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DENTIN-PULP

H. R. MUHLEMANN, *moderator*

Reactions of Dentin and Pulp to Drugs and Restorative Materials

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The reactions of dentin and pulp to drugs and restorative materials are mainly the consequence of the tissue destruction induced by dental caries. Through improvements in technology, many new products are developed in dentistry and it is essential to know precisely their behavior toward the dental tissues. Hundreds of papers have been devoted to the biological testing of drugs, liners, varnishes, bases, and fillings. Precise methodological rules have been recommended for their experimental evaluation. In addition to the study of the pulp, attention has been focused, in recent years, on the reaction of the inorganic part as well as of the cytoplasmic and organic components of dentin.

Structure of Normal Pulp and Dentin

The prominent pulpal cells are the fibroblasts and the fibrocytes. Great variations in cell density can be observed. The fibroblasts are slender bipolar cells containing a well-differentiated Golgi complex and endoplasmic reticulum closely associated with mitochondria.¹ The fibrocyte is characterized by a scarcity of organelles. Besides these prominent cell types, normal human pulp contains only a few macrophages, plasmocytes, mast cells, and leukocytes.

The intercellular substance filled with ground substance contains two types of fibrous elements. Collagen fibrils are disseminated as discrete bundles within the ground substance. With increasing age, collagen fibrils become more prominent. Besides the collagen, small nonstriated filaments, 150 Å in diameter, sometimes grouped in bundles, are considered to be similar to the so-called oxytalan fibrils of the periodontal membrane.^{1,2}

The blood vessels of the pulp consist

mainly of numerous capillaries connected with arterioles and venules. Many neural elements follow the pathways of the larger vessels which have a thin layer of muscle cells surrounding the endothelium-lined tubes. Two types of blood capillaries are located in the dental pulp. Capillaries with continuous thick or thin endothelial lining are surrounded by a basement membrane and crowns of pericytes. They were seen alternating with fenestrated capillaries.¹ These have thin endothelial cells and show numerous pores about 600 Å in diameter and were found in regions where important and fast liquid exchanges occur. These fenestrated capillaries contribute to a faster control of hydremia and electrolyte balance between the intravascular compartment and the interstitial tissue. Riedel, Fromme, and Tallen³ and Kukletova⁴ have claimed to have identified lymphatic capillaries in the pulp under the electron microscope. Such lymphatic capillaries had open walls with their vessel lumens communicating directly with the surrounding connective tissue.

The subodontoblastic layer is classically constituted by the acellular Weil's zone, located along the odontoblasts, and a cell-rich layer described by Gotjamanos.⁵ However, the acellular zone can be absent in normal adult pulps and a cell-rich layer is then interposed between the odontoblasts and the pulpal tissue.¹

All nerve fibrils penetrating in the pulp through the apical region are surrounded by Schwann cells. The myelinated nerve fibrils have a rounded or folded myelin sheath.¹ The myelin sheath surrounds the axon. A basement membrane, located on the external cell membrane of the Schwann cell, limits the myelinated fiber.

Several amyelinated nerve fibrils are in-

vaginated within the cytoplasm of a Schwann cell. The plasma membrane of this latter cell constitutes typical *mesaxons*. A basement membrane is seen around the amyelinated nerve fibrils, which are more numerous near the subodontoblastic layer of the pulp chamber. In the plexus of Raschkow, both types of nerve fibers can be seen loosing their Schwann cell covering and their basement membrane, and close contacts between fibroblasts and odontoblasts have been observed.⁶ Myelinated fibers can also loose their myelin sheaths.⁶ In the coronal dentin, some nerve fibers pass between the odontoblasts and reach the predentin and inner dentin.

The odontoblasts in normal adult dentin may have different ultrastructural aspects. When engaged in secretory activities, the cell has a well-developed Golgi zone located along the dentinal side of the nucleus with different types of vesicles, vacuoles, and elongated and multivesicular bodies. This Golgi zone is surrounded by a rich endoplasmic reticulum with numerous mitochondria containing dense calcium granules. Microfilaments and microtubules are disseminated in the cytoplasm. When engaged in catabolic activities, large lysosomelike structures are visible within the odontoblast which can also take the aspect of a resting cell with just a few organelles. The lateral surfaces of these cells are connected by desmosomes, whereas toward the predentin these surfaces are attached by a junctional complex consisting of a desmosome, an intermediary junction, and a tight junction located near the predentin. In the lateral intercellular spaces, some collagen bundles as well as some nerve fibers can be observed.

The odontoblast process, a cellular extension of the odontoblast, extends through predentin and dentin. Brännström and Garberoglio,⁷ through use of a scanning electron microscope, observed that these processes in young human premolars were only found within a distance from the pulp equaling about one-quarter of the total length of the tubule. With transmitted electron microscopy,⁸ most of the dentinal tubules near the human dentinoenamel junction showed absence of odontoblastic processes; however, in young human premolars, hyaline peripheral degeneration of these processes was observed.

Bound by a plasma membrane, the cyto-

plasmic process at the level of predentin and inner dentin contains numerous microtubules and microfilaments with few organelles. Elongated small granules, associated with transfer of collagen^{9,10} and ground substance precursors¹¹ during dentinogenesis, are rarely seen in adult dentin. In the latter, large vacuoles with light or dense contents, which seem to be associated either with exocytosis or endocytosis,¹² are observed at different levels of the odontoblast and its process. At the peripheral extremity of the process, centrally located large vacuoles, with light cores, are associated with a hyaline cytoplasmic degeneration of the process.¹³ Lateral cytoplasmic processes penetrate in lateral branching of the tubule.

The odontoblast process does not fill the tubular lumen and between the odontoblast process and the calcified wall of the tubule, a periodontoblastic space is visible.¹³ In the inner dentin, it contains a few uncalcified collagen bundles in areas where the tubular walls are made up by intertubular dentin. In addition, this space as well as the peripheral lumen of the tubules devoided of odontoblast process (dead tracts) are filled with the so-called dentinal fluid,¹⁴ which has the composition of interstitial fluid.^{15,16} The odontoblast process is suspended in this fluid phase.

At a certain distance from the predentin-dentin border, the wall of the dentinal tubule is made up of hypercalcified peritubular dentin, which, in comparison to intertubular dentin, contains more minerals, fewer collagen fibrils, and more ground substance. Even in normal conditions, the dentinal lumen can be completely occluded by apatitic mineralization.⁹ This dentinal sclerosis, also observed in transparent dentin during the carious process,¹⁷ also can occur, in this latter case through deposition of rhombohedral crystals consisting of $\beta\text{Ca}_3(\text{PO}_4)_2$ whitlockite.¹⁸ It is important to note that in an area of dentinal sclerosis, all tubules are not occluded and some scattered lumens remain permeable.¹⁷

In recent years, important progress has been made in the understanding of the morphological basis of dental innervation. The most convincing evidence for dentin innervation using light microscopy has been established by Fearnhead,¹⁹ and recently confirmed by Kerebel²⁰ and Langeland, Yagi,

and Langeland.²¹ With the electron microscope, unmyelinated nerve fibers have been located in the inner third of fully formed coronal dentin in humans,^{1,7,13,22,23,26} in mice,²⁴ white rabbits,²⁵ cats,⁶ and fish.⁶ Presence of complex tight junctions between the nerve fiber and the odontoblast process, with many attributes of synaptic or transducer sites, has been described.^{23,26} In addition, unmyelinated axons surrounded by Schwann cells^{23,24} and myelinated fibers²³ have been observed in tubules of inner dentin.

Controversial data have been obtained from electrophysiological investigations concerning the presence of intradentinal receptors.²⁷ Scott²⁸ recorded electrical activity which according to him originated in the inner dentin of cat canines. However, Matthews²⁹ thought that the recorded activity was conducted through the dentin from nerves located in the underlying pulp of the cat. In fact, conclusive evidence has now been presented about the intradentinal presence of sensitive neurons. With the light microscope Christensen³⁰ showed that nearly all nerve fibers in the pulp disappeared after sectioning of the fifth nerve in the cat but removal of the sympathetic superior cervical ganglion caused no appreciable change in the pulpal nerve distribution. Fearnhead,¹⁹ after resection of the inferior dental nerve in a green monkey, observed in the light microscope, after one month, the disappearance of the plexus of Raschkow and the intradentinal beaded nerves. After resection of the inferior alveolar nerve, degeneration or absence of the unmyelinated pre-dentinal and dentinal nerve fibers was noted under the electron microscope in mice,³⁰ white rabbits,²⁵ and cats,³¹ together with a total absence of nervous activity after electrophysiological recordings.³¹

Absence of nerves near the enamel-dentinal junction and the outer part of dentin is generally recognized,^{8,9,19,28} although these areas are known to be clinically highly sensitive. Strong evidence has been presented through numerous *in vitro* and *in vivo* experiments that transmission of pain stimuli to intradentinal and pulpal nerves are mediated through a hydrodynamic link.^{32,33} A rapid outward flow in the dentinal tubules can produce an immediate sharp pain that can be elicited by most

stimuli such as drilling, probing, air blasts, and cold.³³ A second type of pain sensation is that which may be elicited by heat. The required stimulus for this response is an extensive inward movement of the tubule contents.³³

Evaluating Dentin and Pulp Reactions to Drugs and Materials

The evaluation of the dentin and pulpal reactions to drugs and materials is the final test required in the step-by-step procedure developed by the US Department of Health, Education, and Welfare.³⁴ Such a biologic evaluation is quite difficult to achieve because of the great variability in the parameters involved and standardization of the experimental procedures appears as a necessity.³⁵⁻³⁷

Generally speaking, the dental tissue reactions of new products are initially tested in animal teeth, followed by experiments on human teeth. Usually, intact teeth from rats, dogs, primates, and miniature pigs are used, but if healing properties of drugs or materials are to be tested, an experimental pulpitis system can be useful.³⁸

In human teeth, age differences seem to have no discernible effect on pulp response³⁶; however, most authors preferably use noncarious human premolars of young patients, 12 to 15 years old, to be extracted for orthodontic purposes. Ideally, four premolars in one patient are tested in two crossed pairs; one tooth in each pair drawn by lot³ is filled with a control material. Usually one cavity is prepared in one tooth, but Mjör³⁹ used buccal and lingual preparations to estimate the reaction on the same pulp. The methods of cavity preparation also must be standardized. Most authors prepare buccal Class V cavities with low speeds and abundant cooling with water spray. An extremely critical factor in pulp response is the remaining dentin thickness³⁶ which cannot be controlled accurately during cavity preparation. The dentin thickness has to be measured on the histological sections.

Important variables in assessments of dentin and pulp reactions are related to the histological technique used. Special care must be taken in the fixation, demineralization, and staining procedures. Serial sections have to be examined. In understanding dentin alterations, it must not be forgotten that

peritubular dentin and sclerosed tubular lumen are dissolved during acid or ethylenediaminetetraacetic acid treatment. Therefore, special techniques such as microradiography, transmitted and scanning electron microscopy, and electron microprobe analysis, may be indicated to study reactions in the dentinal tubules.

Adequate differentiation must be made between normal histological variations,⁴⁰ reaction caused by cavity preparation, and that caused by the drug or material itself. Different types of criteria have been used to estimate the severity of pulpal reactions to materials, which in most instances follow in fact a relatively uniform evolution. For example, Stanley³⁶ used three histopathological characteristics based on odontoblast and leukocyte displacements in dentinal tubules, importance of the inflammatory cell infiltrate in the superficial and deeper pulpal tissue, and the predominating inflammatory cell. Holz and Baume⁴¹ paid special attention to the state of the odontoblast processes in the dentinal tubules of the cavity floor and based their study on four criteria consisting of odontoblast aspects, secondary dentin formation, pulpal degeneration, and inflammatory response. In fact, almost every author used his own technique for the rating of pulpal reactions.

In most experiments, postoperative periods of short and long durations have been used, but here again great variations are noted between different studies. Langeland³⁷ observed inflammatory changes at the pulp-dentinal junction as early as three hours. Short-term experiments may give misleading results in that they do not allow adequate time for the recuperative powers of the dental pulp to reach their full expression. The great importance of long-term experiments must be emphasized. Following the repair of dental pulp after cavity preparation up to 21 months, Marsland and Shovelton⁴² noticed that repair occurred in the pulp with deposition of an important layer of secondary dentin by new odontoblasts differentiated from the less specialized cells of the pulp after destruction of the original odontoblast lining. We agree with these authors⁴² when they state that the condemnation of a filling material is not justified if it produces a localized pulpitis in a young, sound tooth after a few days. It will,

however, warrant rejection if it consistently produces important pulp lesions after 200 days. One of the main pulpal functions is dentinogenesis; therefore, new formation of dentin under a filling should be considered as biologically satisfactory. Several studies^{43,44} using tritiated thymidine have shown that after initial odontoblast degeneration, new odontoblasts can be differentiated from spindle-shaped cells of the pulp.

If pulpal-dentinal lesions can result from the action of drugs or fillings, irritations through salivary or bacterial infiltrations along the cavity walls can also play an important role. Marginal leakage has been demonstrated through percolation and diffusion of different dyes or radioisotopes, as well as through observations with reflected light microscopy and scanning electron microscopy. Recently Brännström and Nyborg⁴⁵ have even assumed that diffusion of bacteria trapped in cavity walls before restoration or entering through marginal leakage, rather than the chemical irritation by fillings, may be the main cause of pulpal inflammation. Accordingly, they recommend that the test and control cavities be cleaned with a microbicidal solution.⁴⁵

Dentin and Pulp Reactions to Drugs

Most drugs and substances applied to dentin, with the possible exception of dilute adrenocorticotrophic hormone and cortisone derivatives, produce an inflammatory reaction within the pulp. All fat solvents such as ether, chloroform, xylol, and acetone produce severe reactions to odontoblasts and are most irritating.⁴⁶ Some essential oils, such as eugenol, are if anything at least nonreactive. Phenol penetrates dentin easily and is highly irritative.⁴⁶ Hydrogen peroxide applied to dentin caused an inflammatory reaction in intact pulp and did not reduce an existing inflammation.⁴⁷

Silver nitrate, often used as a cavity sterilization or desensitizing agent, is able to penetrate the dentinal tubules of primary and secondary dentin.⁴⁷ Silver nitrate granules have been observed as early as five minutes after its use at a distance of 50 micrometers in the odontoblast process.⁴¹ A microbicidal cavity cleaner^a containing chlorhexidine and dodecyl diaminoethyl glycine in a

^a Tubulicid, Dental Therapeut. A.B., Nacka, Sweden.

3% sodium fluoride solution, applied for five seconds after cavity preparation, was claimed to eliminate all bacteria remaining on the walls without an irritating pulpal effect.⁴⁵

Camphorated parachlorophenol, when applied to dentin, produced pulpal inflammation.⁴⁷ It could be shown that this drug as well as eugenol and Formocresol destroyed lysosome fractions prepared from bovine pulp.⁴⁸ A radioautographic comparison of the dentin penetration of tritiated aqueous parachlorophenol and camphorated parachlorophenol placed in the pulp chamber and root canal showed that the first solution penetrated the dentin and reached the cementodentinal junction, whereas the camphorated parachlorophenol did not.⁴⁹

Topical fluoride solutions have been applied to freshly prepared dentin cavities for remineralization of carious tissue and for reduction of recurrent marginal caries. Remineralization was demonstrated in vitro with a 10% stannous fluoride solution⁵⁰ as well as a reduction in acid solubility of dentin treated with a 2% sodium fluoride solution.⁵¹ Stannous fluoride applied to freshly cut dentin or to the exposed pulp tissue produced no adverse effects in rats,^{52,53} dogs,⁵⁴ or primates.⁵⁵ By diffusion of sodium fluoride, stannous fluoride, and acidulated-phosphate fluoride solutions through dentinal disks onto monolayers of marmoset gingival fibroblasts, no cytotoxic effects were noticed at clinically used concentrations and exposure times.⁵⁶ No harmful effects on human pulps were observed after a 2% sodium fluoride treatment of experimentally prepared cavities for two minutes.⁵⁷

Cervical root hypersensitivity has been treated with sodium fluoride and other compounds containing fluoride. Microradiography and electron microscopic studies of hypersensitive dentin with CaHPO_4 showed mineral deposition and sclerosed dentinal tubules.⁵⁸ Some workers have attempted to enhance chemical penetration by using iontophoresis. Iontophoresis was effective when used either with or without a fluoride dentifrice,⁵⁹ but a placebo effect was demonstrated in the control group. A desensitizing effect also was observed with a calcium hydroxide paste.⁶⁰

Finally, it must not be forgotten that low

molecular weight medicaments commonly used in contact with viable pulp may serve as haptens. Immunologic sensitization through pulp canals in rabbits⁶¹ and primates⁶² has been demonstrated.

Pulp Capping Agents

Numerous pulp capping agents have been used, but the ideal remedy has not been found. Calcium hydroxide preparations are most widely used but seem to have their limitations. Despite the opinion of Langeland and Langeland,⁶³ convincing evidence indicates that calcium hydroxide will increase the density, hardness, and mineral content^{64,65} of underlying carious dentin in primary and permanent teeth. It sterilizes the residual deep layer of caries⁶⁶ and produces secondary dentin deposition.⁶⁷ With ⁴⁵Ca, it has been shown that calcium hydroxide did not participate directly in the formation of reparative dentin.⁶⁸ In comparative studies, zinc oxide and eugenol (ZOE) was thought to be as effective as calcium hydroxide for covering residual caries.^{69,70} However, no visible change could be demonstrated through microradiography in ZOE-covered dentin.⁶⁵

Different types of calcium hydroxide preparations are commercially available: Pulpdent^b is suspended in methyl cellulose, whereas Hydrex^c and Dycal^d contain resins. Controversial evaluation has been made of these materials as base materials, especially under composites. Whereas Tronstad and Mjör⁷¹ found all of these three products acceptable, Holz and Baume⁴¹ obtained unsatisfactory pulpal reactions with Pulpdent and Hydrex. This latter product gave good protection under a composite according to Langeland, Dogon, and Langeland.⁷² However, Sekine and others,⁷³ testing different calcium hydroxide preparations, obtained the worst results with Hydrex and the best with Calvital.^e

Direct pulp capping with calcium hydroxide on pulp exposures seemed to produce an irregular calcified bridge caused by calcification of collagen produced by fibroblasts followed by a regular dentin bridge.^{74,75} However, Langeland³⁷ cast some doubts on

^b Rorer Dental Mfg. Corp., Boston, Mass.

^c Kerr Mfg. Co., Detroit, Mich.

^d L. D. Caulk Co., Milford, Del.

^e Neo Chemical Products Co., Japan.

the quality of the dentin bridge formed and underlined the risk of residual chronic pulpal inflammation. Zinc oxide eugenol cement seemed to provide more favorable pulp healing than calcium hydroxide, but no complete dentin bridge formed.⁷⁶ Clinical⁷⁷ and experimental⁷⁸ studies apparently substantiated the efficacy of Dycal as a direct pulp capping agent, whereas in pulp exposures of intact rat molars HydreX produced chronic inflammation and pulp necrosis.⁷⁹

In pulpotomies, after sterile amputation of the coronal pulp and calcium hydroxide application on the pulp stumps, Schröder and Granath⁸⁰ observed that in young human premolars after one month a calcific barrier was formed first by an irregular bone-like substance while the last one resembled dentin. In primary teeth, after pulpotomy, dressings of calcium hydroxide or Formalin-containing compounds have been recommended. They were evaluated in primary and young permanent teeth of rhesus monkeys.⁸¹ It seemed that the Formocresol therapy gave results superior to the hydroxide pulp therapy. In incompletely formed pulpless teeth, the relationship of calcium hydroxide paste to continued root formation and absence of inflammatory response in the periapical tissues has been demonstrated in dogs.⁸²

Indirect pulp capping with antibiotics does not seem to be adequate: dentinal application of penicillin⁴⁷ or association with camphorated paramonochlorphenol⁶³ produced pulpal inflammation. Studies with conventional and germfree rats demonstrated that the presence of bacteria is a significant factor in prohibiting healing of pulp exposures.⁸³ The association of calcium hydroxide with vancomycin^f as direct pulp capping agents was more successful than calcium hydroxide alone.⁸⁴ However, the single use of sodium cephalothin^g proved to be too irritating for vital pulp therapy.⁷⁸

Controversial results also have been obtained with corticosteroids used alone or associated with antibiotics. When corticosteroids were used for indirect pulp capping, suppression or reduction of pulpal inflammation without alteration of dentinogenesis

was observed by most authors⁸⁵⁻⁸⁷; in direct pulp capping, persistent inflammation with increased dentinogenesis⁶³ or the absence of dentin formation^{87,88} was noted. In germ-free animals,⁸³ it is interesting to note that application of corticosteroids is neither helpful nor harmful to exposed pulp healing. Most authors observed a persistent chronic inflammation of the pulp with a corticosteroid-antibiotic preparation^h in direct pulp capping.^{63,87}

Preliminary results seemed to indicate that lyophilized⁸⁹ or demineralized⁹⁰ dentin could be better direct capping agents than calcium hydroxide, antibiotics, or corticosteroids.

Base Cements, Liners, and Varnishes

A combination of ZOE is still widely used for temporary fillings and protective bases under permanent fillings. It has been stated that ZOE, like zinc phosphate cement, can be irritating in deep cavities; nevertheless, most testing experiments of materials use ZOE as a control material.

Since ZOE has low compressive strength, different additives have been proposed to reinforce the original formulation. IRMⁱ (a resin-reinforced ZOE), EBA,^j Kalsogen,^k and Cazi^l seemed to be biologically acceptable but also slightly more irritative than ZOE.^{41,91}

It was thought that oxyphosphate cements and copper cements were damaging to the pulp. According to Langeland,³⁷ this is seemingly true for copper cements, but not for oxyphosphate cements. It seemed that the reactions observed were due to overdrying of the cavity. Whereas Plant and Tyas⁹² and Eriksen⁹³ observed mild reaction with Dropsin,^m a modified zinc phosphate, Holz and Baume⁴¹ consider this cement as improper for pulpal protection.

The polycarboxylate cement system, first developed by Smith,⁹⁴ consists of a modified zinc oxide powder and an aqueous solution of polyacrylic acid. Zinc phosphate and polycarboxylate cements appear to have similar properties especially in setting time

^h Ledermix, Lederle Arzneimittel, Cyanamid GmbH, Munchen-Pasing, West Germany.

ⁱ L. D. Caulk Co., Milford, Del.

^j Opatow Dental Mfg. Co., Brooklyn, NY.

^k De Trey, Zurich, Switzerland.

^l National Bureau of Standards, Washington, DC.

^m Svedia, Enköping, Sweden.

^f Vancocin, Eli Lilly Co., Indianapolis, Ind.

^g Keflin, Eli Lilly Co., Indianapolis, Ind.

and pH,⁹² but the latter cement seemed to have better biologic properties and bonding potentials. As a base material on dentin or as luting agents, almost all reports⁹⁵⁻¹⁰⁰ have mentioned mild pulpal reactions with Durelon.ⁿ Only Holz and Baume⁴¹ reported dentin and pulp lesions and even pulp necrosis with Poly C^o after 120 days.¹⁰¹

The intended effects of liners and varnishes are to protect the pulp from chemical irritants of the restorative materials, to prevent marginal leakage and ingress of bacteria, and to ensure thermal insulations. A cavity varnish is a natural gum such as copal, resin, and synthetic resin dissolved in an organic solvent, whereas a cavity liner is a liquid in which calcium hydroxide or zinc oxide or both are suspended in a solution of natural or synthetic resins. Going and Massler¹⁰² found that copal resin varnishes, polystyrene ethylcellulose liner, and calcium hydroxide liners were effective in preventing penetration of radioactive ions into the dentin and pulp. However, it must not be forgotten that *in vivo* dentin surfaces are wet¹⁴⁻¹⁶ and therefore the application of liners or varnishes may not lead to impervious sheaths.^{37,103}

It was found that a vinyl copolymer liner^p was not adequate to protect pulp under composite fillings.^{104,105} Whereas Holz and Baume⁴¹ noticed favorable reaction with cyanoacrylate liners under amalgam fillings, this was not the case under composites. However, in dogs, Tobias et al¹⁰⁶ found that this type of liner was well tolerated and Berkman et al,¹⁰⁷ using isobutyl cyanoacrylate as direct pulp capping agents on human teeth, observed more even healing of the pulp with reparative dentin bridge formation and less inflammation than with calcium hydroxide preparations.

A polystyrene liner^q developed by Zander, Glenn, and Nelson¹⁰⁸ and modified by Brännström and Nyborg^{45,109,110} was found effective in thick layers in protecting pulp under amalgam, silicates, and composite resins^{45,93,109-111} and seemed to be effective against microleakage.

ⁿ ESPE Co., Seefeld, West Germany.

^o Amalgamated Dental Trade Distr., Ltd., London, Eng.

^p 3 M cavity liner, Dental Restorative System, 3 M, St. Paul, Minn.

^q Tubulitec, Dental Therapeutics A/B, Sweden and Buffalo Dental Mfg. Co., Brooklyn, NY.

Permanent Restorative Fillings

Amalgam material, still widely used in restorative dentistry, is not considered injurious to the pulp but requires protection in deep cavities. Microleakage can be reduced with the use of copal varnishes.⁴¹

Despite certain inadequacies such as pulpal irritation, high solubility in oral fluids, poor resistance to abrasion and microleakage, silicates are still appreciated for their remarkable resistance to recurrent dental caries (probably due to their relatively high fluoride content) and for their initial esthetic qualities. Recent investigations still confirmed the necessity for pulpal protection^{101,112} under silicates, even if improved formulas were used.¹⁰¹ However, no agreement has been reached about the cause of the harmful pulpal effects. ³²P of silicate cement tagged with phosphoric acid can penetrate the dentin of monkey's teeth *in vivo*¹¹³ and it could be shown with vital microscopy, on the rat incisor pulp, that silicate liquid penetrated dentin with liberation of CO₂, producing vascular pulpal thrombosis.¹¹⁴ However, buffered phosphoric acid solutions applied to Class V cavities in human teeth produced similar inflammatory changes as distilled water.¹¹⁵ The toxic effects of silicate ions and of phosphates and fluorides of calcium, aluminum, tin, and arsenic also were questioned. The fact that direct application of silicates on dentin produced more severe lesions in human teeth after six months than after one month raised the problem of the poor sealing properties of silicates¹¹⁶; the pulpal effects were due either to mechanical percolation or to the presence of microorganisms between the filling and the cavity walls. With a polystyrene liner applied on the cavity floor and walls, the sealing properties were improved in deep silicate restorations, according to Brännström and Nyborg.¹⁰⁹

Cold-curing unfilled acrylic materials have been condemned because of severe pulpal inflammations and poor marginal adaptation, with risks of recurrent caries. Zinc oxide and eugenol cement cannot be used because of reactivity between eugenol and acrylic material.

However, increasing clinical use has been made of composite resins, based on the original system of Bowen.¹¹⁷ It appears that direct application of these composites

in unlined dental cavities gave rise to mild but persistent pulpal inflammation.^{44,72,104,106,110,111} Zinc oxides are not compatible with composite materials because of discoloration of the restoration¹¹⁸ and some authors think that calcium hydroxide bases are the preferable sealing product.^{72,105,106,118} Holz and Baume⁴¹ and Baume, Fiore-Donno, and Holz¹¹⁹ found that liquid liners or varnishes offer insufficient pulpal protection; they used modified zinc oxide eugenol cements, applying the composites after complete hardening of the base.¹¹⁹ A polystyrene (Tubulitec[†]) reduced the irritative pulpal reaction significantly but not totally.¹¹¹ According to Brännström and Nyborg,⁴⁵ it is not the chemical irritants of the composite that are responsible for the pulpal reaction, but the toxins as a result of trapped bacteria or ingrowth of microorganisms through microleakage. They apparently obtained satisfactory results with a microbicidal cleanser, Tubilicid, and a polystyrene liner (Tubulitec) before inserting the composite. Further evaluation of this procedure and consideration of the prevailing importance of microleakage seem necessary.

Since enamel and dentin surfaces of a cavity may be covered by debris, saliva, and dentinal fluid that exudes from cut tubules, an acid cleansing and etching treatment, which would facilitate the bonding of composite resins (Enamelite[‡] and Restodent[§]) was recommended. According to Lee, Jr. et al,¹²⁰ a treatment for one to five minutes with 50% citric acid or 50% phosphoric acid produces only a superficial dentin etching without penetration of acids along tubules. It must be said that short treatment of intact enamel fissures with 50% phosphoric acid followed by application of a fissure sealant[†] did not induce any pulpal reaction.¹²¹ The use of cavity cleansers on the walls of dentin cavities seemed to induce moderate to severe pulpal reactions.¹²²⁻¹²⁴ The use of Enamelite, without prior etching, in unlined Class V cavities in monkeys, produced mild inflammatory response.¹²⁵ However, further biological evaluation of these products is necessary.

Conclusions

Because of the increased number of new drugs and materials, biological tests with well-standardized methodology are necessary. Important progress has been made in the fields of pulp capping agents, base materials, and permanent fillings. Almost all these materials produce moderate to severe reactions because of chemical irritation or of bacterial toxins, or both, in contact with dentin and pulp. However, the control of dentinal-pulpal reactions must not become an academic, histological exercise that loses the point of view of clinical dentistry. It is biologically evident that the contact of any drug and material with cytoplasmic cell processes will induce odontoblastic alterations and transient inflammatory reactions. The purpose of biological testing is not to overstate these normal reactions, but to check the recovery potentials of the pulp and the absence of persistent inflammation.

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