ORIGINAL RESEARCH PAPER
Volume - 9 | Issue - 9 | September - 2020 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

PULP CAPPING AGENT- A REVIEW

Dental Science

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ABSTRACT

Pulp capping is a technique used in dental restoration to prevent the dental pulp from dying, after being exposed or nearly exposed during a cavity preparation. There are two types of pulp capping Direct pulp capping and indirect pulp capping. This paper discusses about different types of pulp capping methods and materials used.

KEYWORDS

Cytotoxic, Bacteria, Endodontic, MTA.

INTRODUCTION

The consequences of pulp exposure from caries, trauma or tooth preparation misadventure can be severe, with pain and infection the result. The morbidity associated with treating pulp exposures is consequential, often requiring either extraction or root canal therapy. Both the loss of the tooth and its replacement, or endodontic treatment and tooth restoration, involve multiple appointments and considerable expense. An alternative procedure to extraction or endodontic therapy is pulp capping, in which a medicament is placed directly over the exposed pulp (direct pulp cap), or a cavity liner or sealer is placed over residual caries (indirect pulp cap) in an attempt to maintain pulp vitality and avoid the more extensive treatment dictated by extraction or endodontic therapy (Hilton, 2009). The healthy pulp has good healing potential when it is exposed, although the exact repair mechanism is still undetermined, and it is not material-specific (Lim *et al,* 1987).

TYPES OF PULP CAPPING

There two types of pulp capping

1. Direct Pulp Capping
2. Indirect Pulp Capping

1. INDIRECT PULP CAPPING

Removal of caries is one of the most basic activities in dentistry. When caries is deep, every restorative dentist is faced with the question of the best way to proceed : is it better to remove all caries regardless of pulpal consequences, or stop and not expose the pulp? When practitioners in a dental PBRN were given a hypothetical scenario that involved this question, only 17% responded that they would stop, leave the remaining caries in place and restore the tooth(Oen *et al,*2007).This procedure, where caries is allowed to remain adjacent to a vital pulp rather than risk pulp exposure, covered with a cavity sealer or liner and restored, is termed an indirect pulp cap. The evidence regarding indirect pulp capping stands in contrast to the response of practitioners, however. Several studies show restored teeth with partial caries removal have equal success compared to restored teeth with complete caries removal. Typically, an initial clinical and microbiological assessment of the caries lesion is carried out, partial caries removal is accomplished and a sealer or liner and the tooth is re-entered and reassessed. Invariably, these studies find that the lesion color has changed from light brown to dark brown; the consistency goes from soft and wet to hard and dry, *s mutans* and *lactobacilli* have been significantly reduced to a limited number or even zero viable organisms, and the radiographs show either no change or even a decrease in the radiolucent zone. The type of liner is less important to success than the placement of a well-sealed restoration. These findings are confirmed by two thorough systematic reviews that concluded the following: partial caries removal reduced the risk of pulp exposure by 98% compared to complete caries excavation in teeth with deep caries; there is no evidence that partial carrier removal is detrimental in terms of signs, symptoms, pulpitis occurrence or restoration longevity; there is substantial evidence that complete caries removal is not needed for success provided the restoration is well sealed (Pinto *et al,* 2006).

2. DIRECT PULP CAPPING

The pulp of a tooth can be exposed due to several causes: caries, trauma or mechanical reasons, the latter typically due to a misadventure during tooth preparation. The direct pulp cap, in which a material is placed directly over the exposed pulp tissue, has been suggested as a way to promote pulp healing and generate reparative dentin. If successful, this procedure precludes the need for more invasive, more extensive and more expensive treatment. A number of factors have been shown to have an impact on direct pulp cap success. It is the purpose of this section to review these factors, with a particular emphasis on the materials that have been used, or suggested for use, in direct pulp capping. Some studies have shown that a tooth is more likely to survive direct pulp capping if the initial exposure is due to mechanical reasons rather than caries(Ricketts *et al, 2006)*. Caries penetration to the pulp will result in bacterial invasion of the pulp, resulting in pulpal inflammation. This leaves the pulp less able to respond and heal, compared to a mechanical exposure in which preexisting inflammation is not present. A logical extension of this is that teeth that are asymptomatic and exhibit no clinical or radiologic signs of pathology at the time of pulp capping tend to fare better than those teeth with such factors present .The placement of a permanent, well-sealed restoration at the time of pulp capping is crucial to clinical success.(Maltz *et al, 2007)*

DIRECT PULP CAPPING MATERIALS

A number of materials have been suggested for use in direct pulp capping. Interestingly, no one material seems to enjoy a significant preference among practitioners. In a survey in which private practitioners were asked what direct pulp capping material they use, the respondents listed four different materials, with none being preferred by a clear majority of users .This section will review the evidence regarding the effectiveness of various pulp capping materials that have been used for direct pulp capping.

1. Zinc Oxide Eugenol (ZOE)

ZOE formulations have been used in dentistry for many years as bases, liners, cements and temporary restorative materials. Its use for direct pulp capping is questionable, however. Eugenol is highly cytotoxic. It is known that ZOE releases Eugenol in concentrations that are cytotoxic (Ho *et al, 2006)*. ZOE also demonstrates high interfacial leakage. Although it has been noted that this leakage is not important since ZOE can provide a biologic seal due to the Eugenol release, it must be kept in mind that Eugenol release drops dramatically with time, and it is anticipated that the effectiveness of ZOE in excluding bacteria is reduced the longer it is in place in the mouth. This review only found one human clinical study using ZOE as a direct pulp capping agent. In this study, all teeth capped with ZOE showed chronic inflammation, no pulp healing and no dentin bridge formation up to 12 weeks post-operatively. Conversely, all control teeth that were capped with calcium hydroxide demonstrated healing within four weeks.

2. Adhesive Systems

Adhesive systems were suggested for use as a potential direct pulp capping agent approximately 12–15 years ago. As with the previous

two pulp capping agents, all components of adhesive systems have been shown to be cytotoxic to pulp cells. The toxic effects of the various components of adhesives are synergistic, especially with increasing duration of contact with the pulp. Toxicity is seen in both multi- and single-component adhesive systems, and the unpolymerized components are more toxic than when the adhesive is well polymerized.

The interest in using adhesives for pulp capping was driven, at least in part, by the fact that some non-primate studies found that mechanical pulp exposures capped with adhesives generally resulted in pulp healing. These results were not unanimous, as some non-primate studies did find inferior healing following pulp capping with adhesives compared to calcium hydroxide. A number of studies of primate, non-contaminated, mechanical pulp exposures capped with adhesive systems generally resulted in healing comparable to calcium hydroxide (de Souza *et al, 1999).*

When the results of human pulp-capping studies are reviewed, the conclusions become very different than what would have been deduced from animal studies. Table 1 summarizes several human studies comparing pulp capping with calcium hydroxide versus adhesives. In each study cited in Table 1, calcium hydroxide provided significantly improved pulpal repair compared to adhesive systems, regardless of whether it was an etch-and-rinse or self-etch system.

3. Glass Ionomer (GI)/Resin-Modified Glass Ionomer (RMGI)

While not as cytotoxic as ZOE, GI/RMGI is also cytotoxic when in direct cell contact. The conventional formulations tend to be less toxic than the resin-modified formulations. This should not be construed as an indictment against the use of GI/RMGI in deep cavities. Because of glass ionomer's ability to chemically bond to tooth structure, it can prevent the diffusion of potentially toxic materials through dentin to the pulp. Glass ionomer also provides an excellent bacterial seal and shows good biocompatibility when used in close approximation but not in direct contact with the pulp. As with ZOE, this review found only one human study of direct pulp capping using glass ionomer—in this case—RMGI. Direct pulp capping with RMGI showed chronic inflammation and lack of dentin bridge formation up to 300 days post-pulp capping, whereas, the calcium hydroxide control groups showed significantly better pulpal healing (lopes *et al, 2000).*

Study	# Teeth	Exposure Type	Restoration	Time	Histo	Results
Accorinte and others, 2006[44]	40	Mechanical	Total-etch/composite	2 months	Y	CaOH
De Souza Costa and others, 2001[4]	33	Mechanical	Self-etch/composite	10 months	Y	CaOH
Accorinte and others, 2008[7]	34	Mechanical	Self-etch/composite	3 months	Y	CaOH
Subay and Demirci, 2005[45]	16	Mechanical	Total-etch/composite	1 month	Y	CaOH
Accorinte and others, 2005[3]	25	Mechanical	Total-etch/composite	2 months	Y	CaOH
Fernandes and others, 2008[5]	46	Mechanical	Total-etch/composite	1 month	Y	CaOH
Hörsted-Bindslev and others, 2006[1]	34	Mechanical	Total-etch/composite	2 months	Y	CaOH

Pulp capping material shown in the "Results" column depicts significantly better performance by calcium hydroxide in all cases.
"Histo" refers to whether histological analysis was done as part of outcomes assessment.

There are several possible explanations for these poor outcomes in human studies. First are the direct cytotoxic effects that adhesives have on pulp cells. Next is the difficulty in obtaining an adequate seal to protect against bacterial contamination. This poor seal may be due to one or more reasons. Etch and primer components of adhesives are vasodilators, which can result in increased bleeding that, contaminates adjacent dentin and degrades adhesion. The increased moisture at the pulp cap site reduces polymerization of the adhesive. This has the dual detrimental effect of decreasing adhesion and increasing the availability of the unpolymerized and therefore more toxic components of the adhesive. Finally, resin components reduce the pulp's immune response, making it less likely that the pulp will be able to defend itself against bacterial contamination. These findings were confirmed in a review of pulp capping with adhesives, in which de Souza Costa and others concluded the following: adhesives result in inferior pulp healing; adhesives result in chronic inflammation, even in the absence of bacteria; inflammation is a poor environment for pulp healing; a pulp inflamed due to caries will have decreased healing capacity.

4. Calcium Hydroxide

Calcium hydroxide was introduced to the dental profession in 1921 and has been considered the "gold standard" of direct pulp capping materials for several decades. Calcium hydroxide has excellent antibacterial properties. One study found a 100% reduction in microorganisms associated with pulp infections after one-hour contact with calcium hydroxide. Most importantly, calcium hydroxide has a long term track record of clinical success as a direct pulp-capping agent in periods of up to 10 years, although reduced success rates have been found in studies in which dental students were the operators (Ricketts *et al 2006).*

Calcium hydroxide is believed to effect pulp repair by one or more of several mechanisms of action. Calcium hydroxide possesses antibacterial properties, and this can minimize or eliminate bacterial penetration to the pulp. Traditionally, it has been believed that calcium hydroxide's high pH causes irritation of the pulp tissue, which stimulates repair via some unknown mechanism. In recent years, this "unknown mechanism" may have been explained by the release of bioactive molecules. It is known that a variety of proteins are incorporated into the dentin matrix during dentinogenesis. Of particular importance to the topic of pulp capping is that at least two of these proteins, Bone Morphogenic Protein (BMP) and Transforming Growth Factor-Beta One (TBF-β1), have demonstrated the ability to stimulate pulp repair. Furthermore, calcium hydroxide is known to solubilize these proteins from dentin, lending credence to the release of these bioactive molecules as a significant mediator in pulp repair following pulp capping.

5. Mineral Trioxide Aggregate (MTA)

Mineral Trioxide Aggregate (MTA) has generated considerable interest as a direct pulp capping agent in recent years. Unset MTA is primarily calcium oxide in the form of tricalcium silicate, dicalcium silicate and tricalcium aluminate. Bismuth oxide is added for radiopacity. MTA is considered silicate cement rather than an oxide mixture, and so its biocompatibility is due to its reaction products. Interestingly, the primary reaction product of MTA with water is calcium hydroxide, and so it is actually the formation of calcium hydroxide that provides MTA's biocompatibility.

There are several disadvantages with MTA, as well. It has shown high solubility, demonstrating 24% loss after 78 days of storage in water. The presence of iron in the grey MTA formulation may darken the tooth. A significant downside to MTA is the prolonged setting time of approximately 2 hours and 45 minutes. This requires that pulp capping with MTA either be done in a two-step procedure, placing a temporary restoration to allow the MTA to set before placing the permanent restoration, or using a quick-setting liner to protect the MTA during permanent restoration placement. The handling characteristics of the powder-liquid MTA are very different from the typical paste formulations of calcium hydroxide that most practitioners find easy to handle. When compared to these paste-paste formulations of calcium hydroxide, MTA is very expensive. One gram of MTA powder costs approximately the same as 24 grams of calcium hydroxide base/catalyst paste, making MTA much less cost effective per use.

Study	# Teeth	Exposure Type	Restoration	Time	Histo	Results
Accorinte and others, 2008[117]	40	Mechanical	RMGI/Composite	2 months	Y	Equal
Tuna and Olmez, 2008[118]	50 (1°)	Caries	ZOE/amalgam	2 years	N	Equal
Aeinchi and others, 2002[108]	14	Mechanical	ZOE/amalgam	6 months	Y	No Stats
Iwamoto and others, 2006[119]	48	Mechanical	Flowable/Composite	4 months	Y	Equal
Min and others, 2008[120]	20	Mechanical	RMGI/Composite	2 months	Y	Mixed
Qudeimat and others, 2007[121]	64	Caries	RMGI/Amalgam/SSC	3 years	N	Equal
Percinato and others, 2006[122]	90 (1°)	Caries	RMGI/Composite	1 year	N	Equal
Nair and others, 2008[52]	30	Mechanical	ZOE	3 months	Y	MTA
Chacko and Kurikose, 2006[123]	31	Mechanical	ZOE	2 months	Y	MTA

"Histo" refers to whether histological analysis was done as part of outcomes assessment.

6. Resin based cements

(I) Composite and MMA-based cement

The sealing ability of the materials based on inorganic compounds used as the clinical standard needs further improvement, and adhesive resins should be helpful in this regard. The effectiveness of adhesives has been demonstrated *in vitro* and *in vivo*. A bonded coronal seal of either core paste (composite resin build-up material) and Tenure adhesives, or amalgam and Panavia, was reported to result in virtually no penetration of the India ink in which the teeth had been immersed for 10 days(Inoue *et al, 2001)*. The inferior outcome of the resin systems used for direct pulp-capping compared with Dycal may be due to the high cytotoxicity of the monomers used in those systems. In terms of monomer cytotoxicity, the MMA based resin should be the best option for a pulp-capping resin. The minimal effect of MMA on pulp tissue has been reported. Pulp tissues removed from rabbit incisors were immersed in MMA for 1 min. The MMA immersed and the untreated control pulp tissues were auto transplanted beneath the kidney capsule. The MMA-immersed pulp and the untreated control pulp tissue were positive for osteocalcin and presented osteodentin formation at 7 days. This suggested that MMA did not inhibit the osteogenic activity of pulp tissue. (Inoue *et al, 2001)*.

(I) MMA-TBB resin cement

A successful clinical trial of the MMA-TBB resin was reported in 1968, indicating a minimal pulp damage histologically after 9–12

months in unlined cavities of vital teeth by filling F1 (MMA-TBB resin). A similar favorable clinical result was reported in 1976. No pulpal necrosis or partial pulpitis could be observed after 2–35 months by filling Polycap (MMA-TBB resin) in unlined cavities of vital teeth. Thus, MMA-TBB resin seems promising as a pulp-capping resin. Christensen has referred to 4-META bonding agent, which is the MMA-TBB resin containing 4-[2-(methacryloyloxy) ethoxycarbonylophthalmic anhydride (4-META), as a clinically successful bonding agent for pulp-capping. In Japan, it has been used for direct capping with clinical success by practitioners experienced with the resin (Masaka *et al, 1992)*. Although clinical reports are scarce, several *in vitro* and *in vivo* studies supporting clinical success have been published.

There are four probable reasons for the success of MMA-TBB resin: (1) MMA is least cytotoxic among the monomers used in dentistry (2) TBB initiator reduces the residual MMA after setting with time (3) TBB has the capacity to induce interfacial polymerization of MMA at the dentin interface and (4) TBB causes graft polymerization of MMA onto dentin collagen to produce a graft polymer composed of collagen and MMA polymer.

Reasons (1) and (2) appear to correlate with the results of the studies by Inoue *et al.*, whose results showed that (a) 4-META resin demonstrated cytotoxicity *in vitro* only at the early period after the start of setting of the resin, and (b) the resin caused slight inflammatory cell infiltration in the early stage *in vivo*. The effects of reasons (3) and (4) enable reliable sealing of the interface to occur. These characteristics of TBB in polymerization will be correlated with favorable dental tissue responses in the filling of MMA-TBB resin in deep unlined cavities in clinical trials and in animal studies, as described above. The comparison of polymerization behavior in a cavity model initiated by conventional benzyl peroxide (BPO)/amine and TBB initiators is illustrated in Fig. 1. (Imai *et al, 1991)*.

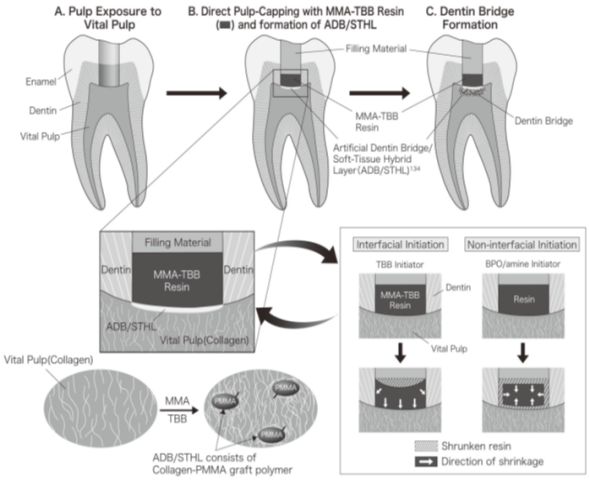

Fig. 1 Formation of Artificial Dentin Bridge (ADB) or Soft-Tissue Hybrid Layer (STHL) in direct pulp-capping with MMA-TBB resin by graft polymerization and interfacial initiation of polymerization mechanism.

A: Exposure of vital pulp.
B: Direct pulp-capping with MMA-TBB resin and formation of ADB/STHL, which consists of collagen-PMMA graft polymer. Interfacial initiation of polymerization begins on the dentin side, to which the resin is attracted during polymerization, leading to elimination of gap formation between dentin and the resin.
C: Dentin bridge formation, which occurred in half of the experiments

The use of lasers for direct pulp capping

The characteristics of a laser depend on its wavelength. For example, the wavelength of a CO2 laser is 10,600 nm and is emitted in a continuous or gated pulsed mode. This is one of the most popular lasers for soft-tissue surgery and generally utilizes an articulated arm system with mirrors. Therefore, it is sometimes difficult to use this system in certain sections of the oral cavity such as root canals and periodontal pockets. However, the CO2 laser wavelength is easily absorbed by water, which enhances its benefits for soft-tissue procedures. There is less carbonization or heat penetration on the surface when a substance being lased by CO2 contains water, whereas carbonization and crack formations occur readily on the surface if it does not contain much water (e.g., dentin and enamel). An emission wavelength of 9,600 nm for the CO2 laser is reported to be absorbed by hydroxyapatite crystals in enamel and dentin, causing tissue ablation, melting, and resolidification of tissues in the dental pulp in both humans and dogs (Wigdor *et al, 2002)*

Table 3: Lasers used for direct pulp-capping

	Wavelength Power	Time	Indication	Advantages	Disadvantages
CO2	10,600 nm	0.5 - 3 s	Soft tissue	Strong homeostasis Decontamination Photobiomodulation Less expensive	Major thermal change (carbonization and strong coagulation) Not able to be guided by optical fibers Large-sized device
Nd:YAG	1,064 nm	0.5 - 20 s	Soft tissue	Strong homeostasis Decontamination Photobiomodulation Fiber-optic or hollow-wave guiding delivery	Major thermal change (carbonization and strong coagulation) Expensive and large-sized Device
Er:YAG	2,936 nm	5 - 15 s	Soft & hard tissue	Low to moderate heamostasis Decontamination Photobiomodulation Minimal thermal change (slight coagulation) Fiber-optic delivery	Expensive and large-sized Device
Er,Cr:YSGG	2,780 nm	5 - 15 s	Soft & hard tissue	Low to moderate heamostasis Decontamination Photobiomodulation Minimal thermal change (slight coagulation) Fiber-optic delivery	Expensive and large-sized device
Diode	810-980 nm	1 - 2 s	Soft tissue	Strong heamostasis Decontamination Photobiomodulation Wide selections of optical fibers Less expensive and small-sized device Fiber-optic delivery	Major thermal change (carbonization and strong coagulation)

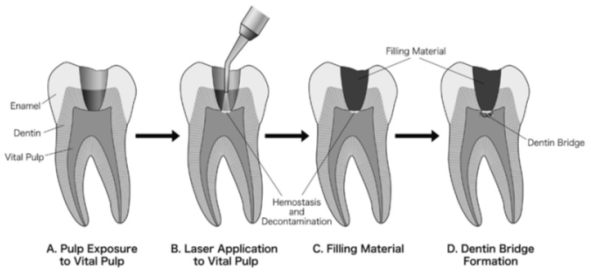

Fig. 2 Treatment steps of direct pulp capping using lasers. (A) Exposure of vital pulp. (B) Hemostasis and decontamination of the exposed pulp tissue using lasers. (C) After laser application and hemostasisn establishment, filling material will be applied. (D) Dentin bridge formation.

CONCLUSIONS

On the basis of this review, the following can be concluded:

Avoid exposing the pulp. The chances for tooth survival are excellent if the tooth is asymptomatic and well sealed, even if residual caries remains. Control hemorrhage with water, saline or sodium hypochlorite. Water and saline are the most benign to the pulp; sodium hypochlorite is best at controlling hemorrhage and disinfecting. ZOE, GI/RMGI and adhesives are poor direct pulp-capping agents and should be avoided for this application. MTA demonstrates comparable results to calcium hydroxide as a direct pulp cap agent in short-term data. Calcium hydroxide remains the "gold standard" for direct pulp capping. It has the longest track record of clinical success, is the most cost-effective and is the likely effective component in MTA. Provide a well-sealed restoration immediately after pulp capping. This will provide protection against ongoing leakage and bacterial contamination that can compromise the success of the pulp cap.

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