials.

The practice of making a pulp cap originated with Philipp Pfaff as far back as 1756.[39] In contemporary practice there are a wide variety of pulp capping materials such as CaOH (Dycal, Kerr-Sybron), (MTA) cement (ProRoot, Dentsply), Biodentine (Septodont) and TheraCal (BISCO Dental Products), that can be utilized. There is considerable research data available regarding the cytotoxicity and antimicrobial activity of these various capping agents as well as their methodology of use. A bioactive pulp capping material optimally should have a requisite biological compatibility *plus* the ability to generate a protective and recuperative response against pulp irritation and pulp

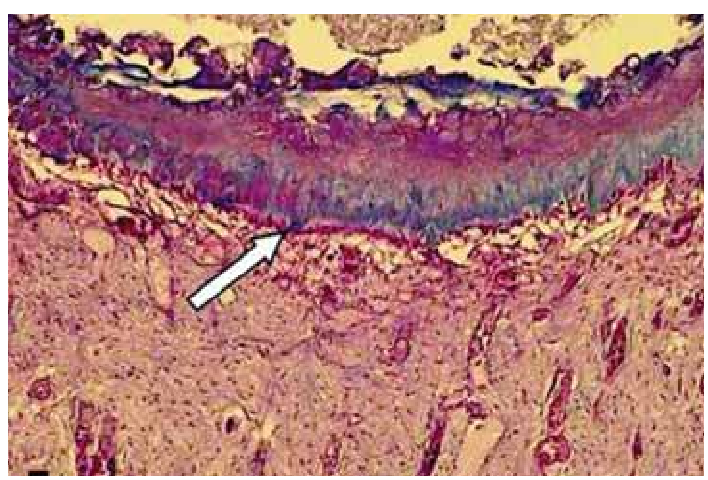

Figure 7: Pulp Cap Repair With Odontoblast Layer Under Repair Bridge (after da Silva Modena).

degeneration.[40,41] CaOH has been used for decades with successful but imperfect or unpredictable results.[42] Currently, there are several new materials that show evidence of stimulating the dentine to develop the bridging of defects by apatite formation and which do so more effectively than CaOH. These materials utilize calcium silicates or calcium aluminates and have been shown to be less cytotoxic and have better antibacterial properties than CaOH. These newer materials are considered to be more bioactive.[41,45]

Dycal has shown an ability to stimulate the pulp to lay down reparative dentine. This however, may not be due to the bio-inductive capacity of the material; rather it is more likely due to the result of a defense mechanism by the pulp induced by the inherent, irritant nature of calcium hydroxide.[43] The toxicity of Dycal, a high alkalinity, self-setting (2.5-3.5 min) radiopaque calcium hydroxide-based material has been employed in direct and indirect pulp-capping procedures and its shortcomings have been well established.[44,45] Dycal, while widely used in dental practice for a very long time as the protective layer of choice, has two additional disadvantages besides its relative toxicity: poor adhesion to dentine and a significant solubility factor that over time creates dissolution. These two factors are responsible for allowing avenues of progressive micro-leakage to the pulp as well as the creation of voids or defects ("tunnel defects") in the reparative dentine under the capping layer.[46]

MTA, Mineral trioxide aggregate, has a composition similar to that of Portland Cement. Both are composed of calcium phosphate, calcium, and silicon oxide. MTA is a powder that contains trioxides and hydrophilic particles that allows the material to set in the presence of moisture. It is applied as a paste or putty depending on how much sterile water it is mixed with. MTA, additionally, contains bismuth oxide, which provides some radiopacity. It has an enhanced interaction with dentine pulp tissue compared to CaOH showing faster and more complete dentine bridge formation[47,48] as well as significantly less cytotoxicity.[45] While MTA has been shown to be a reliable and biocompatible pulp capping and dentin sealing material, its formulation and chemical curing, plus its very long clinical setting time, make it an inefficient material to use routinely for restoration lining or as a pulp capping material.[49]

Biodentine is a powder-liquid material having chemistry similar to MTA. The powder contains tricalcium silicate, dicalcium silicate, calcium carbonate, and zirconium oxide; the liquid contains water, calcium chloride (accelerator), and modified polycarboxylate. Biodentine, like other silicate based materials rates low in cytotoxicity.[45] It does sets somewhat faster than other calcium-silicate cements like MTA, but still takes beyond ten minutes of set time when used as a pulp cap before a restoration can be placed over it. This, in addition to the capsule based tituration preparation makes for clinical inconvenience compared to other materials.

TheraCal is a new category of resin-modified calcium silicates based on a light-cured, resin-based, single-paste system. TheraCal consists of CaO, calcium silicate particles (type III Portland cement), Sr glass, fumed silica, barium sulphate, barium zirconate and resin, containing Bis-GMA, and polydimethacrylate. It is a highly radiopaque lining and capping material designed to release calcium to promote the formation of reparative dentine.[50] The biologic availability of calcium ions supplied from a pulp capping or lining material is integral to stimulating pulp cells to form new mineralized hard tissue. This is the basis of the success of CaOH as well as the more recently introduced silicate based products.[51,52,53] TheraCal shows the highest Ca availability of all tested materials.[54] TheraCal also has distinctive application advantages over other materials in that it is supplied directly from a paste container and then light polymerized to form an almost instantaneous hard, secure and low-solubility barrier over which a restorative material can be immediately placed.

The objective of vital pulp therapy is to maintain the pulp vitality and its function. Several factors influence the success of direct pulp capping such as carious contamination, the age, vitality and regenerative power of the pulp, the materials and technique used to perform the procedure and the ability to control pulp bleeding in a physiologic way. If pulp bleeding cannot be controlled, it is difficult or impossible to create a wound seal that would allow intimate contact of the capping material to the pulp tissue. If a blood clot is left on the surface without direct contact of a bioactive capping material, a chronic inflammatory response impairing the healing process will ensue.[55,56] Control of pulp bleeding is usually attempted by placing a cotton pellet soaked in a solution onto the bleed site. A variety of solutions have been used, including saline, sodium hypochlorite (concentrations ranging from 0.12% to 5.25%), hydrogen peroxide, ferric sulfate and chlorhexidine. Saline or calcium hydroxide solutions are the most benign to the pulp in performed cytotoxicity tests.[57] Saline exhibits the mildest pulp response but is only moderately hemostatic. Sodium hypochlorite is effectively hemostatic plus has the benefit of being antibacterial, but it is more cytotoxic and will induce a pulpal inflammatory response that fortunately in most cases is transient. Chlorhexidine is antibacterial but is not very effective at hemorrhage control. Ferric Sulfate is highly hemostatic but is seriously cytotoxic, creating post-operative pulpal pain and is not recommended.[58] Ankaferd Blood Stopper (ABS) is a new hemostatic agent derived from herbal extract that has been shown to be as effective as ferric sulfate. It has been proposed for bleeding control of exposed pulps but there is very little research on it and its cytotoxicity on the pulp is not well established.[59]

Recommendations on Vital Pulp Lining and Pulp Capping:

Dentists should recognize that the dental pulp has good recuperative powers even when it becomes exposed, but they should also be aware that a carious exposure of the pulp significantly reduces the probability of pulp survival and that when bacterial contamination occurs, root canal therapy, should be considered. In the case of an operative created exposure with no contamination, pulp capping can have a high incidence of success, particularly if best protocols and materials are utilized.

1. *If the pulp bleeds, the bleeding needs to be arrested so that the capping material can attach or be secured in a stable way around the perimeter of the exposure. As a first pass, use a cotton pellet moistened with saline solution and very gently compress for a few minutes. If bleeding continues repeat the process using NaOH which is more cytotoxic, but not overtly so, if judiciously used.*
2. *When ready for capping, apply a thin lining of TheraCal which is confirmed to be bioactive, sets immediately on light activation, and has enough stability to receive a hydrophilic self-etching dentine adhesive followed by a restoration directly over it. Blot off moisture but do not dessicate the area before applying the TheraCal layer.*
3. *Do not use high heat generating wands to cure the layer and for the same reason do not exceed the minimal time needed for polymerization. A gentle supplement of air syringe during curing can help keep the heat from the light at minimal.*
4. *As a protective liner use the same protocol as in No. 2 & 3, assuming there is no pulp bleed.*

Effects of Threaded Pin Placement:

Threaded and cemented pins or dentinal micro-screws are commonly used in restorative dentistry to enhance the retention and stability of restorative dental materials. According to Segovic et al. (2002), the insertion of self threaded pins causes micro-cracks in the dentine slightly in excess of 50% of cases. However, there is very little information published on the effects that pin placements have on the dental pulp or on the structural integrity of the tooth or on the significance of the micro-cracks induced. On the other hand, it is reasonable to presume that pin placement into the pulp will create an inflammatory response due to the mechanical insult and it is probable that unless the pin channel is otherwise sealed it may act as a path of ingress for bacterial leakage. If the penetration into the pulp is superficial and the wound in not bacterially infective, it is reasonable to assume that the pulp may respond by creating an isolating, reparative zone of dentine. It is also reasonable to expect that if there is pin perforation into the periodontium there will be a localized inflammatory response that may create a chronic periodontal condition.

Recommendations on Pin Placements:

The use of retention pins to stabilize coronal restorations in vital teeth poses some risks, particularly when they are placed in narrow diameter teeth such as maxillary laterals and mandibular incisors. Careful consideration should be given to the, type of pin placed, the diameter of the pin, the placement location, the number of pins and the risk versus benefit of utilizing pins.

1. *Use sharp drills on ultra-low rpm's to create the pin channel so as not to induce heat or dentine crazing.*
2. *Choose to locate the drill holes at the 4 line angles of the tooth where pin placement will be most remote from the pulp. An exception is the mesial-buccal line angle of the maxillary first molar where there is a pronounced pulp horn.*
3. *Self-shearing, straight pins are imprecise for bottoming out or not. Pins with a coronal depth-limiting flange are more accurate and may be less likely to create dentine stress.*
4. *If a pin must be bent, use a pin-bending tool to minimize the torque that will be transferred to the tooth structure.*
5. *Consider the use of cementable pins that are passive, compared to self-tapping pins. Use a cement that is minimally cytotoxic such as conventional glass ionomer compared to resin. A cemented pin will also create a pin channel seal to resist possible bacterial micro-leakage.*
6. *Follow the contour of the root when aligning the drill to minimize the risk of external perforation. (Figure 8)*

Effects of Chemical Treatments to Enamel, Dentine and Cementum:

The application of chemicals onto and into teeth is an integral part of what clinical dentists do in everyday practice. Tooth whitening is one of the most commonly used examples of chemical application in dentistry. It utilizes hydrogen peroxide or carbamide peroxide in the dental setting, but these agents are also sold over the counter (OTC) for home use. In operative dentistry various other substances are also utilized as conditioning agents to prepare enamel, dentine and cementum for remedial treatment enhancement. Agents such as phosphoric acid and

Figure 8: Four Pins Placed at the Axial Line Angles.

citric acid are used for conditioning enamel and dentine prior to adhesive bonding. Sodium hypochlorite, EDTA and citric acid are commonly used in endodontic procedures. Tetracycline HCl, EDTA and citric acid are used for conditioning cementum prior to connective tissue grafting procedures. Many of these agents are cytotoxic and can possibly be harmful as well as beneficial.

Effects of Tooth Whitening:

It is a widespread elective practice to whiten teeth by applying different agents to the surfaces of teeth for cosmetic purposes. Hydrogen peroxide, sodium perborate and carbamide peroxide are the principle products used for tooth bleaching purposes. Side effects, such as changes in the tooth structure, gingival burns, micro-leakage in restorations, tooth sensitivity and pulpal irritation all have been reported when using these agents.[60,61,62] The greatest negative consequence, however, may arise in utilizing powerful light units to activate powerful 35% to 50% hydrogen peroxide based bleaching agents.[63] Heat application seems to be effective in potentiating the bleaching effect of tooth whitening agents compared to cold light which has been shown to be relatively ineffective.[64] Halogen, LED and LED Laser lights all have the potential to raise the intra-pulp temperature.[63] Temperature elevations of 5.6°C or greater can cause pulpal damage and may result in necrosis in 15% of cases, depending on pulp health its physiological response capacity.[10]

In an in vitro study, Carrasco et al. determined that of the three contemporary light systems tested, the halogen light generated the most heat but when bleaching gel was applied the gel actually acted as a modulator of heat production diffusing its effect. LED and LED Laser units produce notably less heat than halogen. However, the heat increases into the pulp chambers for all units tested, including halogen, were deemed unlikely to be injurious to pulpal health because they did not exceed the 5.6°C threshold even though the in vitro study did not factor on the effect of blood circulation in the pulp chamber which could account for a greater intra-pulp temperature rise than the study showed.[65] The most common effect of tooth whitening is post treatment cervical tooth sensitivity which ranges in incidence from 15 to 78% with the highest rate resulting from the combination of 30% hydrogen peroxide used in combination with heat.[66]

The success of whitening procedures is directly related to the ability of bleaching agents to penetrate enamel and dentine. Recent studies have shown that both hydrogen peroxide and carbamide peroxide are capable of penetrating enamel and dentin and will enter the pulp chamber.[67,68] The higher the concentration of these products and the longer the application, the higher is the penetration into the pulp chamber.[69] While *in vitro* studies show a significant penetration of peroxide into the pulp chamber, in vital pulps it is postulated that pulpal fluid pressure is capable of reducing inward diffusion of these and other chemicals so as to diffuse potentially harmful effects. This factor along with the other defense mechanisms of the pulp are apt to significantly reduce the level of hydrogen peroxide penetrating into the pulp and which therefore are not expected to develop into any permanent, negative outcome.[70]

A number of studies have been made regarding the effect of bleaching agents on the CEJ with analysis of the effects of erosion and abrasion and cervical sensitivity. The majority of studies have shown that at-home bleaching agents based on hydrogen or carbamide peroxide have no harmful effects on enamel and dentin properties. Cervical sensitivity in most instances can be controlled by the application of fluoride or desensitizing agents.[71,72] The greatest post-operative sensitivity is generated by in-office applications of 35% hydrogen peroxide based products particularly when used in combination with heat based curing lights.[73]

Post-bleaching sensitivity differs from dentin hypersensitivity because it is related directly to the penetration through the enamel of the sub-products of the bleaching gels into the dentin and pulp tissue, causing reversible pulpitis and thermal sensitivity, but not causing permanent damage to the pulp. The degree of post- operative pain is dependent on the peroxide concentration, time, frequency of gel application, and the degree of pulp temperature rise with light activation.[74,75]

Recommendations on Tooth Whitening:

Tooth whitening is a socially driven, elective procedure that in most instances is simple and effective and relatively inexpensive. It is therefore a popular treatment that is requested and performed *by most dentists and it is also available as an over the counter product that can be used at home. Because tooth whitening is so common there is the belief that it is absolutely safe. For the most part this is true but vital tooth bleaching can be subject to overuse and abuse.*

1. *Use high concentration hydrogen peroxide bleaching products with care and discretion. Avoid using on adolescents who are more susceptible to post operative sensitivity or on adults with gingival recessions and erosions. Use with rubber dam and soft tissue barrier protection agents.*
2. *Avoid the use of lights that create heat. Recognize that non heat-generating lights have limited benefit.*
3. *Use according to the manufacturers recommendations for duration and frequency. Results are time and concentration dependent, so weaker concentrations over more time may be more appropriate than strong and fast. Do not over-prescribe or abuse these products.*
4. *Use fluoride treatments or other agents to alleviate post-use sensitivity.*
5. *Instruct the patient on proper protocol with take home or OTC products.*

Effects of Conditioning to Enamel and Dentine in Adhesive-Based Restorative Procedures:

Effective adhesion to tooth substrate is the basis for using contemporary composite resins as a restorative material and as a luting agent. This process depends on creating a suitable micro-retentive surface on enamel or dentine. On both enamel and dentine, this works best by conditioning (etching) the surface with a phosphoric acid gel of approximately 32-37% concentration (pH < 1.0) for about 20 seconds and then rinsing with water. On enamel, the phosphoric acid will create an etched micro-retentive surface directly onto the prismatic mineralized surface to which the bonding agent will directly and effectively attach with an adhesive strength of around 45 MPa.[76]

On dentine, which has much greater percentile organic composition, the acid works by removing the smear layer to expose dentinal tubules into which the hydrophilic resin primers will penetrate and then be polymerized creating an adhesive, hybrid zone.[77] An effective hybrid interface in dentine will create adhesive values of around 40 MPa. While the process of conditioning is effective, some concern has to be given to the possibility of a cytotoxic effect when using a relatively strong acid product close to pulp tissue. Conditioning applied for 15-20 seconds onto a very thin layer of dentin only slightly affects the blood supply to the dental pulp; however, prolonged etching time for 60 seconds results in immediate failure of microcirculation in the dental pulp of rats.[78,79] An *in vivo* testing of direct acid etching in deep dentine sites, followed by a bonding agent, creates inflammatory and degenerative pulp responses compared to placing a protective bioactive lining prior to using a self-etching adhesive agent.[80]

Recommendations On Pulp Protection When Dentine Bonding:

Dentine bonding is universally used in dental offices throughout the world because for the most part it is safe and effective. However, there are a number of issues pertaining to bonding in deep dentine or when bonding over an exposed pulp. If the pulp is exposed and there is bacterial invasion, endodontics is almost always a necessity. If the pulp is not exposed it must be protected from the effects of etching, the application of adhesive resins and the future possibility of micro-leakage. Each of these events individually, or together, can be injurious to the pulp. Protection layering over the pulp must also be resistant to degradation due to hydrolysis and the overlying restoration must protect the pulp by creating a dependable perimeter seal that will also resist micro-leakage.

1. *Prior to total-etching or one-step etching onto an exposure or in a deep dentine zone, a thin layer of a suitable biocompatible and bioactive liner such as TheraCal should be used. TheraCal has the ability to rapidly create a hard, well-sealed, light-activated, resinous capsule over the pulp area.*
2. *The best protocol for adhesive bonding over the capped area is with a "total etch" and rinse, 4th generation, bonding which will use a hydrophilic primer for effective penetration of the resin into the exposed dentinal tubules, followed by a secondary hydrophobic layer primer that will give maximum protection against water-tree hydrolytic degradation and then over which a universal bonding agent can be used. It is important that the dentine in this protocol is not dessicated, or the bond will not be very effective.*
3. *Alternatively, an 8th generation single step universal adhesive can be placed over the capped area. The universal adhesives of this generation will help to recondition over-dessicated dentine. This simplified procedure, while not as good as the 4th generation protocol, will deliver very adequate adhesion and protection and will reduce post-operative sensitivity. Two products that are representative of this system are: Bisco Universal Adhesive and 3M ESPE ScotchBond Universal Adhesive.*
4. *When light-wand curing the primer layer and the adhesive layer, remember that output strength of the light, plus*

proximity, plus time, cumulatively can potentiate a harmful effect to the pulp. Short, but adequate exposure time with moderate light output therefore is more suitable. If necessary, air syringe adjunct cooling can be used.

5. *Because 8th generation, single step adhesive agents are only mildly acidic, it is unlikely that peripheral enamel will be etched adequately to create a good marginal restoration bond that will resist micro-leakage. It is therefore recommended that a bead of 37% phosphoric acid gel be applied to regions of enamel that will be in contact with the composite restorative material.*

Effects of Conditioning of Cementum in Periodontal Therapy:

Root conditioning for periodontal treatments is somewhat controversial but remains a standard procedure that is performed prior to applying connective grafts to be able to obtain cementum root coverage with soft tissue. Cementum is a mineralized tissue layer that has as its primary function the insertion of periodontal ligament fibers onto the root surface. This suspensory fiber apparatus acts as a proprioceptive agent that governs the functional and parafunctional forces elicited from teeth to the surrounding alveolar bone.

Root surfaces of periodontally diseased teeth are hyper-mineralized and contaminated with organisms, endotoxins and other biologically active substances.[81] Biomodification of root surfaces and removal of the smear layer and debris is deemed critical for regeneration of the periodontium.[82] Removal of all bacterial components by meticulous root planning is not enough because the resultant and residual smear layer will prevent the new attachment of periodontal fibers and will inhibit the migration and proliferation of fibroblasts.[83]

There are many agents such as phosphoric acid, EDTA, tetracycline HCl and citric acid that can be used for the biomodification removal of the smear layer of root surfaces following debridement. All of these products are effective but Citric acid is the commonly used because it is highly effective, readily available and inexpensive. The most effective concentration and method of applying citric acid gel is to use it at the 25% concentration (pH 2.2) with a brushing technique for 1-3 minutes.[84,85,86]

Citric acid is cytotoxic to the dental pulp. Chan et. al. investigated the cytotoxic and cytostatic effects of citric acid on cultured dental pulp cells which when exposing the cells to pure 1% citric acid (pH = 2.26) for 60s caused immediate cellular death. The authors recommended judicious care of using citric where it can come into direct contact with the dental pulp.[87,88]

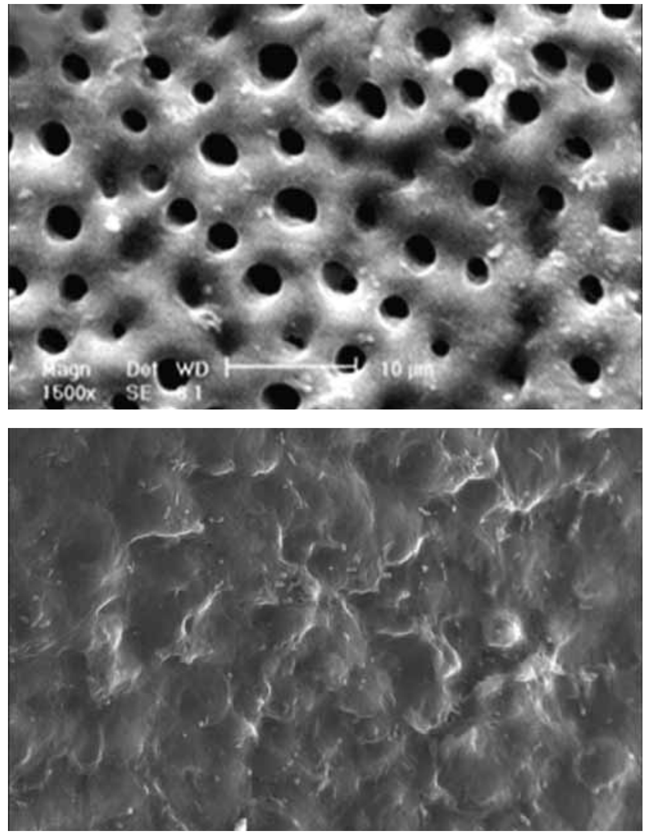

Figure 9: Citric Acid Effect on Dentine (above) and on Cementum (below).

Other authors have shown that citric acid, in low concentration, placed into cavities on the pulp demonstrated transient pulp inflammation but no severe or irreversible damage.[89]

There is little investigation of the effects of very high concentration citric acid with its low pH on the pulp when used as a root surface conditioner but the few available studies indicate that citric acid does not penetrate into the dentinal tubules nor does it alter the collagen content of the roots obtained by scaling and root planning,[89,90] nor does it seem to have an adverse effect on regenerative fiber healing or on bone regeneration.[91] While there seems to be no deleterious effect to the pulp and the vitality of the tooth, low PH citric acid will have an immediate (within 20 s) necrotizing effect on both mucosal flaps and surrounding periodontal tissue so care should be taken to avoid soft tissue contact.[92] (Figure 9)

Recommendations On Using Citric Acid To Condition Cementum:

Epidemiological studies show that more than 50% of the population have one or more sites with recession of at least 1 mm.[93] Loss of gingival root coverage predisposes the root to erosion and to loss of esthetics; so there is an indication and a need and for remedial procedures. The most common, current, surgical method to re-establish lost gingival form and coverage, is by using connective

Figure 10: Occlusal Trauma on 3.1 and 3.2

Figure 11: Periapical Periodontitis From Occlusal Trauma.

tissue grafts harvested from the palate by pouch technique and then installing them over a recipient sites by a tunneling technique so that the graft is covered by a vascularized zone of epithelialized tissue with undetached papillae. Prior to transferring the donor grafts, the exposed root areas are usually conditioned with EDTA, tetracycline HCl or citric acid to enhance the attachment of the graft as per the method described following. Because citric acid can be harmful to the soft tissues due to the low pH, care must be taken to minimally expose it to the soft tissues.

1. *Preparing an optimum surface for graft attachment requires a mechanical debridement of all calculus, plaque and bacterial components from the root surface by using ultrasonic instruments or hand scalers. This is followed by an application of a conditioning medium to remove the smear layer. Studies have shown this is most effectively accomplished by rubbing a 25% concentration of citric acid with a small cotton pellet or with a bonding-application brush onto the root area for approximately 2-3 minutes. It is important to avoid solution contact with the mucosal tissues. Wash with saline and blot dry.*
2. *It is common to apply enamel matrix protein, i.e."Emdogain" (Straumann) to enhance periodontal ligament fibroblast proliferation.*
3. *Apply and position the CT graft and suture to secure the graft.*
4. *Instruct to avoid brushing the site for 1 week and use chlorhexadine as a mouthrinse, bid. Avoid flossing for 4 weeks. Do not probe for 6 months.*

Effects of Traumatic Occlusion On Pulpitis and Pulp Degeneration:

It is recognized that repetitive micro-traumatic forces on teeth can cause tooth migrations and periodontitis. It has also been considered that parafunctional forces, when sustained, may be a contributing factor to pulpitis, and to the pulpal degeneration of teeth along with accompanying apical periodontitis.[94] Review of the literature reveals a paucity of studies about the reaction of dental pulp to occlusal forces but other related traumatic forces such as orthodontic intrusive and extrusive forces have been shown to affect the dental pulp by creating inflammatory vascular changes.[95,96] Orthodontic forces have been shown to cause edema and odontogenic degeneration of the pulp by compromising the apical blood supply.[97,98] Generally, in the first few days after activation of an orthodontic appliance, patients will often suffer transient pulp ischemia, causing pain and discomfort. Usually these symptoms settle within a week, but pulp death following orthodontic treatment is occasionally reported.[99]

Kvinnsland et al. did rat studies creating hyper-occlusion and using fluorescent microspheres to detect blood flow. They found that teeth on the hyper-occluded side had an increase in pulpal blood flow.[100] Lui did a clinical analysis of 19 cases where pulpitis could not be explained except by traumatic occlusion and after he performed occlusal adjustment found that 6 teeth resolved but 13 required endodontic intervention.[101] Shi et al. attributed 100 teeth in 89 cases having pulpitis with apical periodontitis to traumatic occlusion. All teeth were caries free and without dental or periodontal disease but all had distinct evidence of marked occlusal trauma.[102]

Okeson in his textbook, *Management of Temporomandibular Disorders and Occlusion*, states that "On occasion, patients come in with pulpitis that has no apparent dental or periodontal etiology… When all other etiologic factors have been ruled out, one must consider heavy occlusal forces … chronic pulpitis can lead to pulpal necrosis." (Figure 10, 11)

Recommendations On Managing Site-Specific Trauma to Teeth.

Occlusal dysfunction can manifest into a number of pathologic symptoms such as temporomandibular joint disturbances, myofunctional disturbances and disturbances to the teeth and periodontium. Tooth fractures, tooth wear and tooth hypermobility *and periodontitis are common consequences of excessive, ongoing loading on teeth. Occlusal trauma may also create pulpitis, particularly if there are other predisposing conditions such as concomitant periodontal involvements or abrasion into dentine.*

1. *During routine examinations test each tooth with soft percussion to see if periodontal support has been altered and if there is a differentiation of periodontal stability from other teeth. Keeping a finger on one side while gently tapping on the other side can proprioceptively identify changes in the stability of the periodontal membrane. If a particular tooth seems hypermobile consider providing occlusal relief by selective adjustment.*
2. *Identify sites of aggressive individual tooth wear. If there is dysfunctional occlusal trauma and the periodontium is resistant, excessive faceting or wear may indicate a specific site of trauma. Again, selectively adjust the tooth as a preventive therapy.*
3. *Identify sites where opposing occlusal materials are incompatible, such as where antagonistic ceramic or other materials that may be wear resistant are positioned against a natural tooth or restorative material that is less hard and less wear resistant. Selectively adjust the wear resistant material and polish very smooth.*
4. *Consider the use of nocturnal anti-bruxing guards that will splint teeth and provide a platform to create an equilibrated occlusal contact pattern and will ameliorate the wear on the occlusal surfaces of teeth.*

Conclusions:

Operative Dentistry, while well intentioned, may have the adverse effect of creating harm instead of benefit. Procedures that generate excessive heat and materials that are cytotoxic can irritate the dental pulp and create pulpitis conditions that may not be reversible. This is particularly relevant as procedures and materials encroach on and are applied closest to the pulp. This article has attempted to identify those factors that have the potential to create irreversible insult to the pulp and has attempted to provide guidance for minimizing unwanted harmful events.

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Comments/Commentaires

Continued from page 25 – References for:

Iatrogenically Induced Pulpitis as a Consequence of Operative Dentistry – Preventive and Remedial Considerations

Pulpite induite Iatrogéniquement, comme une conséquence de la dentisterie opératoire –considérations préventives et correctives

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