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Invited Paper

Keys to Clinical Success with Pulp Capping: A Review of the Literature

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Clinical Relevance

Confusion and misconceptions surround direct and indirect pulp capping. This review of the literature provides evidence-based recommendations to guide clinicians in their decision-making process when they encounter a situation requiring pulp capping.

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. Although many products have been suggested, a recent Cochrane Review found that evidence is lacking as to the most appropriate pulp capping material.[1] In addition, various factors are believed to influence the success of both direct and indirect pulp capping. It is the purpose of this literature review to examine the evidence, issues and materials relevant to pulp capping.

This review was undertaken as preparatory work for an essay at the annual meeting of the Academy of Operative Dentistry. It also served to provide the background and scientific rationale for a clinical trial on direct pulp capping being undertaken in the Northwest PRECEDENT Practice-based Research Network (PBRN).

LITERATURE SEARCH PARAMETERS

No specific criteria were applied *a priori* as to what articles would be accepted into this review. Rather, it was hoped that the span of literature reviewed would be as comprehensive as possible. PubMed and Ovid databases were searched for any articles that met the criteria of containing "pulp capping," "direct pulp capping," "indirect pulp capping," "sealed dental caries" or "pulp capping materials." No date limits were applied. An initial screen of returned abstracts was accomplished, and relevant full-length articles from peer-

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reviewed periodicals were obtained. Pertinent citations contained in the full-length articles were used as sources for additional review.

INFORMED CONSENT

The ultimate goal of a review such as this is to derive conclusions based on the evidence that can be applied to clinical practice. Just as any astute clinician will discuss the procedures, advantages, risks and patient questions (PARQ) prior to initiating a course of treatment, it is important for the reader to be aware of the shortcomings in the greater body of literature regarding pulp capping. It is only in this context that the reader can be aware of the challenges and shortcomings inherent in drawing definitive conclusions from the pulp capping literature. The following "informed consent statements" are for the purpose of stressing these challenges and shortcomings.

Clinical Pulp Capping Studies Rarely Reflect Clinical Reality

The typical clinical study for pulp capping contains the following features:

1. The patient is young (typically 15-25 years of age) and healthy.
2. The patient is going to have premolars (subject teeth) extracted for orthodontic reasons.
3. The subject teeth are free of caries, cracks or other defects.
4. The teeth are isolated with a rubber dam, receive a pumice prophylaxis and are often times disinfected (sometimes with two antibiotic solutions).
5. A sterile bur is used to initiate cavity preparation. When nearing the pulp, a new sterile bur is replaced in the handpiece and pulp exposure is initiated as atraumatically as possible.
6. Hemorrhaging is controlled with sterile materials.[2-6]

While these procedures help to standardize the experimental technique and maintain internal validity, they do not reflect the circumstances under which most practitioners are confronted with a potential pulp cap situation.

Histological Pulp Status Cannot be Determined by Clinical Signs and Symptoms

The true "gold standard" of pulp status is histological analysis. Unfortunately, the true state of pulp health or pathology cannot be determined by clinical signs, symptoms or radiologic appearance. Clinicians have only relatively crude assessments, such as the application of hot or cold temperatures, an electric current, percussion of the tooth, changes in the appearance of associated soft tissues and patient reports of symptoms. However, numerous studies including histological analysis have demonstrated a chronically inflamed pulp, but the patients reported no symptoms, the investigators discerned no signs and no apical/radicular pathology was noted on radiographs. It must also be kept in mind that most studies that include histological analysis are of quite a short duration, typically two to four months.[3-4,6-9]

Outcomes in Animal Studies Not Necessarily Predictive of Human Outcomes

Much research on pulp capping has been accomplished in animals, from lower species, such as mice and dogs, to primates. However, the results of pulp capping in animals often does not reflect what will happen in humans. It is necessary to be very cautious in taking the results of animal pulp capping studies and applying them to human patients.[3-4,7,10-12]

Inconsistencies in Research Protocol

Some studies do not maintain a consistent methodology within the study. For example, the restorative regimen may vary among the experimental groups. Different restorative materials have different restoration-cavity preparation sealing characteristics. This can hamper interpreting the results, since it is difficult to determine whether differences in the pulp status are the result of the pulp cap regimen or the restorative procedure.[13-15]

BASIC PRINCIPLES

A controversy has existed within dentistry as to what is more detrimental to the pulp: toxicity from dental materials or bacteria and/or their toxins. For many years, even decades, practitioners believed that some restorative materials "killed" pulps due to their inherent toxic properties. However, research since the mid-1970s has indicated that the pulp can tolerate a variety of restorative materials if bacteria and/or their toxins can be excluded from the pulp. This is tempered by the particular material involved and whether or not the material has direct contact with pulp tissue or it has an intervening layer of protective dentin. Once bacterial invasion encroaches on the pulp, serious and adverse pulpal reactions ensue.[16-19] Therefore, one of the crucial principles, and one that will be reiterated throughout this article, is that the key to pulp survival after capping is a well-sealed restoration.[20-25]

However, it must be kept in mind that pulp is a soft tissue, and similar to other soft tissues in the body, it will react to a noxious stimulus with an inflammatory response. There are a number of materials-related sequela associated with direct pulpal contact with certain materials, including cytotoxicity and immunosuppression. The first reaction will destroy pulp cells, and the latter will reduce the ability of the pulp to respond to a bacterial invasion. In addition, many materials require light curing for polymerization, and such units have demonstrated the ability to raise intrapulpal tem-

perature to levels incompatible with pulp cell survival.[26-30] Multiple pulp cap studies have demonstrated that pulp inflammation can be unrelated to bacterial presence, reinforcing the concept that certain materials applied directly to pulp tissue may elicit significant inflammatory response.[2,4,31]

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.[32] 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.[33-35] A number of studies have evaluated the fate of caries lesions in which partial caries removal was done. 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 restoration is placed for a period of 4-12 months before 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.[20,34,36-41] In addition, partial caries removal significantly reduces the chance of pulp exposure during caries excavation.[22,42] 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 caries 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.[24,43]

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.[25,44] Caries penetration to the pulp will result in bacterial invasion of the pulp, resulting in pulpal inflammation.[16-19] 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.[25] The placement of a permanent, well-sealed restoration at the time of pulp capping is crucial to clinical success.[20-25,36,45]

Controlling Pulpal Bleeding

Another factor that has been demonstrated to have an effect on direct pulp cap success is the ability to control pulp bleeding after the exposure and prior to placing the pulp cap agent.[46-48] This is likely a result of two reasons. First, increased bleeding can be indicative of a greater degree of inflammation in the pulp, with a resultant diminished capacity for repair. The second reason is that the moisture and contamination of dentin adjacent to the exposure site due to bleeding can make it more difficult to obtain an adequate seal that will prevent subsequent bacterial exposure. Bleeding is normally controlled by placing a cotton pellet soaked in a solution on the exposed pulp. A variety of solutions have been used, including saline, sodium hypochlorite (concentrations ranging from 0.12% to 5.25%), hydrogen peroxide, ferric sulfate and chlorhexidine. Saline or calcium hydroxide solutions are the most benign to the pulp in cytotoxicity tests.[49]

In-vivo studies confirm that saline shows the mildest pulp response and is the solution used in most studies. Sodium hypochlorite shows increased pulpal inflammatory response but has the advantages of possessing antibacterial properties and providing enhanced hemorrhage control. It, too, has been used effectively in many studies and clinical reports. Chlorhexidine is antibacterial but may not be as effective at hemorrhage control as sodium hypochlorite. There is less data on other hemostatic agents that are typically

associated with hemorrhage control and tissue retraction for impression taking. What little research that has been done is short-term, but it would seem to indicate that there is not a significant difference in pulp response relative to other solutions more commonly used for controlling pulp bleeding. The one exception is ferric sulfate, which demonstrated significantly increased post-operative pain.[7,9,15,26,50-52]

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.[53] This section will review the evidence regarding the effectiveness of various pulp capping materials that have been used for direct pulp capping.

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.[54-57] It is known that ZOE releases eugenol in concentrations that are cytotoxic.[56,58-60] ZOE also demonstrates high interfacial leakage.[61] 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,[58] 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.[62]

Glass Ionomer (GI)/Resin-Modifed 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.[57,59,63-64] 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.[65-68]

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.[69]

Adhesive Systems

Adhesive systems were suggested for use as a potential direct pulp capping agent approximately 12-15 years ago.[70] As with the previous two pulp capping agents, all components of adhesive systems have been shown to be cytotoxic to pulp cells.[71] The toxic effects of the various components of adhesives are synergistic, especially with increasing duration of contact with the pulp.[72] 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.[71]

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.[73-75] These results were not unanimous, as some non-primate studies did find inferior healing following pulp capping with adhesives compared to calcium hydroxide.[76-77] A number of studies of primate, non-contaminated, mechanical pulp exposures capped with adhesive systems generally resulted in healing comparable to calcium hydroxide.[14,78-82]

However, this outcome changes when the results are examined from studies of bacteria-contaminated mechanical pulp exposures in primates. This experimental regimen was chosen to more closely resemble the situation that might be encountered if a pulp exposure occurred due to caries or without a rubber dam in place. These contaminated exposures capped with adhesives resulted in poor pulp healing compared to calcium hydroxide.[26,83]

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.

There are several possible explanations for these poor outcomes in human studies. First are the direct cytotoxic effects that adhesives have on pulp cells.[71] 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

Table 1: *A Comparison of Human Study Outcomes of Direct Pulp Capping Comparing Calcium Hydroxide to Adhesive Systems*

Study	# Teeth	Exposure Type	Restoration	Time	Histo	Results
Accorinte and others, 2006[84]	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[2]	34	Mechanical	Self-etch/composite	3 months	Y	CaOH
Subay and Demirci, 2005[85]	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[6]	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.

result in increased bleeding that contaminates adjacent dentin and degrades adhesion.[6,9,86] 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.[87] 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.[29] 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.[10]

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.[25] There are a number of well-known advantages to calcium hydroxide that have caused it to receive this recognition. Calcium hydroxide has excellent antibacterial properties.[88] One study found a 100% reduction in microorganisms associated with pulp infections after one-hour contact with calcium hydroxide.[89] 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,[46,84,90] although reduced success rates have been found in studies in which dental students were the operators.[6,25,44-45]

Calcium hydroxide has some disadvantages as well. The self-cure formulations are highly soluble and are subject to dissolution over time,[91] although it has been noted that, by the time the calcium hydroxide is lost due to dissolution, dentin bridging has occurred.[84] Calcium hydroxide has no inherent adhesive qualities and provides a poor seal.[92] Another criticism noted of calcium hydroxide is the appearance of so-called "tunnel defects" in reparative dentin formed underneath calcium hydroxide pulp caps.[93-94] A tunnel defect has been described as a patency from the site of the exposure through the reparative dentin to the pulp, sometimes with fibroblasts and capillaries present within the defect.[94] However, other researchers have found that the quality of reparative dentin improves as the bridge gets thicker,[95] and that many times, the tunnel defects are not patent with the pulp.[76] It appears that tunnel defects are not a common finding in human studies involving direct pulp capping with calcium hydroxide. There are fewer studies that note observing tunnel defects and more studies that do not observe tunnel defects.[2-3,6,9,84]

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.[88] Traditionally, it has been believed that calcium hydroxide's high pH causes irritation of the pulp tissue, which stimulates repair via some unknown mechanism.[96] 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.[97-99] 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.[96,99]

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.[100-101] MTA is considered a silicate cement rather than an oxide mixture, and so its biocompatibility

is due to its reaction products.[102] Interestingly, the primary reaction product of MTA with water is calcium hydroxide,[100,102-104] and so it is actually the formation of calcium hydroxide that provides MTA's biocompatibility.[105]

As a result, many of the advantages and potential mechanisms of action for MTA are similar to calcium hydroxide, including its antibacterial and biocompatibility properties, high pH, radiopacity and its ability to aid in the release of bioactive dentin matrix proteins.[103-104,106-109] There are some differences between MTA and calcium hydroxide. First, MTA comes in two colors, white and grey. The grey version is due to the addition of iron.[110] Another significant difference is the fact that MTA provides some seal to tooth structure.[111]

There are several disadvantages with MTA, as well. It has shown high solubility, demonstrating 24% loss after 78 days of storage in water.[103-104] The presence of iron in the grey MTA formulation may darken the tooth.[108] A significant downside to MTA is the prolonged setting time of approximately 2 hours and 45 minutes.[106-107] 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-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.

A review of animal direct pulp capping studies comparing MTA to calcium hydroxide generally reveals better pulp healing with MTA.[112-116] As with pulp capping studies comparing adhesives to calcium hydroxide, the results are different when comparing MTA to calcium hydroxide in humans. Table 2 demonstrates that most human studies show similar pulp-cap outcomes of MTA and calcium hydroxide. However, two of these studies demonstrate superior performance of MTA, and both share an interesting study characteristic: the pulp-capped teeth were restored with a temporary ZOE material, versus a permanent restoration for the other studies. As discussed in the section on ZOE, these materials leak significantly and lose their antibacterial eugenol release rapidly. So, these results may point to the ability of MTA to provide a seal over the pulp exposure that calcium hydroxide does not. Additional human studies using MTA as the sole pulp cap agent with no control group have shown good success in periods ranging from six months to four years.[51,124-125]

On the basis of the literature to date, it would appear that MTA's success is likely due to the fact that it serves as a reservoir for calcium hydroxide and/or its capacity to provide a seal at the site of the pulp exposure. Even though MTA seals better than calcium hydroxide, it should be kept in mind that a glass ionomer (GI) or resin-modified glass ionomer (RMGI) will be needed as a liner over either pulp cap material. In the case of calcium hydroxide, the GI/RMGI liner is needed to provide a protective antibacterial seal that calcium hydroxide alone cannot provide. In the case of MTA, the GI/RMGI liner is needed to protect the MTA during restoration placement due to the prolonged setting time. Without this GI/RMGI protective sealer, it would be necessary to place a temporary restoration for a period of time until the MTA is set, requiring the patient to present for a second appointment for definitive restoration placement.

MTA Over-exuberance?

Certainly, the results of pulp capping studies using MTA are encouraging. However, it appears that some statements regarding the efficacy of MTA as a pulp-capping agent are not supported by the study results. Two examples may help to clarify this. One study made the following statement: "In light of the results of the

Table 2: *A Comparison of Human Study Outcomes of Direct Pulp Capping Comparing Calcium Hydroxide to Adhesive Systems*

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
Aenichi 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.

present and other relevant studies, MTA is superior to calcium hydroxide for pulp capping mechanically exposed human teeth."[108] In this study, the pulps of 14 teeth were intentionally exposed, half capped with calcium hydroxide and the other half with MTA. The teeth were extracted at one, two, three, four weeks and six months and evaluated histologically. By the final evaluation period (six months), only one tooth per group was evaluated. There were too few specimens for statistical analysis. In light of these results, it would appear that the comment of MTA superiority is unwarranted.

In another article, the authors stated, "The outcomes suggest that MTA is a more predictable pulp-capping material than calcium hydroxide."[51] Forty-nine teeth received an MTA direct pulp cap and were followed over an average of approximately four years. Clinical assessment revealed an apparent 98% success for the pulp-capped teeth. However, no histological analysis was done to assess the true state of pulpal health or disease. Most importantly, no calcium hydroxide control group was included in the study, and so it would not be possible to conclude that MTA was a more predictable pulp-capping material than calcium hydroxide in this evaluation.

Does calcium hydroxide provide any benefits over MTA?

MTA is a promising material, but calcium hydroxide shows a long-term track record of clinical success that MTA cannot claim at the present time. A review of 14 clinical studies, including over 2,300 cases of calcium hydroxide pulp capping, noted success rates of up to 90% when done by experienced clinicians.[25] This review article highlighted two keys to calcium hydroxide direct pulp capping success: restricting pulp capping to asymptomatic teeth and providing a well-sealed restoration following the pulp cap. In addition, calcium hydroxide has demonstrated clinical success even when done under less-than-ideal circumstances. A three-year study of 44 carious exposed pulps capped with calcium hydroxide resulted in an 80% success rate.[46] Thirty-four traumatically exposed teeth that experienced an approximately four-hour delay before calcium hydroxide pulp capping demonstrated 97% success when followed for periods of up to 17 years.[90] To better elucidate the relative benefits of MTA versus calcium hydroxide for pulp capping, a large scale, prospective clinical trial comparing MTA to calcium hydroxide as a direct pulp-cap material is needed. NW PRECEDENT, a NIDCR-supported practice-based research network is engaged in such a study.

CONCLUSIONS

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

1. Avoid exposing the pulp. The chances for tooth survival are excellent if the tooth is asymptomatic and well sealed, even if residual caries remains.
2. 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.
3. ZOE, GI/RMGI and adhesives are poor direct pulp-capping agents and should be avoided for this application.
4. MTA demonstrates comparable results to calcium hydroxide as a direct pulp cap agent in short-term data.
5. 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.
6. 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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