endodontics

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Therapeutic induction of root formation in the exposed incompletely formed tooth with vital pulp

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It is suggested that root canal treatment subsequent to pulpotomy which has resulted in completion of root formation is indicated only when a post and core are required for adequate restoration of the crown of the tooth.

The primary objective in the management of the incompletely formed tooth with a vital pulp which has been exposed by either trauma or caries is to induce continued root formation. The treatment of choice in vital teeth is vital pulpotomy. Even dentists who otherwise have objections to and/or reservations about pulpotomy for the completely formed vital permanent tooth concur. When root formation is complete, most general dentists and endodontists subsequently intervene with pulpal extirpation and obturation of the root canal space. We suggest that root canal treatment subsequent to pulpotomy which has resulted in completion of the root formation is indicated only when a post and core are required to adequately restore the crown of the tooth. This article deals with the salient biologic considerations for a technique of pulpotomy and, further, with

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the basis for the opinion that root canal therapy is not routinely indicated subsequent to the completion of formation of the root apex.

For the present discussion, *vital pulpotomy* is defined as the amputation of the entire coronal pulp, which is followed by the application of a dressing to the radicular pulp at the orifice(s) of the canal(s). In addition to induction of continued root formation, the procedures are performed to promote healing of the remaining pulp, to stimulate the growth of new dentin, to maintain the vitality and the integrity of the pulp tissue, and to protect the pulp from additional irritation.

Pulpotomy is indicated in the vital tooth with an open apex when the radicular pulp is still sound. On the clinical level this is determined by (1) a normal radiographic appearance; (2) the absence of sensitivity to percussion; (3) no more than momentary response to thermal changes; (4) no more than a small, beadlike serous or purulent exudate; (5) no odor; and (6) no more than a reasonable amount of hemorrhage at the exposure site which will clot within normal limits.

The final clinical verification is made when the roof of the pulp chamber is dissected off and the odontoblastic membrane can be visually inspected. When the membrane is intact beneath the dissected dentin, it indicates that the degenerative processes have not progressed to such an extent in the coronal pulp as to cause disruption of the membrane. Under such circumstances, it is unlikely that the degeneration extends into the radicular tissue.

Pulpotomy is preferable to pulp capping because it is more frequently successful for the incompletely formed cases where the pulp is exposed by trauma or caries. In the case of pulpotomy, the dressing is placed within the confines of the pulp chamber, where it is protected by the overlying cement base, and therefore the remaining pulp is not recontaminated even if the temporary restoration is lost. With pulp capping, the loss of the temporary restoration results in the loss of the dressing and subsequent pulpal contamination and possible consequent failure.

Since maintenance of the vitality and function of the radicular pulp is obviously desirable in order to achieve completed root formation, the nonvital or formocresol pulpotomy is contraindicated because most of the remaining pulp tissue is fixed or mummified.

Pulpotomy is contraindicated in the tooth with an open apex when the radicular pulp has undergone pathologic changes. Clinically, this is determined by the presence of any one or a combination of the following conditions: (1) necrosis of the pulp; (2) sustained pain after the application of heat; (3) throbbing toothache; (4) an odor noted upon opening the pulp chamber; (5) a degenerated membrane seen upon the removal of the roof of the pulp chamber; or (6) a pathologic periapical radiolucency related to the pulp.

THE VITAL PULPOTOMY

Vital pulpotomy should be instituted as soon as possible after exposure by fracture or the removal of caries, in order to minimize contamination of the pulp. The clinical considerations in a pulpotomy procedure include (1) obtaining profound anesthesia; (2) isolation of the tooth from contamination; (3) modification

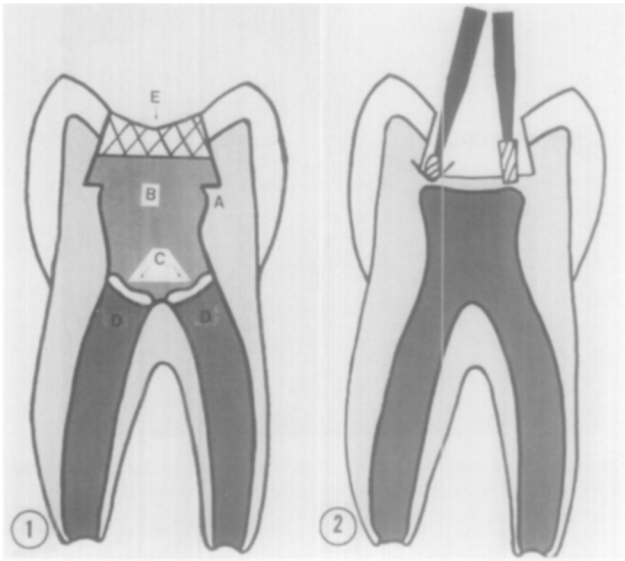

Fig. 1. Diagram showing the cavity preparation extended beyond the outline of the pulp chamber, and thereby providing a shelf *(A)* for support of the cement base *(B)* and keeping its position secure in order to prevent displacement of the underlying dressing *(C)* into the radicular pulp *(D)* when the final amalgam restoration *(E)* is condensed.

Fig. 2. Diagram showing the use of a No. 6 round bur *(left)* to penetrate the dentin and to begin the dissection of the roof of the pulp chamber. Only a small part of the sphere should penetrate the dentin, whereas the remainder is supported by the hard tissue. The fissure bur *(right)* does not get such support and is therefore more likely to "fall" into the chamber.

of the steps of cavity preparation; (4) access for amputation; (5) amputation of the coronal pulp tissue; (6) control of hemorrhage; (7) the choice of the pulpal dressing—and its protection; (8) the immediate placement of the final restoration; and (9) criteria for success.

1. *Profound anesthesia* is imperative to ensure the patient's comfort and cooperation. Two per cent lidocaine hydrochloride with epinephrine 1:50,000 is recommended because it provides the desirable depth and duration of anesthesia and reduces hemorrhage. Depending on the location of the tooth, the anesthesia may be obtained through infiltration or block. On occasion, it may be necessary to use a supplementary periodontal ligament, palatal, or lingual injection. Injection directly into the pulp should be avoided because this procedure can cause the contaminants in the coronal pulp tissue to be forced into the radicular pulp, in addition to tissue laceration.

2. *Isolation of the tooth* to prevent contamination is most readily accomplished through the use of the rubber dam. The inclusion of only one tooth is recommended in order to minimize the risk of leakage. However, in cases in which it is desirable to include adjacent teeth in order to facilitate the insertion of the final restoration, this is permissible provided that such inclusion does not result in seepage.

3. *Modification of the steps of cavity preparation* is necessary to enhance vision, to prevent contamination of the pulp with dentin dust, and to provide a shelf of dentin on which to support the cement base that protects the underlying

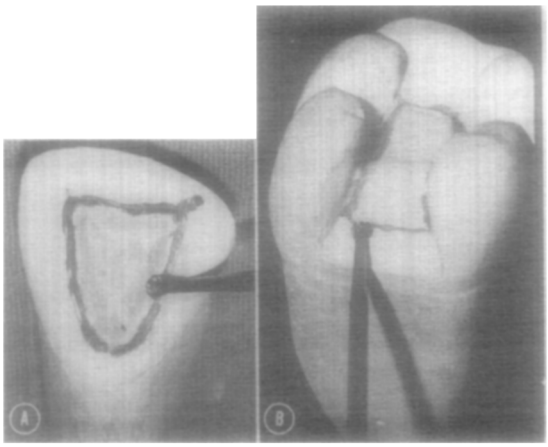

Fig. 3. Models showing the outline of the dissection separating the central island from the peri-pulpal shelf in an incisor *(A)* and a molar *(B)*.

pulpal dressing. All the steps of cavity preparation should be accomplished in sequence, except that prior to exposure of the pulp, all caries should be removed from the side walls of the cavity, and the toilet of the cavity should be completed. Convenience form for pulpotomy involves removal of a sufficient amount of occlusal tooth structure to facilitate greater visibility, the subsequent dissection of the roof of the pulp chamber, and the amputation of the coronal pulp tissue. The floor of the cavity preparation should extend peripherally to the outline of the pulp chamber, approximately 1 to 2 mm. throughout as the thickness of dentin permits, to provide a shelf for the support of the protective cement base so that, when the final restoration is condensed, the base is secure and will prevent the displacement of the underlying dressing into the remaining pulp (Fig. 1).

4. *Access for amputation* is accomplished by the careful dissection and removal of the roof of the pulp chamber. The dissection is accomplished by circumscribing the dentin overlying the pulp chamber, thereby leaving an island of dentin resting on the odontoblastic membrane. A No. 4 or No. 6 round bur should be used for this dissection, as shown in Fig. 2, *left,* where the penetration into the chamber will occur with only a small part of the rotating sphere while the remainder is supported by dentin, thus preventing the bur from "falling into" the coronal pulp. Such support is not obtained with a fissure bur, with which penetration is apt to involve the total cutting end surface (Fig. 2, *right*). When the line of penetration has been extended along the outline of the underlying pulp chamber, it separates the peripheral dentin shelf from the central dentin island, as shown in Figs. 3, *A* and *B,* and 4, *A*. Laceration and contamination of the underlying pulp are minimized by this approach.

Prior to removal of the remaining island of dentin, toilet of the cavity is repeated to be sure that all dentin dust and debris have been removed. The importance of this step is emphasized by the finding in a histologic study that the forcing of sterile dentin fragments into the pulp of a caries-free tooth results in failure of the pulp to heal.[1] The mere presence of dentin dust or fragments produced inflammation with an accumulation of lymphocytes and plasma cells. Any

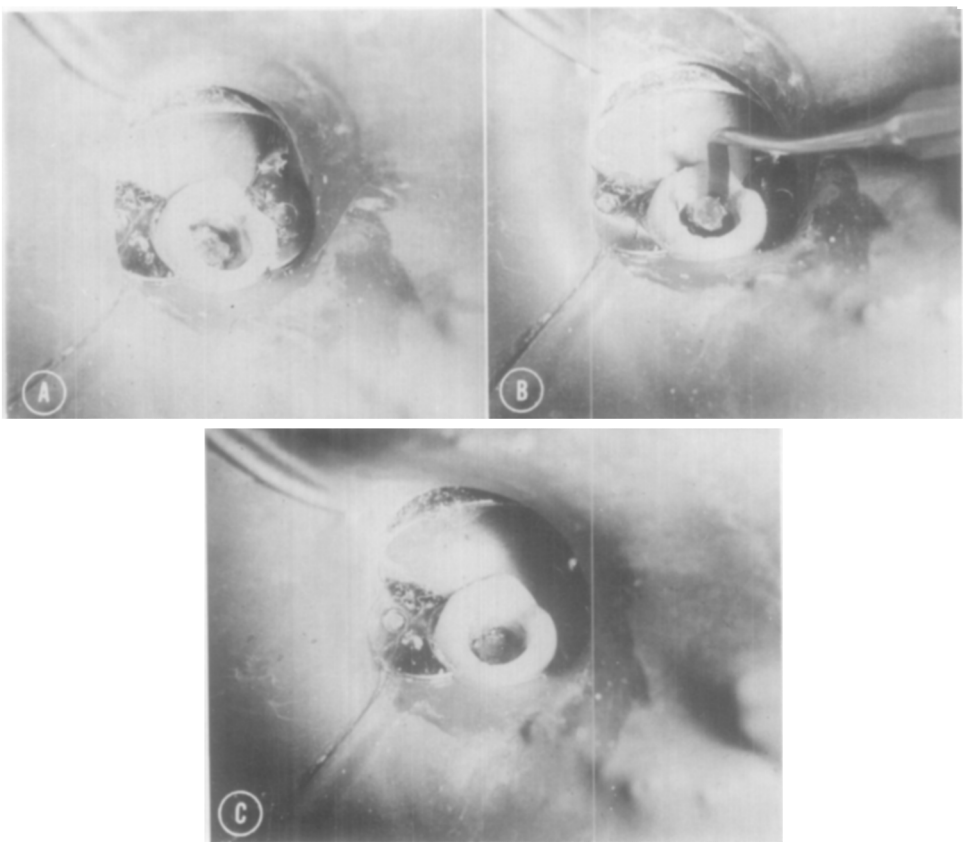

Fig. 4. Clinical case showing the outline of the dissection separating the central island from the peripheral shelf *(A)* and the removal of the island of dentin with a spoon excavator *(B)*. The odontoblastic membrane becomes apparent after the removal of the dentin island *(C)*. The intact membrane is shiny, firm, resilient, and purplish-gray in color, and no bleeding is evident.

reparative dentin formed after the application of calcium hydroxide to a pulp contaminated with dentin dust was defective. The removal of the island of dentin is accomplished with a spoon excavator (Fig. 4, *B*), which affords an opportunity to inspect the underlying pulp surface. A healthy, intact, odontoblastic membrane appears as a shiny, glossy sheath that is purplish-gray in color (Fig. 4, *C*). It is firm and resilient. When slight pressure is applied, it returns to its original shape. Bleeding does not occur until the membrane has been punctured. If, however, the membrane is no longer firm and resilient, degenerative changes may have extended into the radicular pulp, and the case should be handled as one of necrosis with an open apex.

5. *The amputation of the coronal portion of the pulp* is accomplished with a sharp, long-shank spoon excavator, which is teased down the wall of the chamber opposite the initial point of exposure, to the level of the orifices of the root canals in posterior teeth, and to the level of the cervical line in anterior teeth. A horizontal incision across the orifice(s) separates the pulp tissue so that the coronal part can be lifted out of the chamber. In this manner, contamination from the

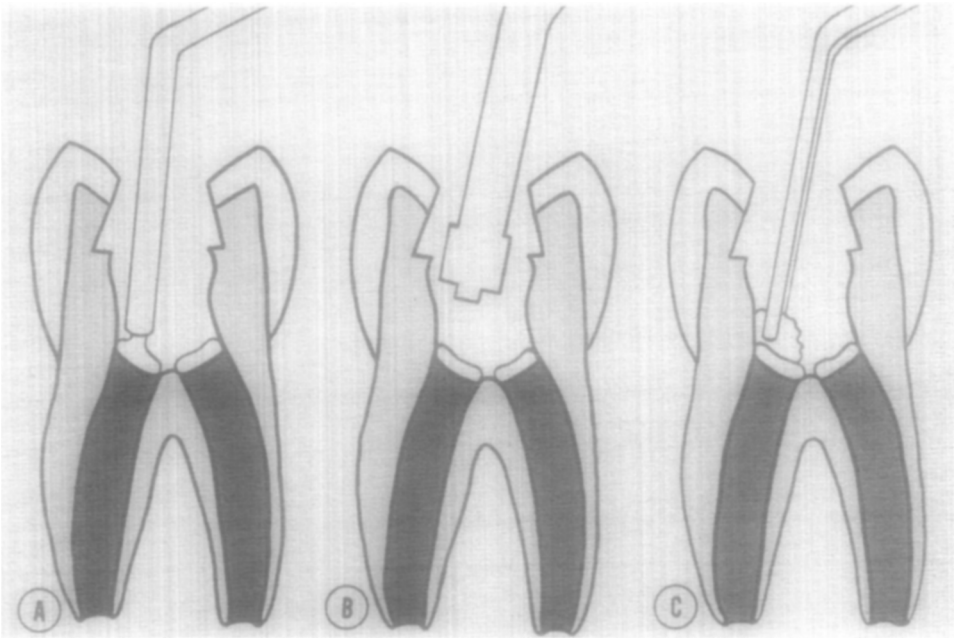

Fig. 5. Diagrams showing the placement of the dressing. A layer of calcium hydroxide, approximately 2 mm. in thickness, is placed over the radicular pulp stump, with use of a syringe *(A)*. An air syringe is used to produce a gentle stream of air over the dressing to create a surface crust *(B)*. When the crust has formed, a sterile cotton pellet is used to gently compress the dressing to ensure contact with the radicular pulp *(C)*.

original exposure site is less likely to occur than when the coronal pulp is teased away in the area of the exposure site prior to the amputation. The use of a rotating round bur for the amputation is not recommended because this approach can force contaminants into underlying tissue and twist and agitate the remaining pulp.

6. *Control of hemorrhage* from the small amount of pulp tissue that is incised at the orifices is not usually a problem. Hemorrhage is easily controlled by inserting dry sterile cotton pellets into the pulp chamber with slight pressure, leaving these in place long enough to allow normal clotting to occur. At no time should escharotic agents be used to control the hemorrhage. However, irrigation with chlorinated soda may be helpful.

7. *The choice of the pulpal dressing and its protection* greatly influences the success of the treatment. A review of histologic findings in many studies indicates that calcium hydroxide is the best agent available to stimulate the deposition of new dentin, and/or the completion of root formation.[2]

The use of aqueous methyl cellulose as the vehicle for the calcium hydroxide (Pulpdent* pulp capping agent) makes the dressing adhesive and cohesive and therefore easier to handle. Aqueous methyl cellulose further reduces the amount of irritation that calcium hydroxide would cause if used with plain sterile water, thereby enhancing the formation of new dentin.[3] A layer approximately 2 mm. thick is applied directly over the remaining pulp tissue with the syringe. A gentle

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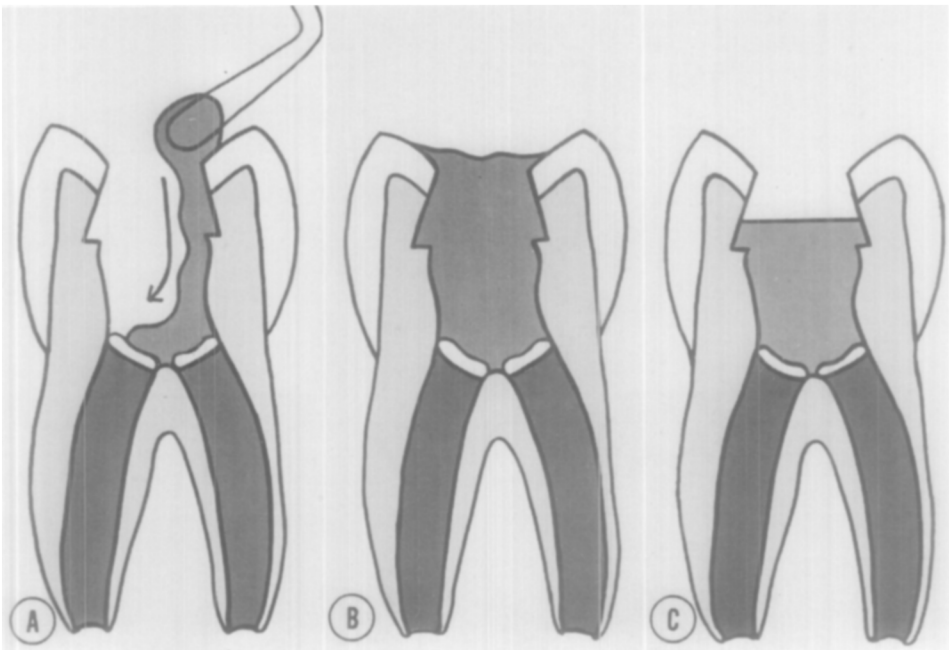

Fig. 6. Diagrams showing the placement of the protective base. A thin creamy mix is applied along one wall so that it flows apically to cover the dressing without entrapment of air *(A)*. Cement is added in the same manner until the cavity is completely filled *(B)*. The cavity outline is reestablished after the cement has set completely *(C)*.

stream of air should be used on the surface to create a crust and to thicken the paste. At this point a dry cotton pellet is used to gently compress the calcium hydroxide to ensure contact between the dressing and the amputated pulp surface. In the absence of a crust, the dressing will adhere to the pellet as it is withdrawn. The clinical steps are shown in Fig. 5, *A-C*. A cement base is applied to seal the dressing into place and to protect it. The cement, applied as a thin creamy mix, is permitted to flow down one side of the preparation, then over the dressing so as to cover it, and then over to the opposite walls without entrapment of air or exertion of pressure against the dressing. Cement should be added in this manner until the cavity is totally filled, and the cement should be allowed to set completely before the cavity outline is re-established, as illustrated in Fig. 6 *A-C*. It is important to avoid forcing any of the dressing into the underlying pulp, where it may cause calcification deep in the pulpal tissue. Histologic evidence demonstrates that such calcifications do occur deep in the canals when the calcium hydroxide has been forced into the stroma of the pulp.[4]

8. *The final restoration* re-establishes the tooth contours and function. Placement is made during the same visit in order to reduce the risk of losing the cement base, with the consequent contamination of the radicular pulp. The role of occlusal function in continued root formation is not known.

9. *The criteria for clinical success include* continued root formation and completion of the root apex, maintenance of the vitality of the pulp, and stimulation of a new layer of dentin at the orifice of the canal. The rehousing of the pulp within hard tissue protects it from irritation and contamination. However, even

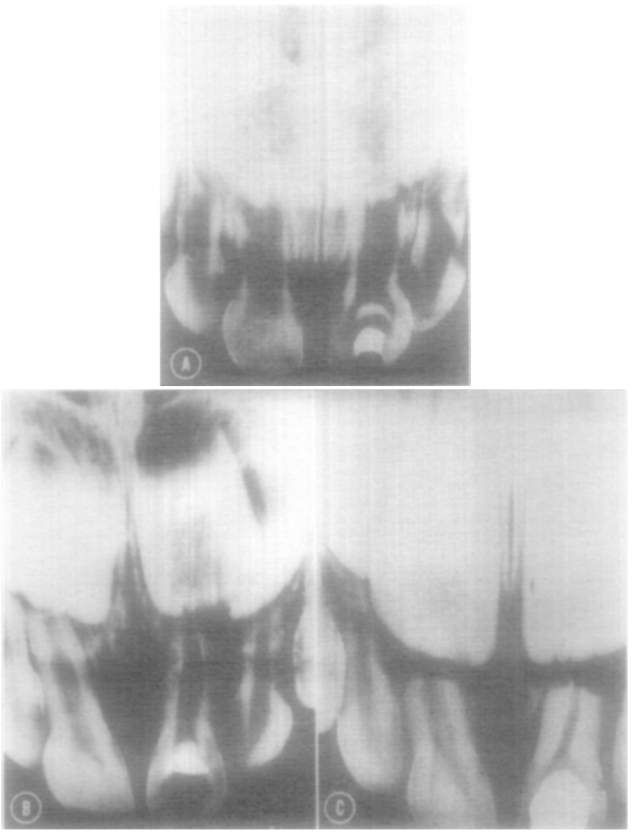

Fig. 7. Clinical case showing successful induction of root formation in a primary incisor. *A,* Radiograph taken 1 month after pulpotomy performed when the patient was 9 months old. A dentin bridge has already formed. Note the incomplete root. *B,* Radiograph taken at age 3 years. There is increased dentin deposition in the crown and the root is completely formed so as to closely resemble the contralateral tooth. *C,* Radiograph taken at age 7 years showing normal physiologic resorption of primary central incisors.

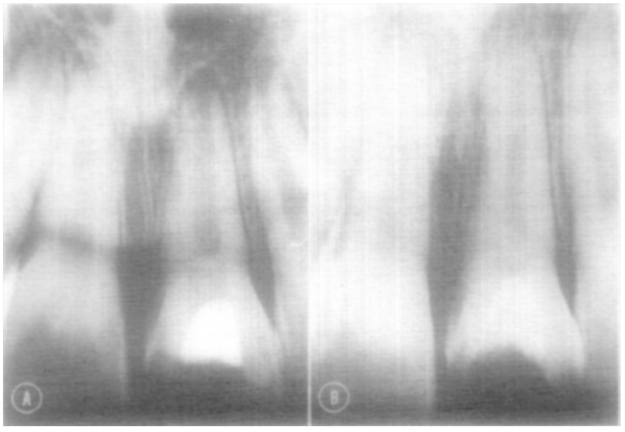

Fig. 8. Clinical case showing successful induction of root formation in a permanent incisor. *A,* Radiograph taken 3 months after pulpotomy. A dentin bridge has formed and the root formation is incomplete. *B,* Radiograph showing completed root formation.

if a new layer of dentin is not formed, the treatment is considered to be successful if the pulp remains vital long enough to complete root formation. Clinical cases involving treatment of an incompletely formed maxillary primary incisor in a 9-month-old child[5] and of a maxillary permanent central incisor in a 7-year-old child are shown in Figs. 7, *A-C* and 8, *A* and *B*, respectively.

CONSIDERATIONS FOR THE NEED FOR ROOT CANAL THERAPY SUBSEQUENT TO COMPLETION OF ROOT FORMATION

As previously mentioned, many dentists institute root canal treatment upon the completion of the formation of the root apex. One reason for this approach is the belief that the pulpotomy procedures might cause calcification of the canals after completion of the root formation, which makes endodontic treatment more complicated if it becomes necessary. The fact that calcification of canals of completely formed teeth is often associated with trauma should not be considered as evidence that the incompletely formed tooth will invariably go on to complete calcification subsequent to root maturation. Calcification of canals has occurred infrequently in our experience. We suggest, therefore, that the concern that the same thing might occur after apex formation could be handled best by periodic radiographic examination. Such an approach would reveal the development of calcification in its early stages and would allow the limitation of root canal therapy to only those cases in which calcification was occurring. Many endodontists may have the impression that pulpotomy leads to pulpal calcification because they see previously pulpotomized teeth that are highly calcified at the time they first see them. All too frequently pulpotomy is attempted in teeth in which the canals are already calcified. Actually, such previously existing calcifications should be considered to be contraindications.[6] When such cases fail and are referred to an endodontist for treatment, he often erroneously attributes the calcification to the use of calcium hydroxide. A high percentage of teeth in older patients seen by general practitioners every day have canals that are extremely calcified without any history of exposure to calcium hydroxide as a cavity liner or pulp-capping agent. On the other hand, we do recognize that the introduction of calcium hydroxide into the stroma of the pulp can lead to calcification. However, the technique that we have proposed avoids forcing the dressing into the remaining pulp, in order to prevent this undesirable result.

A second reason for subsequent endodontic intervention is the contention that the pulp will undergo necrosis after completion of the root apex, and that the success rate for endodontic treatment of teeth with necrotic pulps is lower than the success rate for treatment of teeth with vital pulps. In our experience, the vitality of the pulp in a majority of these cases appears to be maintained. Furthermore, in spite of all the extensive work done to determine the success rates of vital pulp therapy and endodontic procedures, no standardization of the criteria for success has yet evolved in either category. Reviewing the literature, Berk and Krakow[6] concluded that pulpotomy and complete endodontic procedures enjoy comparable high rates of success. Consequently, only a very low percentage of pulpal necrosis would occur because of failure of pulpotomy procedures after the completion of root formation. Therefore, the fear of pulpal necrosis as a sequel to vital pulp therapy and root formation does not constitute

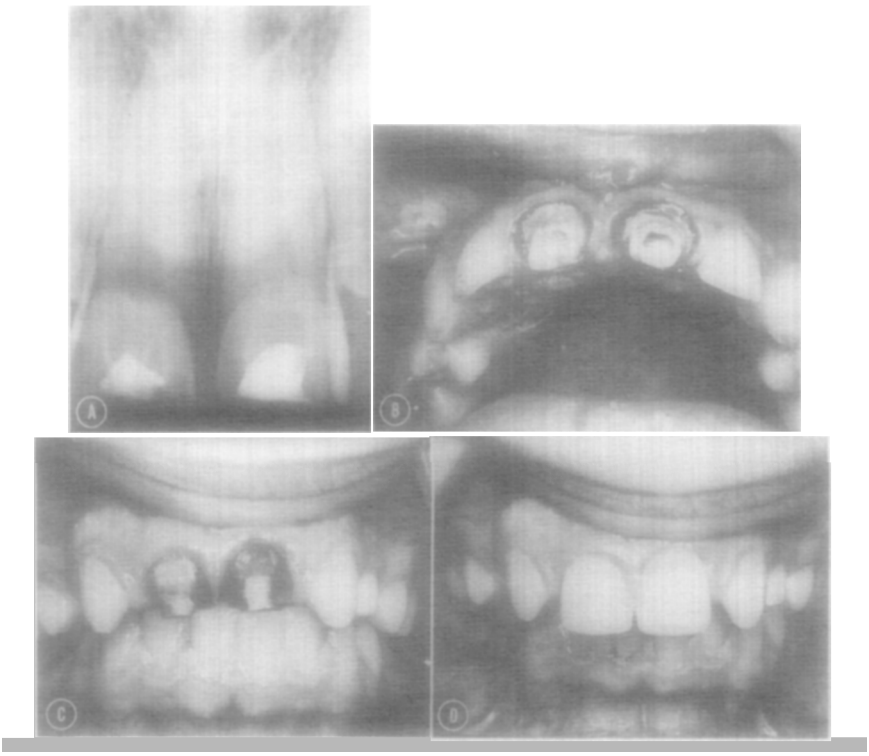

Fig. 9. Clinical case showing restoration of pulpotomized incisors with cast cores and crowns, without endodontic intervention subsequent to complete root formation. *A*, Radiograph taken after completion of root formation. The dentin bridges are apparent. *B*, Intracoronal preparation for the cast cores has been accomplished, extending to the dentin bridges. A calcium hydroxide liner has been applied in preparation for cementation. *C*, The crown preparations are completed after cementation of the cores. *D*, The permanent crowns are cemented in place.

a valid indication for routine root canal treatment in these instances. If one considers the large percentage of cases in which the need for complete endodontic treatment would be obviated, the difference between the success rate for endodontic procedures in vital cases (92 per cent) and that in necrotic cases (76 per cent)[7] becomes insignificant.

A third reason why many endodontists routinely perform endodontic therapy subsequent to the completion of the root apex is that they believe that the new dentin bridges formed may contain dead tracts and poorly mineralized areas that lead to the underlying tissue. This can be seen histologically, but one may question the clinical significance. There are dead tracts in all dentin, and dentin is permeable. The fact that dead tracts and porosity have been seen histologically in these dentin bridges is, therefore, not an indication for routine endodontic therapy.

Even if a tooth has undergone a pulpotomy to induce completion of root formation and thereafter needs to be restored with a full crown that requires a core, it is not necessary to routinely institute root canal therapy. Such a case is shown in Fig. 9, *A-D*. In this instance, cores were fabricated which gained their reten-

tion and support within the pulp chamber coronal to the dentin bridges formed after pulpotomy. Additional retention, if needed, may be obtained by the use of pins. The dentin bridges were covered with a calcium hydroxide liner for protection of the pulp prior to cementation of the cores, as is indicated for any newly cut dentin. The crowns were completed and cemented subsequently.

The present study led to the following conclusions concerning the clinical management of the tooth with an exposed vital pulp and an open apex: (1) Vital pulpotomy is the treatment of choice. (2) Realization of successful completion of the root depends upon a technique predicated upon sound biologic principles. (3) Root canal therapy after root maturation is not routinely indicated.

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