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AN UPDATE ON MATERIALS USED FOR VITAL PULP THERAPY IN PRIMARY TEETH: A REVIEW

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ABSTRACT
Dental caries is the most common cause of pulpal disease. As the carious processadvances, the pulp undergoes various morphologic and histologic changes. Pulpal disease induced by dental caries can occur before bacteria actually invade the pulp. Caries disease progresses more quickly in primary teeth because of their anatomical characteristics. Bacterial infection resulting from caries lesion contaminates the dentin and reaches the pulp and periradicular tissues, causing inflammatory reactions, tooth resorption, and periradicular lesions with abscesses. The resorption caused by chemical mediators and by-products ofbacterial metabolism cause a devastating effect on primary teeth if not properly treated, leading to a rapid destruction of the tooth between cemento-enamel junction and furcation. Most of the protocols used to treat endodontically compromised primary teeth simply reflect the non-observance of infection on the part of the practitioners, for they only consider pulpotomy for teeth with signs of pulp inflammation or necrosis without preparing the root canals biomechanically. The treatment for carious lesion approaching the pulp or involving the pulp of primary teeth vary from indirect pulp capping to pulpectomy depending upon the infection rate and progress. The current article illustrates on the materials that are used in treating vital pulp therapy i.e, indirect pulp capping, direct pulp capping, pulpotomy in primary tooth.

INTRODUCTION

Dental caries is a multifactorial disease caused by alteration in the composition of the bacterial biofilm, leading to an imbalance between the demineralization and remineralisation processes and manifested by the formation of caries lesions in primary and permanent dentitions. Pulpal disease induced by dental caries can occur before bacteria actually invade the pulp. The consequences of such an infection in a primary tooth can have repercussions on the permanent dentition, ranging from enamel hypoplasia and partial or total interruption in the succeeding tooth formation to localized or generalized occlusal imbalance in the permanent dentition.

Reeves & Stanley found that bacteria needed to be within 1.1 mm of the pulp before significant inflammatory changes were observed in the pulp. They also observed that once the carious lesion was within 0.5 mm of the pulp, the

degree of pathosis increased. However, evidence of irreversible pathosis was not observed until the reparative dentin was invaded.

The goals of pulp therapy:

- Conservation of tooth in healthy state of functioning
- Preservation of the arch space
- Enhance aesthetics
- Mastication
- Prevention of deleterious effects on succedaneous tooth and periapical tissue.

INDIRECT PULP CAPPING:

A procedure in which only the gross caries is removed from the lesion and the cavity is sealed for a time with a biocompatible material **(McDonald).**

ADVANTAGES AND DISADVANTAGES OF VARIOUS PULP CAPPING AGENTS[1]:

Pulp capping agent	Advantages	Disadvantages
Ca $(OH)_2$ (1960's)	Gold standard antibacterial properties Induction of mineralization Low cytotoxicity	Highly soluble in oral fluids Extensive dentin formation obliterating the pulp chamber Lack of adhesion Presence of tunnels in reparative dentin
Zinc oxide eugenol cement (1960-70's)	Reduces inflammation	Lack of calcific bridge formation Releases eugenol in high concentration-cytotoxic Demonstrate interfacial leakage
Corticosteroids and antibiotics (1970's)	Reduces pulp inflammation Vanocmycin + $Ca(OH)_2$ stimulated a more regular reparative dentin bridge.	Should not be used in patients at risk from bacteremia.
Polycarboxylate cement (1970's)	Chemically bond to the tooth structure	Fail to stimulate calcific bridge formation
Collagen (1980)	Less irritating than Ca $(OH)_2$	Does not help in thick dentin bridge formation
Bonding agents (1995) 4-META-MMA-TBB adhesives	Superior adhesion to hard tissues Effective seal against microleakage.	Have cytotoxic effect Absence of calcific bridge formation *In vivo* studies showed dilatation and congestion of blood vessels as well as chronic inflammatory pulpal response
Calcium phosphate (1900's)	Helps in bridge formation with no superficial tissue necrosis significant absence of pulp inflammation compared to $Ca(OH)_2$	Clinical trials are necessary to evaluate this material
Hydroxyapatite (1995)	Biocompatible Act as scaffold	Mild inflammation with superficial necrosis
Lasers (1995-2010) CO2 Nd: YAG	Formation of secondary dentin sterilization of targeted tissue Bactericidal effects	Technique sensitive Causes thermal damage to pulp in high doses
Glass ionomer/Resin modified glass ionomer (1995)	Fluoride release, coefficient of thermal expansion and modulus of elasticity similar to dentin Bond to both enamel and dentin Good biocompatibility	Causes chronic inflammation Lack of dentin bridge formation Cytotoxic when in direct cell contact RMGIC is more cytotoxic than conventional GIC, so it should not be applied directly to the pulp tissue
Mineral trioxide aggregate (1996-2008)	Good biocompatibility Less pulpal inflammation More predictable hard tissue barrier formation Radiopacity Releases bioactive dentin matrix proteins	More expensive Long setting time Grey MTA causes tooth discoloration High solubility
MTYA1-Ca (1999)	Helps in dentine bridge formation	Presence of 10%

	without formation of a necrotic layer Shear bond strength is higher than conventional GIC and similar to RMGIC Dentin bridge formation without reduction of pulp space in MTYA1-Ca, but there is reduction of pulp space is seen in dycal.	$Ca(OH)_2$ interferes with complete curing of material, residual monomers causes cytotoxicity
Growthfactors (1900-2007) (BMP 2,4,7) IGF, FGF,PDGF,TGF-β 1	Formation of osteodentin and tubular dentin Dentin bridge formation was equal to dycal after 28 days Only TGF-β1 induced reparative dentin formation	Fail to stimulate reparative dentin in inflamed pulp Half -life is less High concentration is required Delivery vehicles used for the molecules show potent effects Possibility of immunological problems due to repeated implantation of active molecules
Biodentin (2000)	Good antimicrobial activity. Stimulate tertiary dentin formation Stronger mechanically, less soluble and produces tighter seals compared to $Ca(OH)_2$	More long-term clinical studies are needed
ENZYMES Heme-Oxygenase-1 (2008) Simvastatin (2009)	Prevent H_2O_2induced cytotoxicity and oxidative stress in human dental pulp cells. Anti- inflammatory action, angiogenesis Improve the function of odontoblasts	Further in vitro and in vivo studies are required Careful evaluation is required before clinical application.
STEM CELLS (2009) (DPSCs) SHED	Regeneration of dentin-pulp complex SHED is superior to DPSCs	Less economic Technique sensitive
Propolis (2005-2010)	Antioxidant, antibacterial, antifungal, antiviral and anti-inflammatory properties Stimulate reparative dentin formation	Showed mild / moderate inflammation after 2,4 weeks with partial dentinal bridge formation.
Novel endodontic cement (2010)	Biocompatible Shorter setting time Induced a thicker dentinal bridge with less pulp inflammation than MTA	Further assessment is required for evaluation of pulp response to this material in inflamed pulp.
Emdogain (2001-2011)	Promote odontoblast differentiation and reparative dentin formation Suppresses the cytokine production	EMD gel-applied on exposed pulps without the adjunctive pulp-capping material was ineffective in producing a hard tissue barrier
Odontogenic ameloblast associated protein (2010)	Biocompatible Accelerates reactionary dentin formation Normal pulp tissue appearance	Till now only in vitro study was conducted.
Theracal (2012)	Act as protectant of the dental pulpal complex Used as a replacement for $Ca(OH)_2$, glass ionomer, RMGI, IRM/ZOE and other restorative materials	It is opaque and “whitish” in colour, it should be kept thin so as not to show through composite

It can be inferred from above materials that none can fulfil all the criteria essential for indirect pulp capping, like homogenous dentin bridge formation, predictable setting time, no tooth discoloration. However, further clinical studies have to be reviewed for superiority of a material over other. Calcium hydroxide is still considered to be the gold standard because of its cost and easy availability.

DIRECT PULP CAPPING: It is defined as the placement of a medicament or non-medicated material on a pulp that

has been exposed in course of excavating the last portions of deep dentinal caries or as a result of trauma.(Kopel).
The materials used for direct pulp capping are:

Zinc Oxide Eugenol (ZOE):
Glass and his colleagues introduced ZOE for DPC showed chronic inflammation, lack of pulp healing, no dentin bridge formation, high toxicity, high interfacial leakage[2]
One human clinical study showed chronic inflammation, no pulp healing and no dentin bridge formation up to 12 weeks post-operatively.

Glass Ionomer (GI)/Resin-Modifed Glass Ionomer (RMGI):
Glass ionomer's ability to chemically bond to tooth structure, excellent bacterial seal, good biocompatibility can prevent the diffusion of potentially toxic materials through dentin to the pulp when used in close approximation but not in direct contact with the pulp.

Adhesive Systems:
Adhesive systems were suggested for use as a potential direct pulp capping agent approximately 12-15 years ago. The adhesives are synergistic, due to direct cytotoxic effects on pulp cells, difficulty in obtaining an adequate seal to protect against bacterial contamination and reduce the pulp's immune response. Toxicity is seen in both multi- and single-component adhesive systems, and the unpolymerized components are more toxic than polymerized.

Calcium Hydroxide:
Calcium hydroxide has a longterm track record of clinical success as a direct pulpcapping agent in periods of up to 10 years. Calcium hydroxide possesses antibacterial properties, high pH, release bio-active molecule, quality of reparative dentin improving as bridge gets thicker.The disadvantages are high solubility, no adhesion, tunnel defects.

Mineral Trioxide Aggregate: Primary reaction product of MTA with water is calcium hydroxide- similar actions to calcium hydroxide. Significant difference is the fact that MTA provides some seal to tooth structure. The disadvantages are high solubility, prolonged setting time, handling characteristics, expensive. Most of the human studies show similar pulp-cap outcomes of MTA and calcium hydroxide. Few authors stated, "The outcomes suggest that MTA is a more predictable pulp-capping material than calcium hydroxide."

Calcium sulfate hemihydrates:
Ulusoy AT et al evaluated the clinical and radiological response of primary molars and stated that it was found to be as successful as calcium hydroxide for direct pulp capping[3]

Aloevera:
Songsiripradubboon et al evaluated clinical and radiographic response stated success rate of direct pulp capping with calciumhydroxide and aloevera were 72.3 and 70% respectively[4].

Paula AB et al compared effectiveness of biomaterials like mineral trioxide aggregate (MTA) cement vs calcium hydroxide cement, tricalciumsilicate cement vs MTA cement, and adhesive systems vs CaOH cement, evaluated that MTA showed higher success rates and adhesives showed least success rates. [5]
AAPD guidelines have inferred that DPC is not recommended for primary teeth due to its failure rate. However, use of few biomaterials have shown high success rate.

PULPOTOMY: It is defined as complete removal of coronal portion of the dental pulp, followed by placement of a suitable dressing or medication that will promote healing and preserve the vitality of the tooth. (Finn 1995)

Classification[6]: (Ranly)

Types	Other name	Features	Examples
Vital Pulpotomy			
Devitalisation	Mummification, cauterization	Mummify or destroy the vital tissue	Formocresol Electro surgery Laser <u>Two stages:</u> Gysi/tyro paste, Easlick's, formal dehyde, Paraform devitalizing paste ZnO paste, Gluteraldehyde Ferric sulphate
Preservation	Minimal devitalisation, non-inductive,	Maintains the maximum vital tissue	ZnO eugenol Gluteraldehyde Ferric sulphate

Regeneration	Inductive, reparative	Formation of dentin bridge	$CaOH_2$ Bone morphogenic protein MTA Enriched Collagen Freezed dried bone Osteogenic protein
Nonvital Pulpotomy			
Mortal pulpotomy		Done in compromised cases	Beechwood cresol Formocresol

Formocresol pulpotomy:

It is a bactericidal and devitalizing agent. It kills off and converts bacteria and pulp tissue into inert compounds. Its function is to fasten the live pulps, maintaining them inert and facilitating the conservation of deciduous tooth until their physiologic fall. It has a potent antibacterial action that justifies its use in long curative in endodontic treatment[7].

Histologically, a zone of fixation usually is evident; coagulation necrosis of the tissue occurs at the amputation site and is produced by poisons such as phenol, formaldehyde or mercuric chloride, which denatures the protein of the cells. In contrast, Berger reported complete loss of vitality with fibrous granulation tissue in the apical third of the root canal[8]. Studies on formocresol therapy have put the clinical success rate between 70% and 90%. Pruhs et al. found a relationship between primary teeth treated with formocresol and enamel defects in the permanent successors[9].

Calcium hydroxide:

The high pH of calcium hydroxide wounds the pulp in a manner that permits the intrinsic reparative cascade to begin. Unfortunately, the stimulus evoked by this compound is delicately balanced between one of repair and resorption[10].

Schröder emphasized on the importance of avoiding a blood clot between the amputation site and calcium hydroxide for clinical success. Calcium hydroxide adequately controls pulpal haemorrhage, to permit good contact between medicament and pulpal tissue. This seems to be important in the prevention of internal resorption, post-pulpotomy[11].

Mineral trioxide aggregate:

Torabinejad et al., Bates et al. and Fischer et al. evaluated the sealing ability of MTA in root canals. MTA is currently being used in pulp therapy has superior biocompatibility and is less cytotoxic and has good seal over the vital pulp than other materials currently used in pulp therapy.

It stimulates the release of cytokines and production of interleukin and induced hard tissue formation. Some of the main disadvantages are discoloration, costs and accessibility. MTA has also shown to revascularize and promote dentin-like tissue formation in several clinical situations[12].

A histological study stated that white MTA had shown intact and continuous odontoblastic layer. While cases treated with white MTA showed dentine bridge formation along with inflammatory cells and areas of partial necrosis, more clinical and radiographic failures were seen with white MTA.

Gluteraldehyde pulpotomy:

It was first suggested by S Gravenmade and was introduced by Kopel 1979. It produces rapid surface fixation of the underlying pulpal tissue. A narrow zone of eosinophilic, stained and compressed fixed tissue is found directly beneath the area of application, which blends into vital normal appearing tissue apically.With time, the gluteraldehyde fixed zone is replaced by macrophagic action with dense collagenous tissue, thus the entire root canal tissue is vital.

Llioyd et al had studied the histological response of the dental pulp to 0.5, 1, 2% gluteraldehyde applied to monkey teeth for 2, 5 or 10mins. After one day all samples had zone of fixed pulp tissue. After 1 week continuing through 8 weeks, reported moderate chronic inflammation to severe inflammation and internal resorption. The severity of the reaction was due to lower concentration and shorter application time of the medicament. For effective anti-microbial agent a higher concentration of 6.25% applied for more than 5mins[13].

Ferric sulphate pulpotomy:

In dentistry, 15%–20% Ferric Sulphate (FS) is used as an astringent and styptic.FS is a coagulative and haemostatic agent which forms ferric ion-protein complex on contact with blood. It seals the damaged vessels mechanically, thus producing haemostasis, and the capillary orifices are occluded by the agglutinated protein complex, which prevents blood clot formation. It causes a local and reversible inflammatory response to the oral soft tissues. The recommended application time is 1–3 min and should be placed directly against the damaged tissue due to its quick action. Solutions of FS above 15% are highly acidic and may cause considerable tissue irritation and postoperative root sensitivity.

Fei et al. published the first human clinical trial using Ferric Sulphate with 100% clinical success,

compared to formocresol (77%) with 1-year follow-up. Similarly, Fuks et al. reported a study employing FS showing high radiographic success rate of 74.5%[14].

Laser pulptomy:

Lasers have an ability of rapid control of bleeding and coagulation. Ebimara reported the effects of Nd:YAG laser on the wound healing of amputated pulps using Nd:YAG laser at 20Hz and placing intermediate restorative material.

After 28 days, pulp exhibited a zone of edema and infiltrates of chronic and acute inflammatory cells below a zone of fixation and necrosis.Flattened but intact odontoblasts were present along much of the length of the pulp.

After 90 days, a typical pulp exhibited moderate but less concentrated acute and chronic inflammatory cell infiltrate beneath the zinc oxide and eugenol base.Columnar odontoblasts were prominent along the dentin wall[15].

Electrosurgical pulpotomy:

Heller et al. and Oztas et al. had noticed evidence of secondarydentin formation. Increased fibroblastic activity in the middleand apical portions of the roots with early resorption,and ithas been reported that pulpal tissue tries to renewitself with proliferation of fibroblasts.Histologically, inflammatory cells were observed in the coronalthird of the pulp canals, indicating that complete healingcould not be achieved despite dentinal bridges formed.The same finding was found in the study of Oztas[16].

Bone morphogenic protein:

BMP is responsible for bone induction. BMP can be isolated from dentine (Butler, Mikulski and Urist, 1977;) as well as cortical bone (Urist, Mikulski and Lietze, 1979; Hu, 1988).

Histologically, there were regularly arranged, odontoblast-like, polarized columnar cells with round or ovoid nuclei and cytoplasmic processes extending into the newly formed mineralized matrix. This tubular dentine had always been laid down adjacent to the osteodentine, from which osteodentinocytes had almost disappeared and in which there were remnants of their lacunae[17].

Tetrandrine:

It is a novel anti-inflammatory agent. In 1993, Seow and Thong evaluated tetrandrin, and found that, histologically it showed acute inflammation after 3 days and chronic inflammation after 6 weeks.[18]

Collagen:

Collagen has a potent haemostatic property and the ability to aggregate platelets that facilitates wound maturation by enhancing blood clot and fibrin linkage formation. These collagen fibres are able to induce mineral formation and orient hydroxyapatite crystals. The pulp tissue was accompanied by large quantity of extravasated erythrocytes and a large number of newly formed blood vessels. There was disorganization of odontoblastic cell layer along the dentinal surface with no inflammatory cells and dentin bridge formation was observed[19]

Lyophilized freeze dried platelet derived preparation:

Lyophilized freeze dried platelet derived preparation is used as a pulpotomy agent which contained TGF, PDGF, IGF, BMPs. These are signalling proteins that regulates the key cellular processes such as cell differentiation, mitogenesis, and chemotaxis.Animal and human in-vivo and in-vitro studies have shown that these proteins stimulates differentiated cell of pulp to differentiate into odontoblast to deposit a layer of dentin[20].

Enamel matrix derivative:

Enamel Matrix Derivative (EMD) is obtained from embryonic enamel as amelogenin.Ishizaki et al. noted abundant tertiary dentin formation after 8 weeks of EMD pulpotomy.

Similarly, Jumana reported the formation of dentinal bridge the interface between the wounded and unharmed pulp tissue below the amputation site. Jumana and Ahmed reported the clinical success of 93% using emdogain for pulpotomy[21].

Propolis:

Lima et al. following histological analysis concluded that the inflammatory response was less severe, the area of pulp necrosis was smaller, and more frequent formation of a mineralized tissue barrier was evident. Ozorio et al. in their histologic study noted the complete calcific bridge formation in propolis group[21].

Platelet rich plasma:

Platelet Rich Plasma gel (PRP gel) is an autologous modification of fibrin glue obtainedfrom autologous blood used to deliver growth factors in high concentrations. Its biocompatible and biodegradable properties prevent tissue necrosis, extensive fibrosis and promote healing. Platelet rich plasma has been found to work via three mechanisms.

- Increase in local cell division, plateletsbegin to stick to exposed collagen proteins and releasegranules containing adenosine diphosphate, serotonin andthromboxane, all of which contribute to the haemostaticmechanism and the clotting cascade.
- Inhibition of excess inflammation by decreasing earlymacrophage proliferation.
- Degranulation of the agranules in platelets, whichcontain the synthesized and pre-packaged growth factors.

PRP was found to be an ideal material for pulpotomy with low toxic effect, increased tissue regenerating properties and good clinical results. Studies have reported good clinical success rates of pulpotomy using PRP[21].

Pulpotec:

Pulpotec is a newly available radiopaque, non Resorbable paste that is used for pulpotomy treatment. Its mode of action is by cicatrisation of the pulpal stump at the chamber-canal interface, while maintaining the structure of underlying pulp.

Previous histological studies reported no signs of inflammation, but there was a discontinuity in the odontoblastic layer lining along the dentin walls.Pulpotec produces a state of chronic inflammation and pulp necrosis following its application to a vital pulp. It possesses strong antibacterial effect against E. faecalis,Klebsiella spp., Streptococcus spp. and limited effect against Staphylococcus aureus[22].

In asymptomatic pulp exposed primary molars, pulpotomy showed high success rates. However, the success rate declines overtime from 90% to 70% in 3 years. MTA had shown higher long-term success rate (>90%).

Conclusion:

We can conclude in this literature review that:

1. IDPC: Calcium hydroxide is considered as a gold standard because of its cost and easy availability.
2. DPC: Though DPC is not recommended for primary teeth use of few biomaterials have shown high success rate.
3. Pulpotomy: MTA pulpotomyshowed high long term success rate but further randomized clinical trials with large sample size and long-term follow-up must be conducted.

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