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Review of the success of pulp exposure treatment of cariously and traumatically exposed pulps in immature permanent incisors and molars

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SUMMARY

The decision to retain immature permanent tooth with pulp disease is problematical. Restoring the tooth would normally involve some form of pulp capping/pulpotomy procedure or a more radical pulpectomy and root canal treatment.

Pulp capping/pulpotomy procedures, where all or part of the pulp is retained, relies upon an accurate assessment of the pulp condition, and the careful management of the remaining healthy tissue. Pulpectomy or root canal treatment is technically difficult as the root apex is open with the result that conventional preparation and filling techniques are compromised. On the other hand, the inappropriate extraction of immature teeth with pulp disease will result in immediate aesthetic and functional difficulties that may require the patient to have orthodontic or restorative care that will have potential life-long implications, e. g. removable or fixed prosthesis. The aim of this article is to provide an overview of the aetiology of pulp disease in immature teeth and to review current evidence of the outcome of conservative pulp treatment.

Key words: non-formed apices, immature teeth, partial pulporomy, $Ca(OH)_2$ pulpotomy, MTA pulpotomy.

DENTINE-PULP COMPLEX – REACTION TO CARIES AND TRAUMA

The ability of the pulp to form reparative dentine is a mechanism that protects pulp tissues from bacterial toxins diffusing from carious lesions. The amount of reparative dentine produced is proportionally equal to the amount of dentine destroyed previously (1). The factors change dentine permeability includes alteration to the odontoblastic processes that occurs in dentinal tubules and the lining of the tubules, the lamina limitans. Dentinal sclerosis under caries lesion reduces the permeability, thus decreasing the quantity of irritants that are introduced into the pulp (2). The inflammatory reaction of the pulp develops long before it is actually infected. Before the inflammation appears in the pulp tissues, there are changes in the odontoblastic layer, in the form of a reduction in the number and the size of odontoblasts (1). The extent of pulpal inflammation beneath caries depends on the depth of bacterial invasion, the degree of dentinal sclerosis and reparative dentine formation. The inflammation includes vascular and cellular responses; vasodilatation increases blood vessel permeability leading to the accumulation of leukocytes . Neutrophils migrate from blood vessels to the injury site. These elements appear when complement is activated in the presence of antigen-antibody complexes. Histologically cariously exposed pulp has micro-abscess formation under the penetrating caries (3).

Physical trauma of teeth results in dentinal fluid desiccation that may cause sufficient damage to the pulp and its blood supply to result in inflammation. This immediate response results in the production of endogenous inflammatory mediators, that is, kinins, neuropeptides and prostaglandins, which increase vascular permeability, blood stasis, and leukocyte extravasations (4). The resultant compromised circulation may lead to haematogenous pulpal infection. In severe trauma with the immediate interruption of the blood supply, the pulp becomes necrotic without

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bacterial invasion. In this situation the optimal time for treatment is within the first 24 hours, when pulp inflammation is superficial (5).

TREATMENT PLANNING

Retaining immature teeth

Retaining immature permanent teeth may present endodontic and restorative problems. Restorative treatment is difficult because (6):

- the apex is immature and open;
- there is thin root dentine;
- the dentine tubules are large and patent;
- the pulp volume is large and the canal is wide;
- there is a short clinical crown leading to an adverse crown-root ratio.

The success of conventional root canal treatment and filling in mature teeth is dependent on a closed apex against which the correct working distance can be measured, the canal prepared and the gutta percha condensed. In immature teeth, there is no apical stop and instead of normal flared shape of the canal, the walls of the root canal are parallel or even wider at the apex than the coronal level. Canal preparation requires large instruments and in some cases conventional cold gutta percha filling may not obdurate the canal fully. Even after root filling has been achieved, there is still risk of failure; the thin dentine walls may not be strong enough to support a post and adhesive crown-ratio of the immature tooth means that the length of post is insufficient to support a crown. It has been shown that endodontic preparation can significantly diminish resistance to coronal-radicular fracture (6).

When there is a poorer long term prognosis for the first permanent molars and the crown cannot be restored they are usually extracted (7).

Extracting immature teeth

There are potential restorative and orthodontic problems in managing space, should the tooth be lost. The replacement of a lost immature incisor by a simple denture until the occlusion has stabilized i.e. with all the permanent dentition present will often mean that the child has to wear a denture for a period of up to five years. The prosthesis needs to be regularly checked and adjusted to allow the eruption of adjacent teeth. There is also the aesthetic and social disadvantages of an active child wearing a denture which may well bring unwanted attention to his/her dental handicap extracted (7).

The extractions of immature permanent molars cause orthodontic problems in the management of buccal segment spaces. Satisfactory results may be achieved by extractions only in Class 1 cases with mild crowding, providing the timing of the extraction is correct. It is accepted that "early" extraction, which is at a dental age of 8-9 years when the bifurcation of second molar is calcifying, will frequently allow eruption of the mandibular second permanent molar into a good relation with the mandibular second premolar. In the maxillary arch, timing is less critical. There are, however, disadvantages to first permanent molar extraction; they are (8):

- with no crowding, the results of spontaneous tooth movements are usually disappointing, especially in the mandibular arch;
- in the mandible, unless there is spontaneous space closure following first molar loss, the familiar narrow "knife edge" alveolar ridge can occur;
- third molars are the most frequently congenitally absent teeth (35%) followed by the second premolar. Lack of either of these teeth would normally be a contraindication to first molar extraction;
- if there is only one molar with poor prognosis the need for balancing and compensating extractions must be explored. Unless crowding is localized to the quadrant in question, balancing extractions should be performed to preserve arch symmetry;
- the first molar, by virtue of its root surface area, is the best anchor tooth; the second molar root surface area being 15-25% less than the first molar.

The second molar's inferior anchorage potential is strained by the movement of the two premolars prior to what would be the commencement of "normal" orthodontic treatment. Loss of all first molars leads to a reduction of overjet in Class I and Class III cases; complex appliance therapy may be necessary (9). Guidelines for first molar extraction in order to achieve the most beneficial spontaneous results have been enumerated (10), but with any biological system there will be cases where the anticipated result is not achieved or the guidelines cannot be fulfilled. In both these situations more complex treatment and/or further tooth loss may be required for satisfactory results (8).

The review of dental problems associated with tooth loss and root canal treatment is outlined above suggests that an alternative approach would be discussed. The maintenance of pulp vitality of immature permanent teeth will help reduce the needs for extensive treatment and avoid root fracture even after successful apexogenesis which causes the tooth loss.

Such methods of treatment as pulp capping, partial and cervical pulpotomy can help to prevent the appearance of these problems (5, 11).

DRESSING MATERIAL

Calcium hydroxide ($Ca(OH)_2$)

The tissue reaction and out come of treating exposed pulp with calcium hydroxide has been intensively studied. When calcium hydroxide is applied to a pulp exposure, it causes superficial cell death with the result that adjacent tissues loose their architecture and liquefication necrosis occurs with squeal coagulation necrosis (12). These tissues become diffusely calcified, beneath which there is hard tissues formation (12, 13); a dentine bridge occurs at the junction of necrotic and vital inflamed tissues (1). It is believed that calcium hydroxide works as a low-grade irritant to stimulate the formation of hard tissue bridge (14). Underlying tissues react to irritant by producing collagen, which is partially mineralized; coagulated tissues are calcified and differentiation of dentine occurs (11). Sometimes, in spite of dentine bridge formation, chronic inflammation continues, and the pulp becomes necrotic cause of presence of blood clot or the formation of an abscess within the inflamed pulp tissues. In these cases root canal treatment is indicated (15).

Other agents have been used as an alternative to calcium hydroxide, including glutaraldehyde and glutaraldehyde/calcium hydroxide combinations (16, 17). It is important to avoid the appearance of a blood clot between the surfaces of the wound and the dressing (5). It was conceivable that blood clot between wound surface and dressing material inhibits the effect of calcium hydroxide on exposures site and it can act as a substrate for the bacteria if there is the lack of the restoration (14).

Substantial work has been completed on mixing calcium hydroxide with corticosteroid/antibiotic mixtures (Ledermix) for use in the pulpotomy technique. The corticosteroids act as inhibitors for the proliferation of mezenchymal cells, and dentinogenesis (18). Delay in healing occurs only in the first days of wounding. Once healing is established, corticosteroids loose their effect (19). The addition of corticosteroid has been stated to improve the effect of calcium hydroxide in reducing the inflammatory process. It was suggested that the addition of corticosteroid/antibiotic material to calcium hydroxide aided the maintenance of vitality, especially in very young teeth affected by advanced caries. However some reports indicate that there is no significant difference between the outcome in older and younger age groups (20, 21); indeed the good results in older teeth could be explained by the fact that only the coronal pulp tissues became inflammed while degenerative process spread to the radicular pulp in young newly erupted teeth (21).

Mineral Trioxide aggregate

MTA is composed of tricalcium oxide, tricalcium silicate, and tricalcium aluminate. Hydration of powder results in a colloidal gel composed of calcium oxide crystals in an amorphous structure. This gel hardens in less than three hours. MTA has demonstrated the ability to form the hard-tissue barrier over the exposed pulp. Compared with calcium hydroxide MTA has a greater ability to maintain the integrity of pulp tissues. Histologically the dentinal bridge is thicker with less inflammation less hyperemia and less pulp necrosis compared to calcium hydroxide. MTA also promote the development of dentine bridge at the faster rate than calcium hydroxide does. The process by which MTA reacts with tissues fluids forming and inducing dentine bridge is not known, but Holland et al, thought that MTA with tissue fluids are producing calcium hydroxide crystals, resulting in the appearance of hard-tissue barrier in a way that calcium hydroxide does. MTA shows the antibacterial effect on some facultative bacteria but no effect on strict anaerobic ones, but this effect is less effective than with calcium hydroxide. The ability of MTA to resist the penetration of bacteria appears to be high. The presence of blood over the exposed site has little impact on the degree of leakage (22).

Portland cement (PC)

Recently it has been reported that both MTA and Portland cement (PC) seem almost identicalmacroscopically, microscopically and by X-ray diffraction analysis. They reported that both substances support matrix formation in a similar manner in cultures of osteoblast-like cells, and also apposition of reparative dentin when used as a direct pulp capping material in rat teeth. Other authors reported that the Portland cements contain the same chemical elements as MTA, except that MTA also contains bismuth. Over the last years, studies have compared healing effects and the composition of PC with those of Mineral trioxide Aggregate (MTA). Regarding the healing effects, it was observed that osteoblast-like cells had similar growth and matrix formation when growing on set PC, while otherauthors noted that PC allowed dentin bridge formation after pulpotomy on dogs and induced calcite crystal granulations deposition when placed in dentin tubes that were implanted subcutaneously in rats. Moreover, it has been demonstrated that PC and MTA have a similar effect on pulp cells when used as a direct pulp-capping material in rats as well as comparable antibacterial activity. Such similarities in healing effects induced by these cements may be related to the similarities in their composition. PC has major ingredients in common with MTA such as calcium phosphate, calcium oxide, and silica. MTA also contains bismuth oxide, which increases its radiopacity and is absent in PC. However, because of the low cost of the cement, it is reasonable to consider PC as a possible substitute for MTA in endodontic applications. In summary, the findings of this study support the idea that PC has potential to be used as a pulp capping material wich is capable of inducing short-term mineral pulp response. Further, long-term studies are necessary before unlimited clinical use can be recommended (23, 24).

Potassium Nitrate (KNO_3), Dimethyl Isosorbide (DMI), Polycarboxylate (PCA) cement

KNO_3 is superior desensitizer for hypersensitive teeth. Used with PCA it serves as an effective liner for deep carious lesions and as a temporary cement (KNO_3/zinc oxide eugenol) to reduce pain following crown preparation. Dmi, as an osmotic agent, helps KNO_3 to reach more rapidly the dentinal and pulp nerves and connective tissues, causing profound tooth desensitization by nerves hyperpolarization due to osmotic cell shrinkage. There are pulpal nerves of central nervous system that conduct pain and an abundance of nerves of the autonomic nervous system that modulate its microcirculation. KNO_3/DMI also working as an anti inflammatory agent preventing intrapulpal pressure from rising. PCA cement has very thin film thickness and bonds firmly to the tooth structure, is capable of withstanding the overlying pressure during restoration procedures. KNO_3/PCA cement was used for saving pulp vitality and eliminating the incidence and severity of post restoration pain. Used in combination with KNO_3/DMI it continues to effective releasing KNO3 and DMI into the dentinal tubules over time. Capping exposed pulps with $Ca(OH)_2$ in mature permanent teeth appears unreliable procedure, because formed dentinal barrier is situated between cavity floor and exposed pulp that provides protection from chemical and physical trauma, and there is no enough strength to be saved from drying and cracking afterwards, reducing possibility to be used as a lining. Another limitation is inability of $Ca(OH)_2$ to bond to tooth structure, also not solving the problem of intrapulpal edema and pressure atrophy, leading to pulp extripation and endodontic therapy or extraction (25). As if only one study was using this material over the exposed pulp performing direct pulp capping procedure further research is necessary in order to determine the true outcome.

Total etch technique

The most popular material for pulpotomy and pulp capping has been calcium hydroxide but recently there has been great interest in using “total-etch” technique (26-28). The first research has been done on mechanically exposed pulp capped with “so-called toxic materials”; pulps capped with tightly sealed surface materials showed little or no inflammation, migration of pulpoblasts, dentine matrix formation and in some cases complete healing. Pulp capped with lack of tight restoration showed inflammatory response in pulp tissues and became necrotic (29). The reports stated that the failure occurred cause of the presence of bacteria (27, 29). The latest study found out that irreversible injury to the odontoblasts closest to the site of the cavity resulted in the death of these cells which was followed by neutrophilic, macrophage and fibroblastic responses, that led to the deposition of dentine and/or a hard tissue barrier formed by the remaining unaffected odontoblasts. In additional, the presence of resin particles observed in the dentine-pulp complex and directly in the pulp seemed to be a trigger, similar to foreign body, in stimulating the inflammatory mononuclear infiltrate as well as the appearance of multinuclear giant cells (26). This unresolved inflammation was associated with the lack of the reparative bridge formation (29). But some study reported that the failure occurred using “total-etch” technique not cause of presence or absence of bacteria in hard tissue barrier formation, vital or non-vital teeth. They stated that bacterial presence had no direct influence on the success or failure of pulp capping procedure (28). At present less than 25% of the pulps capped by this method demonstrate bridge formation (30). Promising results of animal experiments using growth factors may provide a more biological approach in the future (31, 32).

Biomaterials

Calcium enriched mixture (CEM)

Recently, a new experimental cement (NEC) in the name of calcium-enriched mixture (CEM) cement (BioniqueDent, Tehran, Iran) consisting of different calcium compounds such as calcium oxide, calcium phosphate, calcium carbonate, calcium silicate, calcium sulfate,calcium hydroxide, and calcium chloride was developed. CEM is a tooth-colored water-based cement with similar clinical applications as MTA, but with different chemical composition and has exhibited proper sealing ability, antimicrobial properties similar to those of calcium hydroxide, hard tissue induction properties and shorter setting time, greater flowability and lower film thickness compared to MTA. Although the chemical composition of CEM is different from that of MTA, they have similar clinical applications. When CEM is used for pulp capping or as a root-end filling material results have been similar to those achieved with MTA. CEM is composed of various calcium components, which provide a rich reservoir of calcium and phosphorus ions. These elements have a role in the process of hydroxyapatite formation, which is a natural product of dental pulp cells. This property, similar to the reaction explained in the case of MTA, might have a role in the biocompatibility of CEM. Scanning electron microscopic studies have shown that the distribution pattern of calcium, phosphorus and oxygen in the CEM as a root-end filling material is similar to that of surrounding dentin (33).

Enamel Matrix Derivative (EMD)

The major constituent of EMD is amelogenin, a family member of hydrophobic proteins derived from a single gene by alternative splicing and controlled postsecretory processing. It is the major organic component in the enamel matrix of developing teeth and plays an important role in enamel biomineralization. It is specifically detected in ameloblasts, but several studies have also detected it in odontoblasts and might induce the differentiation and maturation of odontoblasts. The amelogenin is also known to self-assemble into supramolecular aggregates that form an insoluble extracellular matrix with high affinity for hydroxyapatite and collagens. A study comparing the effect of EMD with calcium hydroxide as a direct pulp capping agent in pigs demonstrated a significantly more pronounced formation of secondary dentine in teeth treated with EMD (34). But in the other study after 6 months, healthy pulps capped with Ca(OH)2 had more favorable results than counterparts capped with EMD gel (35).

TREATMENT MEHTODS

Direct pulp capping

Direct pulp capping involves the placement of a medicated dressing on the pulp exposure and is indicated when a healthy pulp has been exposed during an operative procedure or trauma. The tooth has to be asymptomatic, and the exposure site has to be pinpoint and free of contamination (11). If there is trauma, the interval before first treatment must be short (<24 h.). Usually the dressing material placed over the wound is calcium hydroxide; the cavity is then sealed to prevent microleakage. The success of pulp capping procedures relies on the ability of calcium hydroxide to disinfect the superficial pulp and dentine. The quality of the bacteria-tight seal provided by the restoration is also an important factor in successful pulp capping. Recontamination through restoration microleakage reduces the success of the procedure (5); in such a situation calcium hydroxide looses its antibacterial effect leading to a hard tissue barrier which has structural defects, increasing dentine permeability and provides the potential for of bacteria to gain direct contact with the underlying pulp (11).

The reported success rate of pulp healing for incisors is 80%, and for molars – 40-50% (5, 11). Some study has been done on the dependence of success rate from age, sex, teeth, spontaneous pain, size of exposure and bleeding; calcium hydroxide has been used as a dressing material. No significant influence on the success rate of previously mentioned factors was found except that less bleeding rises up the healing of pulp tissues (36). Recent research gives a possibility to use bonding agents as a dressing materials, but the results are not clear (25, 29, 37).

Partial pulpotomy

Partial pulpotomy was advocated by Cvek (38), and involves the removal of sufficient diseased coronal pulp tissues (about 2 mm) to leave a healthy pulp then exposure site is covered with calcium hydroxide and tightly sealed with restorative material. It is indicated in mature and immature teeth, with a pulp exposure size that is more than pinpoint (5). Cell rich coronal pulp tissue, a necessary element for better healing, is thus preserved and aids the defence reaction of the pulp to resist further bacterial contamination (32). This method applies equally to the treatment of pulpally exposed immature anterior and posterior teeth (39-42). Compared with direct pulp capping, because both methods make minimal trauma for pulp, it is obvious that partial pulpotomy has the following advantages (5):

- superficially inflamed pulp is removed during the cavity preparation;
- calcium hydroxide disinfects dentine and pulp;
- space provided for the material gives the opportunity to seal the cavity tightly.

The previously mentioned advantages give a possibility for pulp healing to be more successful (Table

1). The reported success rate for incisors is 94-96% and for molars 93-94% (11, 34, 39).

Cervical pulpotomy

Cervical pulpotomy involves removal of the entire coronal pulp to a level of the root orifices. It is indicated when inflammation has spread to the deeper levels of the coronal pulp and traumatic exposure after 72 hours (5). Usually the pulp wound is dressed with calcium hydroxide, and then sealed with restorative material. Since the cervical pulpotomy is performed in cases of deep inflammation

Table 1. Teeth treated by partial pulpotomy

Author	No of teeth	Dressing material	Examination period	Success rate (%)
Cvek M, 1978 (38)	60 incisors 28 – im; 32 – mt	$Ca(OH)_2$	14-60 months	96
Klein H et al., 1985 (52)	34 incisors 7-22 y.o.	$Ca(OH)_2$	7-36 months	94
Fuks A et al., 1987 (43)	63 incisors 10 – im; 53 – mt	$Ca(OH)_2$	6-36 months	92
Springer-Nodzak M et al., 1989 (44)	56 incisors 7-15 y.o.	$Ca(OH)_2$	6-12 months	85
Cvek.M, 1993 (45)	169 incisors	$Ca(OH)_2$	3-15 years	95
Fuks A et al., 1993 (46)	40 young incisors	$Ca(OH)_2$	7,5-11 years	88
Calişkan M et al., 1993 (47)	1 incisor 7 y.o.	$Ca(OH)_2$	14 months	100
de Blanco LP, 1996 (54)	30 incisors 7-42 y.o.	$Ca(OH)_2$	8 years	100
Blanco L, Cohen S, 2002 (57)	40 incisors	$Ca(OH)_2$	12-144 months	100
Karabucak B et al., 2005 (58)	2 incisors 9 y.o.	MTA	18 months	100
Sonmez IS, Sonmez H, 2007 (59)	Incisor – im; 7 y.o.	$Ca(OH)_2$	84 months	100
Abarajithan M, Velmurugan N, Kandaswamy D, 2010 (64)	Incisor 15 y.o. Incisor 25 y.o.	MTA MTA	24 months 24 months	100 100
Calişkan MK, Savranoğlu S, 2010 (66)	Incisor	$Ca(OH)_2$	36 months	100
Emine ST, Tuba UA , 2011 (67)	2 incisors – im; 9 y.o. 1 incisor – im; 8 y.o.	MTA MTA	54 months 24 months	100 100
Zilberman U et al., 1989 (40)	15 molars 7-17 y.o.	$Ca(OH)_2$	12-99 months	93
Mass E et al., 1993 (41)	35 molars 7-25 y.o.	$Ca(OH)_2$	48 months	91
Mejare I et al., 1993 (42).	37 molars 15 – im; 22 – mt	$Ca(OH)_2$	24-140 months	94
Mass E et al., 1995 (56)	1 molar 7.9 y.o.	$Ca(OH)_2$	41 months	100
Nosrat I et al., 1998 (39)	6 molars 10-27 y.o.	$Ca(OH)_2$	26 months	100
Qudeimat MA, Barrieshi-Nusair KM, Owais AI, 2007 (60)	51 molar 6.8-13.3 y.o.	$Ca(OH)_2$ MTA	25.4 – 45.6 months	91 93
Mass E, Zilberman U, 2011 (69)	49 young molars 6.9-17.7 y.o.	$Ca(OH)_2$	7-154 months	93.3

im – immature teeth;
mt – mature teeth.

of the pulp, the site of pulp amputation is arbitrary and it is probable that errors have therefore been made in the treatment of this degree of inflamed pulp with the result that there is a reduced success rate of 72-79% (11). (Table 2).

DIFFERENT VARIABLES IN TREATMENT METHODS

Age of patient

Most of the authors were trying to provide their treatment to children within the age group 7-16 year olds for incisors (22, 38, 43, 44-50,).

The age groups stated were diverse, the youngest being 7 years and the oldest 42 years. In those studies where the age range was not stated, the patients were described as "children" or the developmental stage of treated teeth was described in terms of immaturity and maturity. The number of subjects included in studies varied enormously with the smallest being 1 (47, 50) and the largest 169 respectively (45). Comparing the success rate for immature and mature teeth, no difference has been found in pulp healing.

Etiology and duration of the pulpal exposure

These methods are indicated for treating asymptomatic teeth. Some authors treated teeth with temporary pain (22, 42) and hyperplastic pulpitis (47, 50, 51, 66), and teeth with the periapical involvement (53, 68). The success rate did not differ between all of these cases. All teeth were treated within different time periods following the accident. The success rate was not affected by the wide range of duration of pulpal exposure.

Type of local anaesthetic agent

The one author who treated teeth with local anaesthetic solution without vasoconstrictor, to avoid

Table 2. Teeth treated by cervical pulpotomy

Author	No of teeth	Dressing material	Examination period	Success rate (%)
Fuks A et al., 1982 (55)	38 incisors 7-14 y.o.	Ca(OH)2	6-36 months	92
Ravn J, 1982 (48)	142 incisors 7-15 y.o.	$Ca(OH)_2$	17-44 months	90
Gelbier M et al., 1988 (49)	175 incisors im	$Ca(OH)_2$	6-168 months	79
Calişkan M, 1994 (50)	1 molar 15 y.o.	$Ca(OH)_2$	7 years	100
Calişkan M, 1993 (51)	24 molar 10-24 y.o.	$Ca(OH)_2$	12-48 months	93
Waly NG, 1994 (16)	15 molars children	$Ca(OH)_2$	5 years	93
Calişkan M, 1995 (53)	26 molars 10-24 y.o.	$Ca(OH)_2$	16-48 months	92
Waly NG, 1995 (17)	20 molars children	$Ca(OH)_2$	5 years	100 80
Barrieshi –Nusair KM et al., 2006 (63)	28 young molars	MTA	12-26 months	79
Whiterspoon DE et al., 2006 (22)	23 incisors and molars 7-16 y.o.	MTA	6-53 months	95
Nosrat A, Asgary S, 2010 (65)	Molar – im; 12 y.o.	CEM	12 months	100
Asgary S, 2011 (68)	Molar – mt; 15 y.o.	CEM	24 months	100
Asgary S, 2011 (68)	Molar – mt; 15 y.o.	CEM	24 months	100
Asgary S, Eghbal MJ, 2012 (71)	208 molars; 205 molars;	MTA CEM	12 months 12 months	95-98 92-97
Nosrat A, Seifi A, Asgary S, (70)	25 molars; 26 molars;	MTA CEM	12 months 12 months	73.8-76.8

im – immature teeth;
mt – mature teeth.

circulatory disturbance, found no influence on the success rate (47, 50, 51, 53).

Rubber dam

Rubber dam is strongly advocated when any of vital pulp therapy methods are used. One author compared treatment with and without rubber dam and found no influence on the success rate (39).

Cervical or partial pulpotomy

All authors used the recommended techniques for partial or cervical pulpotomy. For pulp removal, all used a high-speed handpiece with adequate water cooling so as not to overheat the pulp (16, 17, 22, 38-56, 57-71). For partial pulpotomy, all practitioners removed pulp tissues 1-1.5 mm for the incisors and 2-3 mm for the molars (38-47, 52, 54, 56, 57, 59, 60, 64, 66, 67, 69). For cervical pulpotomy all practitioners removed pulp to a level of the root orifices (16, 17, 48-51, 53, 55, 65, 68, 71).

Rinsing solution

One author rinsed the pulp wound with non-sterile water in contrast to sterile solutions used by all other authors. There was no influence on the success rate which in fact was 100% (39).

Solution of 6% Sodium Hypochlorite was used in order to stop pulp bleeding showing no difference in the success rate of pulp healing (22). Other authors were using chlohexidine for rinsing pulp exposure site (64, 68) showing no changes in the success rate.

Dressing material

Most of the authors used calcium hydroxide for the wound dressing (38-55, 57, 59, 66, 69). One practitioner used calcium hydroxide mixed with gluteraldehyde and had a 100% success rate (16, 17).

Have been several studies using MTA in partial pulpotomy technique in human permanent molars (22, 59, 60, 71). Several studies showed no significant difference in clinical presentation and histological status between groups treated with calcium hydroxide and MTA (58-60, 71). Concerning pulpotomy technique performed on permanent teeth authors reported similar clinical and radiographic success for MTA and calcium hydroxide as pulpotomy agents in immature permanent teeth, concluding that MTA was a suitable alternative to calcium hydroxide (58-60).

Recent studies were using new biomaterial such as CEM (65, 68) and comparing it with MTA (71, 70) showing rather high success rate of pulp healing.

More recent research has reported the use of the total etch technique in human teeth. The success of this technique is still not clear and further research is necessary in order to determine the true outcome.

8. Evaluation criteria

All authors evaluated success using the following criteria (11):

– no clinical symptoms;
– demonstrable radiographic intraradicular or periradicular pathological changes;
– continued root development in immature teeth;
– radiographically observed and clinically verified continuous hard tissue barrier;
– sensitivity to electrical stimulation.

All authors defined what they considered to be a successful result and all authors used radiographs as an integral part of the evaluation process with tight coronal seal, the exposed dental pulp has capacity to maintain vitality and build a new dentinal bridge.

Despite the progress in reduction of caries development in children in Riga, the aims proclaimed by the WHO for 2000 year have not been achieved, and children of early age may suffer from caries in just erupted permanent teeth followed by inflammation of pulp if left untreated. Lithuania also showed little tendency towards a decline in the prevalence of dental caries (72).

Notwithstanding so many variables, vital pulp therapy has proven to be repeatedly successful and should therefore be recommended routinely for the pulpal exposure of immature permanent teeth.

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