

Pulp Capping with Mineral Trioxide Aggregate (MTA): A Retrospective Analysis of Carious Pulp Exposures Treated by Undergraduate Dental Students

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Clinical Relevance

Carious pulp exposures present a therapeutic challenge for clinicians. Mineral trioxide aggregate (MTA) is a treatment option that may provide successful outcomes for the capping of carious pulp exposures in adult patients. However, the success measured as pulp survival over a period of one and two years of pulp caps performed by undergraduate dental students may be low. This study provides data regarding the impact of exposure sizes and other pre-operative variables on outcomes of MTA pulp caps in adults.

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SUMMARY

The current study estimated pulpal vitality after MTA pulp caps were performed by undergraduate student clinicians. At recall after 12 to 27 months, 51 pulp caps were clinically and radiographically assessed. Kaplan-Meier analyses were used to estimate overall success at 12 and 24 months, determined as the presence of a vital pulp, as well as impact of preoperative variables on pulp vitality at recall. Overall, one-year pulp survival was 67.7%, while the two-year survival rate was 56.2%. Tarone-Ware statistics indicated that neither age of the patient nor size of the exposure (“minimal” or “moderate”) and the

amount of bleeding (“none,” “minimal” or “moderate”) had a significant effect on survival rates.

Within the limitations of the current study on procedures performed by student clinicians, it may be concluded that, for MTA pulp caps applied to carious exposures in adults, certain preoperative conditions—patient age, exposure size and amount of bleeding—are not predictive of clinical outcome. Considering the comparatively low success rate for the current cohort, more research is needed to define predictive criteria for successful pulp capping with MTA.

INTRODUCTION

Carious pulp exposure presents a treatment dilemma for dentists. Treatment options include reliable, but expensive endodontics and affordable, but irrevocable extraction. Another alternative is a direct pulp cap—the treatment of an exposed vital pulp with a dental material to facilitate the formation of reparative dentin and maintenance of a vital pulp¹ prior to placement of a direct restoration. However, there is conflicting data regarding pulp-capping outcomes.²⁻⁴ While the sequelae of unsuccessful pulp capping are well established, that is, often painful, irreversible pulpitis or clinically silent pulpal necrosis, the factors that lead to these outcomes are not as clear. When can direct pulp caps be expected to succeed? How can the practitioner maximize the chances for success?

It appears that material choices, such as zinc phosphate cement,⁵ amalgam,⁵ zinc oxide eugenol cements,⁶ polycarbonate cements,⁷ glass ionomer cements,⁸⁻¹¹ resin adhesives¹²⁻¹⁴ and cyanoacrylates¹⁵ do not lead to predictable success for the treatment of exposed pulps. Outcomes with calcium hydroxide were superior but unpredictable for carious pulp exposures.^{2,16-17} Retrospective analysis of pulp caps performed by undergraduate students using calcium hydroxide showed a 44.5% failure rate after five years and a 79.7% failure rate after 10 years.¹⁸

More recently, a new pulp capping material was introduced: mineral trioxide aggregate (MTA, Dentsply Tulsa Dental, Tulsa, OK, USA). Current results suggest better post-operative outcomes when applied by an experienced clinician.¹⁹ One factor contributing to more favorable results with both calcium hydroxide and MTA may be an antibacterial effect directed against microorganisms, and specifically their toxins.²⁰

One of the vexing aspects of calcium hydroxide pulp capping therapy has been the fact that such treatments may eventually fail after early success. Several factors have been described for this phenomenon; for example, the solubility of calcium hydroxide, even in products that feature a setting reaction.²¹ Reparative dentin near the calcium hydroxide-pulpal interface is likely pro-

duced by odontoblast-like cells stemming from undifferentiated pulp cells.²² These cells must replace destroyed mature odontoblasts in the presence of live bacteria and operative debris.²³ Even when the initial pulpal response is favorable, any reparative dentin formed in this situation is often associated with so-called “tunnel defects.”²³⁻²⁴ Microleakage of the coronal restoration then allows bacteria to migrate pulpally and initiate degenerative pathosis.²⁵⁻²⁶

MTA has proven to be one of a very few exogenous materials that is not only well tolerated by connective tissues,²⁷ but also contributes to a bacteria-tight seal.²⁸ Both properties suggest that an application of MTA as a pulp capping material may be clinically successful under the conditions of minimal bacterial exposure. Indeed, several studies document that MTA is an effective material for direct pulp capping²⁹⁻³¹ and pulpotomies³²⁻³⁶ in primary teeth. Excellent tissue healing has been observed over the useful life of the primary teeth and no adverse effects were noted on exfoliation or the eruption of succedaneous teeth.

Pulp capping in permanent teeth is less well understood and case reports dominate the literature. An exception is a recent study that reports on the outcome of 49 pulp caps performed by a single operator in a carefully controlled setting.¹⁹ While such control is desirable, pulpal diagnoses and clinical application procedures vary widely across clinicians.

The current study analyzed the outcome of pulp caps in adult patients placed in conditions encountered in an undergraduate dental school clinic. The effect of preoperative conditions as well as pulp capping outcomes following guidelines that are likely to be seen in the average clinical practice of dentistry were assessed.

METHODS AND MATERIALS

Clinicians

All procedures in the current study were performed by student clinicians in their first or second clinical year of dental school: 68 students treated one patient each and seven students treated two patients each. All treatments were performed under routine faculty supervision. Supervising faculty consisted of members of the Department of Restorative Dentistry and Endodontics, all of which were calibrated regarding the school's guidelines for pulp capping with MTA (see below).

Students at the dental school are taught to remove caries methodically, establishing caries-free margins prior to excavating dentin close to the pulp. If a student suspects that further caries removal risks pulp exposure, faculty may recommend placing glass ionomer cement as an indirect pulp cap. It is standard process at the school for a student discovering a pulp exposure in the process of removing caries to ask for an endodontic consult. Performing a pulpectomy is typically sug-

gested upon frank exposure of the pulp, but a pulp cap using MTA is also routinely considered. Treatment is then provided by students under the direct supervision of endodontic and/or restorative faculty.

Student clinicians participating in the current study were informed in detail about the study design; they were given an assessment form to document demographical and clinical data (see Table 1). The student clinicians were asked to judge pulp exposure size as “minimal” (barely visible), “moderate” (up to 1 mm) or “large” (>1 mm). The amount of bleeding was classified as “none,” “minimal” (barely visible), “moderate” (controlled with dry cotton pellet) or “significant” (difficult to control). These data were tabulated, along with survival times.

Treatment Guidelines

The clinical guidelines for the pulp capping procedure followed in the current study were issued in October 2002. The guidelines cautioned that direct pulp capping has not been proven to be a reliable procedure but suggested the use of MTA when the following conditions were present:

- asymptomatic teeth without a history of pain.
- no treatment plan for a laboratory-fabricated prosthesis that is placed on the tooth.
- no difficulty controlling bleeding from exposure.
- pinpoint (up to 1 mm) exposure after caries has been removed.

Figure 1 illustrates the clinical procedures suggested in the guidelines that were employed in the current study. The teeth selected to receive MTA pulp caps first had bleeding controlled by placement of a cotton pellet moistened with 2.5% sodium hypochlorite. No further excavation of the exposure site was carried out at that time; that is, no attempt was made to fully remove carious dentin as soon as a bleeding pulp was observed. Care was taken to minimize the time to control bleeding and the time between exposure and application of the pulp capping material.

MTA was mixed with an anesthetic solution (2% lidocaine with 1:100,000 epinephrine, Novocol Pharmaceuticals, Cambridge, ON, Canada) to the consistency of wet sand. A thin layer of the mix was placed over the exposure. A resin-modified glass ionomer lining material, Vitrebond (3M ESPE, St Paul, MN, USA), was mixed and immediately placed to completely cover the layer of MTA. The liner was light cured for 20 sec-

Table 1: Preoperative Variables Determined from a Questionnaire Answered by the Treating Student Clinicians After the Pulp Cap Had Been Done

	Teeth (all patients)	Teeth (recalled patients)
Pre-operative Condition	75	51
Asymptomatic	59 (79%)	40 (78%)
Cold Sensitivity	14 (19%)	11 (22%)
Heat Sensitivity	2 (3%)	2 (4%)
Biting Sensitivity	7 (9%)	4 (8%)
Percussion Sensitivity	4 (5%)	3 (6%)
Spontaneous Pain	4 (5%)	3 (6%)
<i>Size of Exposure</i>		
Minimal (barely visible)	52 (70%)	34 (67%)
Moderate (up to 1 mm)	21 (28%)	16 (31%)
Large (>1 mm)	2 (3%)	1 (2%)
<i>Bleeding</i>		
None	22 (29%)	16 (31%)
Minimal	47 (63%)	31 (61%)
Moderate	6 (8%)	4 (8%)
Significant	0	0

Numbers in parentheses are percentages relative to the subset of teeth.

onds with an Optilux 501 curing light (Kerr, Orange, CA, USA). After the liner was cured, preparation of the tooth for a direct restoration was completed and either amalgam, composite or glass ionomer restorations were placed. Postoperative radiographs were not routinely taken.

Patients

The current study presents data on a series of 75 consecutively treated patients on which pulp caps were performed between February 2005 and December 2006. Data was collected after approval of the study protocol by the University's Institutional Review Board. All patients who had received treatment, including a direct pulp cap with MTA, were at least 18 years of age. Inclusion was not limited to patients whose situation strictly conformed to the guidelines outlined above; this was assessed from reports filed by the treating student clinicians (Table 1), which identified the pre-operative conditions of the affected tooth.

One year after each procedure was performed, attempts were made to have the patient return for a follow-up appointment. Additional contemporary information about cases was gathered from clinic records identifying teeth that had since undergone endodontic treatment (n=19) or extraction (n=1). Records were examined to ascertain the reason for these subsequent procedures, whether the patient experienced symptoms consistent with irreversible pulpitis (n=15) or restorative considerations required a more predictable foundation (n=5). The reason for the subsequent treat-

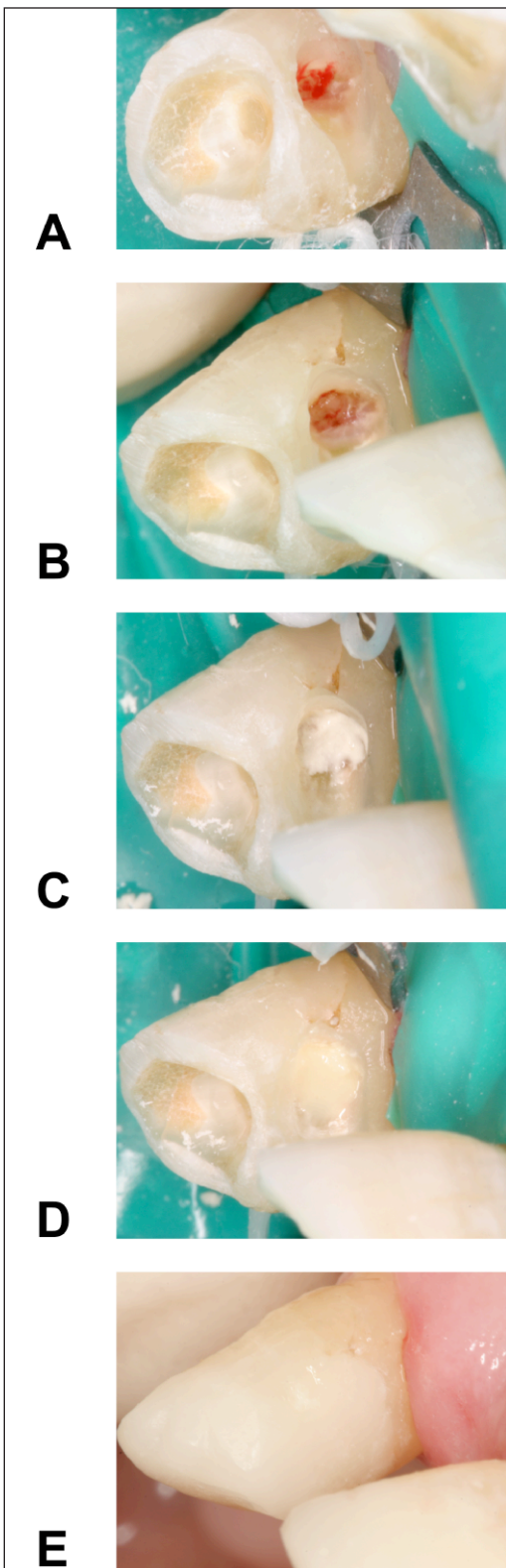


Figure 1. Clinical procedures stipulated by the guidelines used in the current study. Pulp exposures (A) were cleaned with 2.5% NaOCl (B); after hemostasis was achieved, MTA was applied (C), which was then covered with a light-curing glass ionomer (D). In the same appointment, a definitive restoration was placed (E).

Table 2: Clinical and Radiographic Observations at Recall Interview of Patients with MTA Pulp Caps

	Teeth (recalled patients)*
Post-operative Condition	31
Asymptomatic	23 (74%)
Cold sensitivity	7 (23%)
Heat sensitivity	0
Biting sensitivity	1 (3%)
Percussion sensitivity	1 (3%)
Spontaneous pain	1 (3%)
Other	0
Intensity of Pain*	
Mild	5 (16%)
Moderate	3 (10%)
Extreme	0
Duration of Pain*	
< 1 day	1 (3%)
1–6 days	2 (6%)
1–6 weeks	1 (3%)
> 6 weeks	5 (16%)
Soft Tissue	
Local swelling	1 (3%)
Local tenderness	1 (3%)
Local inflammation	0
Within normal limits	30 (97%)
Cold Test	
Positive–normal	22 (71%)
Positive–hypersensitive	3 (10%)
Positive–lingering	0
Negative	6 (19%)
EPT	
Response	27 (87%)
No response	4 (13%)
Radiographic Evaluation	
No pathosis	31 (100%)
Radiolucency	0

*Patients reported pain type, intensity and duration in the time period immediately following the pulp capping procedure. Patient records indicated that 18 of the 51 followed teeth with pulp caps had undergone root canal treatment and two of those teeth had been extracted.

ment was established by examination of each patient’s record and it was entered into the data for the study.

Subtracting those teeth (n=20) left 31 teeth with “at-risk” pulp status, which were recalled for a follow-up appointment. Attempts were made to contact all of the other patients by telephone and mail. Patients who responded were offered monetary compensation for their participation; those who consented to participation were interviewed as to their post-operative symptoms (Table 2).

Patients were asked about the type, severity and duration of any pain experienced after treatment. A periapical radiograph (F-speed, Carestream Health Inc, Rochester, NY, USA) was taken with a 0.25 second exposure (65 kVp; Gendex 765DC, Kavo Dental Corp, Lake Zurich, IL, USA). Pulpal sensitivity of the treated teeth was assessed with ethylene chloride (Endo Ice, Hygienic, Akron, OH, USA) on a cotton swab and with an electrical pulp tester (Vitality Scanner 2005, Kerr Analytic, Redmond, WA, USA). The teeth were considered vital if either cold testing or electrical testing showed a positive response. Recall radiographs were compared to preoperative films and interpreted for the absence or presence of apical pathosis. All clinical tests, evaluations and radiographic assessments were done by a single clinician.

Statistical Evaluation

Possible outcomes for pulp-capped teeth considered to be “at-risk” were vital and asymptomatic pulp and no periapical pathosis (“survival”), extraction, root-canal treated, non-vital with periapical periodontitis or painful/symptomatic pulps at recall (“clinical failure”).

Kaplan-Meier survival analysis is appropriate for exploring such data, where no fixed, uniform observation points are established at the end of the study, and the timing of the measurements is determined by event occurrence (“clinical failure”) or patient characteristics (attendance at the clinic). No distinction is made in survival analysis between patients who have dropped out and those who are still in the study but have not been recently evaluated. Of the three tests for differences in predictive factors in survival rate most commonly in use, the Tarone-Ware statistic was selected, because it assigns a moderate weight to early cases.³⁷ Median survival times (“half-lives”) were also analyzed.

RESULTS

Patient ages ranged from 21 to 85 years, with a mean age of 42 ± 15.6 years. Of the 75 pulp caps in 73 patients that were included in the current study, the authors were able to collect post-operative data on 51 teeth in 49 patients (Table 1) by a review of the records or by clinical evaluation. In this population, pulp caps were

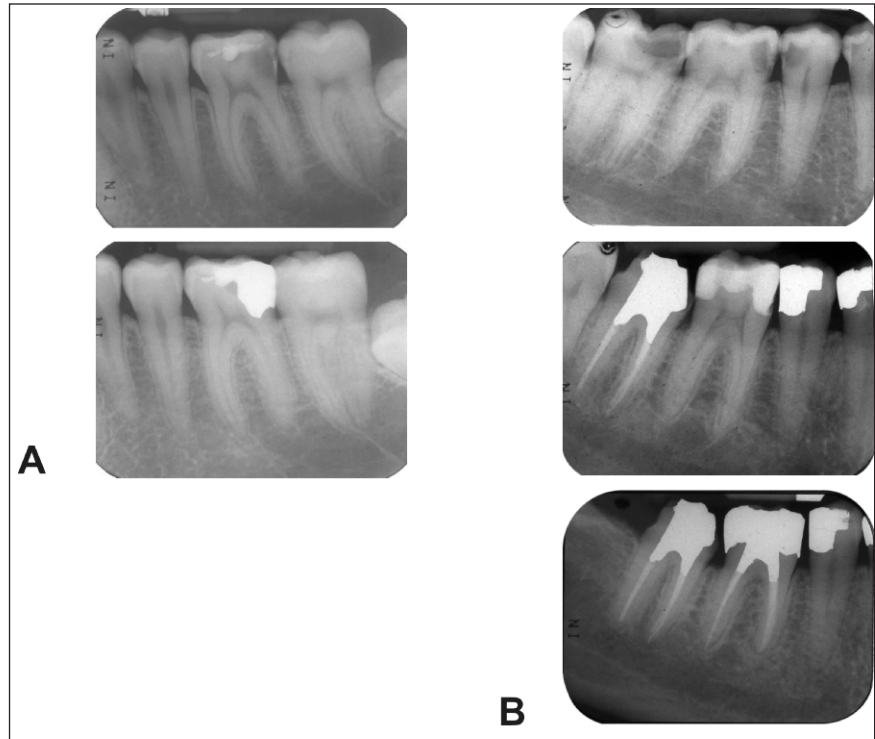


Figure 2. Examples of radiographic appearance of teeth included in this study. A: Case 1 (tooth #19) showed no apical pathosis before pulp capping and at recall. B: Case 2 (tooth #30) tested positive to cold initially and was treated with an MTA pulp cap. However, the tooth became painful before the scheduled recall appointment and a root canal treatment was performed.

done in eight incisors, five canines, 15 premolars and 23 molars. Out of the 51 teeth with available post-operative data, 24 were restored with composite (Esthet-X, Dentsply Caulk, Milford, DE, USA), 23 with amalgam (Valiant, Ivoclar Vivadent, Amherst, NY, USA) and four with glass ionomer (Ketac Fil, 3M ESPE).

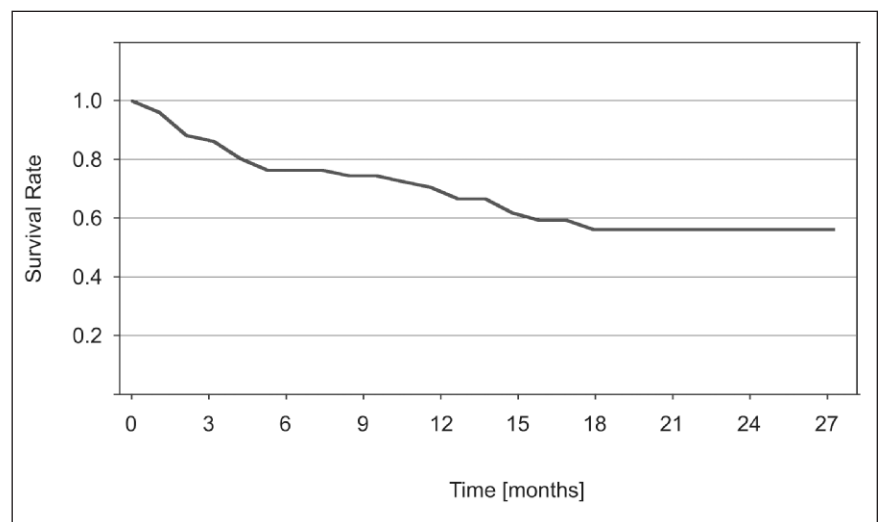


Figure 3. Overall success of pulp caps with MTA. Kaplan-Meier curve for pulp survival for 51 teeth of recalled patients and teeth with known root canal treatments/extractions.

Table 2 includes results from pulp testing on 31 teeth. These teeth were tested at a minimum of 12 months and as much as 30 months after placement of the pulp cap. Three of the teeth tested negative with both Endo Ice and an electric pulp tester. None of these teeth were symptomatic. All of the 31 teeth had radiographically normal periapical tissues (Figure 2). Twenty-eight teeth tested positive with an electric pulp tester, while 22 responded to cold testing (Table 2). Eight of the patients interviewed reported mild-to-moderate post-operative sensitivity from the pulp-capped teeth immediately after the pulp cap had been performed. Sensitivity persisted for more than six weeks in five of those cases.

Data collected through the school's computerized patient management system had identified 20 teeth in the cohort of participating patients who had been treated with endodontic therapy or extraction following pulp capping. Chart entries indicated that 16 of these teeth were treated due to postoperative symptoms consistent with irreversible pulpitis or pulpal necrosis (15 root canal treatments, one extraction). The other four teeth received intentional endodontic treatment preparatory to definitive prosthodontic treatment.

The Kaplan-Meier method was used to estimate survival rates for capped pulps. The overall one-year survival rate was .677; the two-year survival rate was .562. The estimated half-life for teeth treated with MTA in this clinic population was between 26 and 27 months (Figure 3). The vertical axis in survival tables, survival rate, is the proportion of "at-risk" teeth at any time point that experienced the event ("clinical failure" in this case) during the period multiplied by the cumulated survival rate at all previous time points.

Three patient characteristics were investigated as potentially affecting survival rate of the pulp capping procedure. The patients were divided into groups based on age (29 and under vs 30 and above); three groups were formed based on the extent of bleeding ("none," "minimal" and "moderate") and two groups were formed based on size of the exposure ("minimal" vs "moderate"). Median survival of capping for patients 30 years of age and older was 26 months and for younger patients, at least 19 months. Median survival of capping for patients with no bleeding was 26 months; for those with "minimal" bleeding, 27 months and for those with "moderate" bleeding, three months. The median survival of capping for patients with "minimal" exposures was 19 months and 24 months for those with "moderate" exposures. The Tarone-Ware tests for these three potential explanatory factors were all insignificant. No obvious differences were noted comparing pulp survival for teeth restored with composite and amalgam, but the numbers were too low to support a statistical analysis.

DISCUSSION

The current study confirms that placing a direct pulp cap with MTA over a carious exposure in a mature permanent tooth may be a reasonable alternative to root canal therapy or extraction. However, it also showed that, when performed by practitioners inexperienced in handling the material and in non-standardized clinical situations, the pulp caps in the current study had a 32% failure rate after one year. Lower failure rates of 2%¹⁹ and 7%³⁸ have been documented in two clinical studies on carious pulp exposures with similar follow-up periods; a possible explanation for this apparent conflict is that the earlier studies showing more predictable results were performed under more controlled clinical conditions, including a single operator.

The current study included factors that are believed to give indications of the health and healing capacity of pulpal tissues prior to treatment: age of the patient, symptoms associated with the tooth, preoperative restorative status and radiographic appearance. Each of these factors has been cited in the literature as having some relevance in the ability of a pulp to recover from a pulp exposure (carious or otherwise), but none has been shown to be reliably predictive.

Survival curves are usually concave, showing a steep initial failure rate and a flattening in the right-hand tail. The expected asymptote in survival rate of the pulp capping procedure was observed in the current study. There was, however, no clear evidence of an initial steep decline in survival (except perhaps for the six cases of "moderate" bleeding). This is customarily interpreted to mean that there is no interaction between the conditions that qualify patients for treatment and the treatment itself. There was no evidence that treatment with MTA had any direct adverse effects; moreover, there was no evidence that patients who are candidates for this therapy presented challenges for subsequent restorative procedures.

The authors of the current study expected that outcomes of carious pulp exposures capped with MTA would be affected by preoperative conditions (that is, case selection). However, this is not reflected in the results of the current study. Table 2 shows that some students and supervising faculty elected to slightly deviate from the suggested guideline and elected to perform MTA pulp caps on patients who reported preoperative symptoms. However, the authors of the current study did not observe different outcomes from these pulp caps compared to patients without preoperative symptoms. Moreover, the authors saw no significant difference in survival of teeth that students identified as having a "minimal" exposure compared to those having a "moderate" exposure. Of the two exposures characterized as having a "large" exposure, one failed and one was lost to recall.

The same holds true for the survival rates of teeth when intraoperative bleeding was described as “none” compared to “minimal” or “moderate.” None of the teeth had bleeding described as “significant.”

The age of the patient was also not a significant factor in success of the treatment. It is well documented that teeth lacking apical closure respond well to direct pulp treatment (pulp cap, partial pulpectomy or pulpotomy).^{26,39-42} All of the teeth in the current study had complete root formation; therefore, direct comparisons to teeth with immature apices cannot be made. However, the results of the current study suggest that changes in pulp physiology occurring after completed root formation do not affect the ability of the pulp to tolerate pulp capping.

The authors of the current study must acknowledge considerable, but unquantifiable variation in technique. While seven students contributed more than one procedure to this study, most were working with mineral trioxide aggregate for the first time. MTA is a material that is unlike any other dental material students are trained to use. It is unique in its sand-like consistency and in its hours-long setting reaction.

Other unknowns in student technique include caries removal and the use of sodium hypochlorite. Students may not always be methodical or meticulous in their caries removal; infected dentin in contact with pulp tissue is likely to encourage inflammation and discourage reparative dentin formation. The use of sodium hypochlorite for hemostasis and disinfection is recommended in the school's guidelines for MTA pulp caps and is cited by several authors as being critical to the success of this procedure.^{19,43} Others preferred a cotton pellet moistened with sterile saline for this step.⁴⁴⁻⁴⁵ The authors do not know if the students used sodium hypochlorite consistently in the cases they followed and cannot rule out the possibility that failure to perform this step contributed to the relatively high failure rate.

There are three plausible reasons for failure to detect statistically significant differences for patient age, extent of bleeding or size of exposure as factors predictive of survival rate of the procedure. Survival analysis tests are inherently underpowered. A sample size of 50 is small for purposes of this research. Second, no follow-up data were available on patients other than at their last visit. In survival analysis, positive results are “censored” at their last known positive state and nothing further is concluded about survival. Several studies on the effectiveness of MTA as a direct pulp capping material in permanent teeth followed the clinical guidelines proven to be most successful in calcium hydroxide pulp capping studies. These included studies of experimentally created mechanical pulp exposures^{44,46-49} and immature permanent teeth.^{26,39-42} Several of these studies directly compared MTA to calcium hydroxide and all

found MTA to be effective as a pulp capping material; several authors found comparable or better outcomes for MTA compared to Ca(OH)₂ pulp caps.^{44,48,50} The most common application for direct pulp caps has been the least studied and has generally been expected to be the least predictable—that of carious pulp exposures on fully formed permanent teeth. The most thorough study of this clinical circumstance was recently presented by Bogen and others.¹⁹ In their study, a single operator, using a carefully standardized technique, placed direct pulp caps on 49 teeth using MTA. Followed for a period of one to seven years, 97% of the teeth that were treated tested positive for pulp vitality without persistent sensitivity.¹⁹ This was a very encouraging clinical result.

In the current study, outcomes were far less consistent and showed independence from the preoperative conditions, such as patient age, exposure size and extent of bleeding.

CONCLUSIONS

Within the limitations of the current study by student clinicians, it may be concluded that, for MTA placed on carious pulp exposures, several preoperative conditions—patient age, exposure size and amount of bleeding—are not predictive of clinical outcome. Considering the comparatively low success rate for the current patient cohort, a prospective clinical study with a larger sample size is needed to define predictive criteria for successful pulp capping with MTA.

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